VOLUME-3
ISSUE-2
2023

e-ISSN: 2791-8335

JOURNAL OF ARTIFICIAL INTELLIGENCE AND DATA SCIENCE

İZMİR KÂTİP ÇELEBİ UNIVERSITY
Artificial Intelligence and Data Science
Research and Application Center

JAIDA

HTTPS://DERGIPARK.ORG.TR/PUB/JAIDA

JOURNAL OF ARTIFICIAL INTELLIGENCE & DATA SCIENCE

Volume 3 – Issue 2 – December 2023 **E-ISSN: 2791-8335**

Aim & Scope

The Journal of Artificial Intelligence and Data Science (JAIDA) is an international, scientific, peer-reviewed, and open-access e-journal. It is published twice a year and accepts only manuscripts written in English. The aim of JAIDA is to bring together interdisciplinary research in the fields of artificial intelligence and data science. Both fundamental and applied research are welcome. Besides regular papers, this journal also accepts research field review articles. Paper submission/processing is free of charge.

Contact

Web site: https://dergipark.org.tr/pub/jaida
E-mail: ikcujaida@gmail.com
Phone: +90 (232) 329 35 35/3731/ 1072
Fax: +90 (232) 325 33 60
Mailing address: İzmir Katip Çelebi Üniversitesi, Yapay Zeka ve Veri Bilimi Uygulama ve Araştırma Merkezi, Balatçık Kampüsü, Çiğli Ana Yerleşkesi, 35620, İzmir

ÖNSÖZ

Yapay Zeka ve Veri Bilimi alanındaki teknolojik ve bilimsel gelişmeler; Yapay Zekanın endüstri, sağlık, otomotiv, ekonomi, eğitim gibi bir çok farklı alanda uygulanmasına imkan sağlamıştır. Ülkemiz Ulusal Yapay Zeka Stratejisinde; yeni bir çağın eşiğine gelindiği, yapay zekayla üretim süreçleri, meslekler, gündelik yaşam ve kurumsal yapıların yeni bir dönüşüm sürecine girdiği vurgulanarak, Yapay Zekanın öneminden bahsedilmiştir.

Sayın Cumhurbaşkanımızın da belirttiği gibi ülkemiz adına insan odaklı yeni bir atılım yapmanın zamanının geldiğine inanıyoruz. Yapay zeka çağına geçiş noktasında Türkiye'nin lider ülkelerden biri olması motivasyonu ile üniversitemizde yapay zeka teknolojilerinin kullanıldığı projeler gerçekleştirmekte, kongreler ve bilimsel etkinlikler düzenlemekteyiz.

Günümüz dünyasına rengini veren dijital teknolojilerin odağındaki ana unsurun yapay zeka teknolojilerinin olduğu düşüncesi ile yola çıkarak hazırlamış olduğumuz Yapay Zekâ ve Veri Bilimi Dergisinin, Ülkemiz Ulusal Yapay Zeka Stratejisinde belirtilen "Dijital Türkiye" vizyonu ve "Milli Teknoloji Hamlesi" kalkınma hedefleri doğrultusunda katkı sağlayacağı inancındayız.

Dergimizin hazırlanmasında emeği geçen üniversitemiz Yapay Zekâ ve Veri Bilimi Uygulama ve Araştırma Merkez Müdürü, Baş Editör Prof. Dr. Ayşegül ALAYBEYOĞLU'na, Editör ve Danışma kurulu üyelerine, akademik çalışmaları ile sağladıkları destek için tüm yazarlara, hakem olarak görev alan değerli bilim insanlarına teşekkür eder, dergimizin yeni sayısının ülkemize hayırlı olmasını dilerim.

Prof. Dr. Saffet KÖSE, Rektör

Dergi Sahibi

PREFACE

Technological and scientific developments in Artificial Intelligence and Data Science enabled the application of Artificial Intelligence in many different fields such as industry, health, automotive, economy and education. In our country's National Artificial Intelligence Strategy; the importance of Artificial Intelligence was mentioned by emphasizing the transformation process of production processes, occupations, daily life and corporate structures with artificial intelligence.

As stated by our President, we believe that the time has come to make a new human-oriented breakthrough on behalf of our country. With the motivation of Turkey being one of the leading countries at the point of transition to the age of artificial intelligence, we realize projects in which artificial intelligence technologies are used, and organize congresses and scientific events at our university.

We have prepared the Journal of Artificial Intelligence and Data Science with the idea that the main element in the focus of digital technologies that color today's world is artificial intelligence technologies, and we believe that our journal will contribute to the development goals of the "Digital Turkey" vision and "National Technology Move" stated in the National Artificial Intelligence Strategy of our country.

I would like to thank Prof. Dr. Ayşegül ALAYBEYOĞLU, the Director of Artificial Intelligence and Data Science Application and Research Center of our university. I would also like to thank to Editor and Advisory Board members, to all authors for their supports with their academic studies and to reviewers for their contributions to the preparation of our journal. I wish the new issue of our journal to be beneficial for our country.

Prof. Dr. Saffet KÖSE, Rector

Privilege Owner

BAŞ EDİTÖR'DEN

Değerli Araştırmacılar ve Dergi Okuyucuları;

İzmir Kâtip Çelebi Üniversitesi Yapay Zekâ ve Veri Bilimi Uygulama ve Araştırma Merkezi olarak Rektörümüz Prof. Dr. Saffet Köse sahipliğinde Yapay Zekâ ve Veri Bilimi Dergisinin 3. cilt 2. sayısını sizlerle buluşturmanın gururunu yaşamaktayız.

İzmir Kâtip Çelebi Üniversitesi Yapay Zekâ ve Veri Bilimi Uygulama ve Araştırma Merkezi olarak hedefimiz; Cumhurbaşkanlığı Dijital Dönüşüm Ofisi Başkanlığı ve Sanayi ve Teknoloji Bakanlığı tarafından hazırlanan "Ulusal Yapay Zekâ Stratejisi" hedefleri doğrultusunda dergi, kongre, eğitim, bilimsel etkinlikler ve proje faaliyetleri gerçekleştirerek ülkemizin yapay zekâ alanındaki gelişim sürecine katkı sağlamaktır.

Farklı üniversitelerden, bilimsel disiplinlerden ve alanlardan değerli araştırmacıların İngilizce dilinde hazırlamış oldukları 6 adet araştırma ve 1 adet derleme makalesi bu sayı kapsamında sunulmaktadır. Siz değerli araştırmacılarımızın destekleri ile kaliteyi daha da arttırarak en kısa sürede ulusal ve uluslararası indekslerde daha çok taranan bir dergi olmayı hedeflemekteyiz.

Dergimizin yayın hayatına başlaması ve tüm merkez faaliyetlerinde büyük desteklerini gördüğümüz başta Rektörümüz Prof. Dr. Saffet KÖSE olmak üzere; dergimize olan destekleri için tüm yazarlara, dergimizin yayına hazırlanmasında heyecanla çalışan ve çok büyük emek harcayan Baş Editör Yardımcılarına, Editör ve Danışma kurulu üyelerimize, hakem olarak görev alan tüm değerli bilim insanlarına en derin şükranlarımı sunarım.

Saygılarımla,

Prof. Dr. Ayşegül ALAYBEYOĞLU

Baş Editör

LETTER FROM THE EDİTOR-IN-CHIEF

Dear Researchers and Readers of the Journal,

As İzmir Katip Çelebi University Artificial Intelligence and Data Science Application and Research Center, we are proud to present you the volume 3 issue 2 of the Journal of Artificial Intelligence and Data Science (JAIDA), hosted by our Rector Prof. Dr. Saffet Köse.

As İzmir Katip Çelebi University Artificial Intelligence and Data Science Application and Research Center, our goal is; to contribute to the development process of our country in the field of artificial intelligence by carrying out journals, congresses, education, scientific events and project activities in line with the objectives of the "National Artificial Intelligence Strategy" prepared by the Digital Transformation Office of the Presidency of Türkiye and the Ministry of Industry and Technology.

6 research and 1 review articles prepared by valuable researchers from different universities, scientific disciplines and fields are presented within the scope of this issue. With the support of esteemed researchers, we aim to increase the quality even more and become a journal that is scanned in national and international indexes more as soon as possible.

I would like to express my deepest gratitude to Our Rector, Prof. Dr. Saffet KÖSE, who supported the publication of our journal and the research center's activities; to all the authors for their support to our journal; to our Associate Editors, who worked enthusiastically and put great efforts into the preparation of our journal; to our Editorial and Advisory Board members, and all esteemed scientists who served as reviewer.

Best Regards,

Prof. Dr. Ayşegül ALAYBEYOĞLU

Editor-in-Chief

CONTENTS

Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida
Vol. 3, No. 2, pp. 54-79 2023
Review Article
Received: 09/06/2023 Accepted: 28/11/2023

Evolution of Machine Learning in Tourism: A Comprehensive Review of Seminal Research

Ferhat ŞEKER*

Abstract

Machine learning is enabling transformative changes in the tourism industry. Various machine learning algorithms and models can detect patterns in huge amounts of data for the prediction process, recommendations, and decisions without any coding or programming. The tourism sector generates massive data through sources as such online reviews and ratings, social media activity, traffic information, and customer relationship management records. Machine learning is poised to unlock insights and opportunities from this data. This paper provides an overview of how machine learning is currently influencing and may shape the future of tourism. Techniques for predictive analytics, personalized recommendation systems, computer vision, natural language processing, and more are powering applications to improve customer experiences, optimize and automate operations, gain competitive advantage, and support sustainability. Current applications are discussed, including demand forecasting, personalized travel recommendations, automated photo filtering, sentiment analysis of tourism reviews, chatbots for customer service, and others. Emerging opportunities are explored, as machine learning may enhance smart tourism for destinations through intelligent transportation, customized experiences, optimized resource allocation, and improved accessibility. Challenges exist regarding data quality, privacy, bias, and job disruption. However, machine learning is expected to become an integral tool for data-driven, personalized, and sustainable tourism. Overall, this review paper aims to synthesize the state of machine learning in tourism by highlighting current applications, opportunities, considerations, and likely future trends. The conclusions point to machine learning as a catalyst for innovation in tourism that may significantly transform the visitor experience, business operations, and destination management in the years to come.

Keywords: Artificial Intelligence; Machine Learning; Tourism; Literature Review

1. Introduction

Machine Learning (ML) has indeed become a pervasive technology that influences numerous aspects of our lives. It has transformed various industries and become essential in many applications and services. ML algorithms and models power voice assistants like Siri, Cortana, Bixby, and Alexa, enabling them to understand and respond to user commands and queries. These assistants utilize techniques including speech recognition and natural language processing to provide users with the desired information and assistance. Chatbots are another area where ML plays a crucial role. They employ ML algorithms to understand and interpret user inputs, enabling them to engage in human-like conversations and provide relevant responses. Chatbots are used in customer service, e-commerce, and various other domains to enhance user experiences and streamline interactions. Personalized marketing heavily relies on ML techniques to analyze user data, preferences, and behavior patterns. This enables businesses to target specific customer segments with tailored recommendations, advertisements, and promotions, improving the effectiveness of marketing campaigns. ML is instrumental in predicting customer behavior and trends. By analyzing large volumes of data, ML models can identify patterns, correlations, and insights that help businesses understand and anticipate customer needs, preferences, and purchasing decisions. This information can be leveraged to optimize business strategies and improve customer satisfaction. ML also plays a crucial role in optimizing processes and improving efficiency in various domains. From supply chain management to logistics, ML algorithms can analyze large datasets, identify patterns, and make predictions, enabling businesses to make data-driven decisions and streamline operations [1-6]

In the realm of tourism, ML plays a crucial role in enhancing various aspects of the industry. ML algorithms are utilized to analyze vast amounts of data and extract valuable insights that contribute to improving the overall travel experience for individuals. One significant application of ML in tourism is personalized recommendation systems. By leveraging ML models, travel platforms can analyze user preferences, historical data, and behavior patterns to provide tailored recommendations for destinations, accommodations, activities, and attractions. This enables travelers to receive suggestions that align with their interests, making their trip planning more efficient and enjoyable. ML is also instrumental in optimizing pricing and revenue management in the tourism sector. ML

*Corresponding author

FERHAT ŞEKER; Adana Alparslan Türkeş Science and Technology University, Faculty of Business, Tourism Management Department, Türkiye; e-mail: fseker@atu.edu.tr; 0000-0001-6397-1232

algorithms can analyze market trends, historical booking data, and competitor pricing to predict demand patterns and dynamically adjust prices for flights, hotels, and other travel services. This helps businesses maximize their revenue by offering competitive prices while accounting for factors such as seasonality, demand fluctuations, and customer preferences. Furthermore, ML techniques are employed in enhancing travel safety and security. ML models can analyze historical data on travel patterns, weather conditions, and security incidents to identify potential risks and anomalies. This allows authorities and travel agencies to implement proactive measures and develop efficient risk management strategies to ensure the safety of travelers. ML also contributes to improving customer service in the tourism industry. Chatbots powered by ML algorithms can provide instant responses to customer queries, offering personalized assistance and support throughout the travel journey. These chatbots can understand natural language, recognize customer preferences, and provide relevant information, thereby enhancing customer satisfaction and engagement. Additionally, ML is utilized in sentiment analysis of customer reviews and social media data related to travel experiences. By analyzing textual data and user-generated content, ML algorithms can identify positive and negative sentiments, helping tourism businesses understand customer feedback and sentiment trends. This enables companies to make data-driven decisions to enhance their offerings and address any areas of concern, ultimately improving customer experiences. Taking everything into account, machine learning plays a significant role in the tourism industry, enabling personalized recommendations, optimizing pricing, enhancing safety and security measures, improving customer service, and analyzing customer sentiment. As ML continues to advance, it holds the potential to revolutionize the way we explore and enjoy the world, making travel experiences more tailored, efficient, and enjoyable for everyone [1-16].

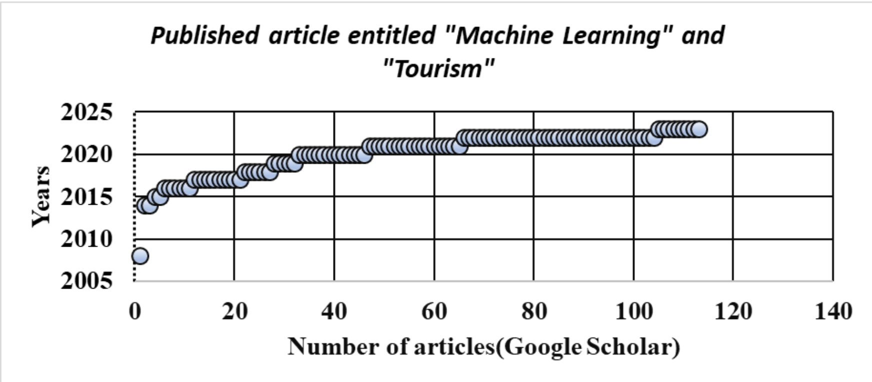
Artificial intelligence (AI), big data, and ML are often mentioned together, particularly in the context of "smart tourism" and "smart destinations." The concept of "smartness" in tourism involves integrating various information and communication technologies (ICTs) into the physical infrastructure, optimizing travel experiences through personalization and real-time analysis, and building a business ecosystem geared towards smartness. Big data plays a crucial role in this context, as it encompasses different types of data, such as transactional data, user-generated content, sensor data, and more. Analyzing and processing this data using ML techniques can provide valuable insights and enable smarter decision-making in the tourism industry. In summary, ML allows computers to learn from data and experience, identifying patterns and making predictions without explicit programming. It involves working with datasets, features, and models, where the trained model can be used to make predictions on new data. In the context of smart tourism, ML and big data play significant roles in optimizing travel experiences and enabling data-driven decision-making [1-21]

In conclusion, the integration of ML into the tourism industry has ushered in a new era of personalized and data-driven travel experiences. This review article explores the diverse applications of ML in tourism, highlighting its role in personalized recommendations, pricing optimization, travel safety, customer service, and sentiment analysis. By harnessing the power of ML algorithms, travel businesses can leverage big data to provide tailored suggestions, optimize pricing strategies, ensure traveler safety, enhance customer service through chatbots, and gain valuable insights from customer sentiment analysis. As ML continues to evolve, it is poised to revolutionize the way we explore the world, making travel more efficient, enjoyable, and customized to individual preferences. This article aims to shed light on the transformative potential of ML in the tourism industry and provide a comprehensive overview of its applications and benefits.

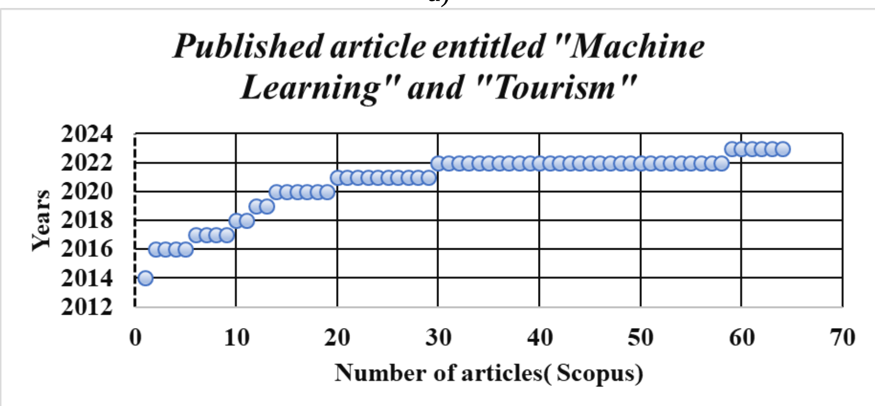
This study presents a detailed overview of the correlation between two fields namely tourism and machine learning to emphasize the demand in the applications of ML approaches within the tourism science. This study also utilizes a systematic search technique by using Web of Science (WoS), Google Scholar, and Scopus databases to determine the publications in the existing literature. Furthermore, this study highlights the pros and cons of using Google Scholar, Web of Science, and Scopus. While Google Scholar's expansive coverage and user-friendly interface are acknowledged, limitations such as potential inaccuracies in citation counts and the lack of advanced tools are also noted. Web of Science and Scopus, on the other hand, are recognized for their selective coverage and more precise citation-matching methodologies. The importance of selecting appropriate journals for publication is also outlined. The analysis of citations from both machine learning and tourism journals underscores the interdisciplinary nature of the research, with potential implications for a broader audience. Additionally, the study also delves into the significance of authors in shaping the credibility and validity of research. Authors with expertise in both machine learning and tourism are identified as crucial contributors to impactful interdisciplinary work. Their ability to bridge the gap between distinct research communities, coupled with established networks, enhances the visibility and influence of their work. In conclusion, this study provides a myriad of the exploration and the landscape where tourism and machine learning intersect. It not only provides insights into the current state of research but also offers valuable guidance for researchers, emphasizing the importance of interdisciplinary collaboration, careful journal selection, and the role of authors in driving impactful research.

2. Published Articles

The analysis of publications related to tourism and machine learning indicates a growing interest in applying ML approaches to various tasks within the tourism domain. A search query combining "Tourism" and "Machine Learning" in keywords resulted in 199 papers in the database of Web of Science for the years 2005 to 2023 [1-200]. Other search queries combining “Tourism” and “Machine Learning” in article titles depicted 42 papers in Web of Science from 2016 to 2023. Then, the Google Scholar database is searched along with title words and keywords separately. 125 paper titled “Machine learning” and “Tourism” is founded in terms of citations of 898, h-index of 14, and g-index of 28. The search query with keywords including machine learning, and tourism is found out as 980 with 25232 citations. The statistical analysis of this search query depicts h-index of 79 and g-index of 145. On the other hand, the published papers titled machine learning and tourism are counted as 64 while the papers with keywords including machine learning and tourism are indicated at 200 via the database of SCOPUS. The most cited paper related to machine learning and tourism searched along with the title is observed by Nilashi et.al titled “A recommender system for tourism industry using cluster ensemble and prediction machine learning techniques” [37]. 144 published article cites this study. Following, another study by Go et.al. titled “Machine learning of robots in tourism and hospitality: interactive technology acceptance model (iTAM) – cutting edge” is among the most cited paper and was published in 2020 [194]. In a short year, the number of citations for this study reached up to 97, The citation results emphasize the importance of the machine learning application in the tourism field. Another most cited paper is proposed by Xie et. al.in 2021 titled “Forecasting Chinese cruise tourism demand with big data: An optimized machine learning approach” along with the number of 83 citations [181]. Another research query utilized by Scopus for titles along with machine learning, and tourism counted on the number of papers as 64. The citations of the overall papers are obtained as 443. The analysis by Scopus depicts the h-index and g-index as 9 and 20, respectively. The most cited paper again is determined as “A recommender system for tourism industry using cluster ensemble and prediction machine learning techniques” titled study by Nilashi et.al. along with the number of 100 citations. Then, the second most cited paper observed “Machine learning of robots in tourism and hospitality: interactive technology acceptance model (iTAM) – cutting edge” titled study by Go et.al. as found in Google Scholar. However, the number of citations observed by Scopus is attained as 59. Figure 1 provides the increment of ML methods in tourism research. The illustrations depict the increasement occurs particularly from 2018 onwards.



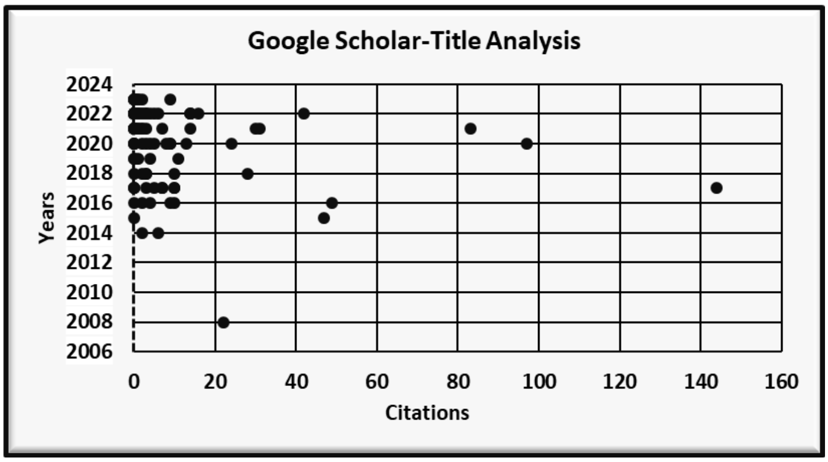
a)



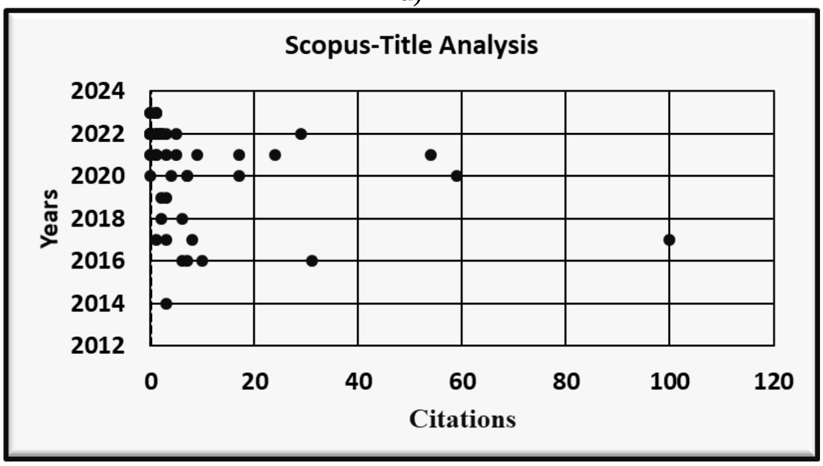
b)

Figure 1. *Published articles with search queries in titles through a) Google Scholar, b) Scopus*

The above results outline that Google Scholar has some advantages and disadvantageous over WoS and Scopus. To sum up these advantages, Google Scholar has a much larger coverage of academic publications compared to WoS and Scopus. It includes most peer-reviewed journals, conference papers, preprints, theses, books, and other scholarly literature. WoS and Scopus have a more selective coverage focused on high-impact journals. Google Scholar has a broader range of languages and includes publications in languages other than English. WoS and Scopus primarily focus on English-language journals and publications. Google Scholar is freely available to anyone. WoS and Scopus are subscription-based databases, so access depends on university or library subscriptions. Google Scholar offers a simple but powerful search interface. Searches in WoS and Scopus may require more advanced skills and knowledge to effectively filter and refine results. Like WoS and Scopus, Google Scholar indexes citation data and shows how many times each publication has been cited. This allows you to track the impact and influence of publications. However, the quality and credibility of sources in Google Scholar can vary. WoS and Scopus have more standardized selection criteria and primarily index reputable, peer-reviewed publications. Google Scholar can contain duplicate records for the same publication. WoS and Scopus have more accurate matching algorithms to avoid duplicates. Citation counts in Google Scholar may include some erroneous citations. WoS and Scopus have more precise citation-matching methodologies. The simple interface of Google Scholar lacks some of the advanced tools and filters available in the WoS and Scopus interfaces. These tools may be useful for more in-depth research and analysis. In summary, Google Scholar is a useful, free discovery tool for researchers thanks to its broad coverage, easy search, and citation tools. For most researchers, using Google Scholar in combination with other databases is a good research strategy. Then, the number of citations about the titled article with machine learning and tourism is outlined in Figure 2. Therefore, in this study, the primary tool selected was Google Scholar to find the most cited papers in the literature. The citation results indicate the importance of this topic.



a)



b)

Figure 2. *Number of citations along with the machine learning and tourism with respect to the years from 2012 to 2023.*

Some journals specifically focus on machine learning, some on tourism and hospitality, and some are interdisciplinary. Choosing a journal, which is most closely related to your topic, exposes any article to the most relevant readers and researchers. Additionally, by selecting a suitable publisher, the potential impact of any work might be increased by this method. On the other hand, the journal you select will determine to a large extent the potential impact and circulation of your research. High-impact journals are more widely read and cited. Journal metrics like the CiteScore or Impact Factor should be considered when assessing the reach of the journal. The prestige and reputation of the journal convey prestige on your own work. Being published in a leading journal in your field is a mark of top-quality research and can open up further networking and collaboration opportunities. Hence, carefully evaluating potential journals and selecting one that will maximize the reach and impact of your work is an important part of the publication process. For interdisciplinary research, finding a journal that balances both fields of study and has expertise in reviewing such work should be a top priority. The rewards of getting published in the right journal can be significant for your career and the influence of your research. That's why, the related journals, conference papers, preprints, theses, books, and other scholarly literature are investigated through SCOPUS and Google Scholar databases. Table 1 and Table 2 depict the journals, conference papers, preprints, and books, where the studies related to machine learning and tourism have been published up to now, along with Scopus and Google Scholar, respectively.

Table 1. *The journals, conference papers, preprints, and books based on SCOPUS*

16th International Middle Eastern Simulation and Modelling Conference 2020, MESM 2020
2016 IEEE/ACIS 15th International Conference on Computer and Information Science, ICIS 2016 - Proceedings
2018 International Conference on Advances in Big Data, Computing and Data Communication Systems, icABCD 2018
2021 IEEE International Conference on Computing, ICOCO 2021
2022 IEEE International Conference on Electrical Engineering, Big Data and Algorithms, EEBDA 2022
2022 International Conference on Computers and Artificial Intelligence Technologies, CAIT 2022
2022 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing, COM-IT-CON 2022
ACM International Conference Proceeding Series
Acta Astronautica
Acta Geographica
Advances in Intelligent Systems and Computing
African Journal of Hospitality, Tourism and Leisure
Annals of Tourism Research
Applied Economics Letters
Asian Journal of Information Technology
CEUR Workshop Proceedings
Computational and Mathematical Methods in Medicine
Computers and Industrial Engineering
Current Issues in Tourism
Electronics
Environment, Development and Sustainability
Eurasip Journal on Wireless Communications and Networking
European Journal of Innovation Management
Frontiers in Psychology
Handbook of Research on Big Data Clustering and Machine Learning
Heliyon
InCIT 2020 - 5th International Conference on Information Technology
Informatics
Intellectual Economics
International Journal of Advanced Computer Science and Applications
International Journal of Technology Marketing
International Transactions on Electrical Energy Systems
Journal of Theoretical and Applied Information Technology
Journal of Tourism and Development
Journal of Tourism, Heritage and Services Marketing
Journal of Travel Research
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)
Lecture Notes in Electrical Engineering
Lecture Notes in Networks and Systems
Machine Learning: Advances in Research and Applications
Materials Today: Proceedings
Microprocessors and Microsystems
Mobile Information Systems
Proceedings - 2021 4th International Conference on Computational Intelligence and Communication Technologies, CCICT 2021
Proceedings - 2021 IEEE 23rd Conference on Business Informatics, CBI 2021 - Main Papers
Proceedings - 2022 4th International Workshop on Artificial Intelligence and Education, WAIE 2022
Proceedings of 2021 13th International Conference on Information and Communication Technology and System, ICTS 2021
Research Anthology on Machine Learning Techniques, Methods, and Applications

Revista de Economia Aplicada
Scientific Programming
Soft Computing
Stats
Studies in Computational Intelligence
Tourism Economics
Tourism Management
Tourism Management Perspectives
Tourism Review

Table 2. *The journals, conference papers, preprints, and books based on Google Scholar*

2016 IEEE Eight International Conference on Advanced Computing
2016 IEEE/ACIS 15th International Conference on Computer and Information Science (ICIS)
2018 International Conference on Advances in Big Data, Computing and Data Communication Systems (icABCD)
2020 - 5th International Conference on Information Technology (InCIT)
2020 CEUR Workshop Proceedings
2021 13th International Conference on Information and Communication Technology and System (ICTS)
2021 Fourth International Conference on Computational Intelligence and Communication Technologies (CCICT)
2021 IEEE 23rd Conference on Business Informatics (CBI)
2022 International Conference on Computers and Artificial Intelligence Technologies (CAIT)
7th International Conference, LOD 2021
Acta Astronautica
Acta Geographica Sinica
African Journal of Hospitality, Tourism and Leisure
Annals of the University Dunarea de Jos of Galati: Fascicle: I, Economics and Applied Informatics
Annals of Tourism Research
Applied Data Science in Tourism
Applied Economics Letters
Asian Journal of Information Technology
Asia-Pacific Journal of Management and Technology
Balkan Journal of Electrical and Computer Engineering
Computational and Mathematical Methods in Medicine
Computer and Digital Engineering
Computers and Industrial Engineering
Current Issues in Tourism
Design of Intelligent Applications using Machine Learning and Deep Learning Techniques
ECONVN 2021: Prediction and Causality in Econometrics and Related Topics
Electronics
Environment, Development and Sustainability
EURASIP Journal on Wireless Communications and Networking
Frontiers in Psychology
Handbook of Research on Big Data Clustering and Machine Learning
Health and Technology
Heliyon
Hochschule für nachhaltige Entwicklung Eberswalde
ICGST International Journal on Artificial Intelligence and Machine Learning
IEICE Technical Report
IFC-Bank Indonesia Satellite Seminar on "Big Data" at the ISI Regional Statistics Conference 2017
IJRAR- International Journal of Research and Analytical Reviews
i-Manager's Journal on Computer Science
Informatics
Information Science and Applications 2017 ICISA 2017
INT BUSINESS INFORMATION MANAGEMENT ASSOC-IBIMA
Intelektinė ekonomika
International Conference on Advanced Computing and Intelligent Engineering, ICACIE, 2016
International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (COMITCon)
International Journal of Advanced Trends in Computer Science and Engineering
International Journal of Computer Applications
International Journal of Contemporary Hospitability Management
International Journal of Engineering Applied Sciences and Technology
International Journal of Technology Marketing
International Transactions on Electrical Energy Systems
Information Technology and Tourism

IOSR Journal of Computer Engineering (IOSR-JCE)
ISWC (Posters and Demos)
Journal of Artificial Intelligence, Machine Learning and Neural Network (JAIMLNN)
Journal of Destination Marketing and Management
Journal of Engineering and Sciences
Journal of Theoretical and Applied Information Technology
Journal of Tourism
Journal of Travel Research
Marketing
Materials Today: Proceedings
MIBES Transactions
MLMI '20: Proceedings of the 2020 3rd International Conference on Machine Learning and Machine Intelligence
Mobile Information Systems
Network (Mbps)
PRAJNAN
Proceedings of International Conference on Recent Trends in Computing
Research Square
Scientific Programming
Soft Computing
Sosyoekonomi
SSRN
Stats
Tourism Analytics Before and After COVID-19 Case Studies from Asia and Europe
Tourism Economics
Tourism Management
Tourism Management Perspectives
Tourism review
Women's voices in tourism research
XIII Congreso Internacional Turismo y Tecnologías de la Información y las Comunicaciones

Citations from both machine learning and tourism journals, as well as interdisciplinary publications, show that your work is influencing and advancing an interdisciplinary research area. This is more meaningful than the impact on just one discipline. Citations should be tracked from diverse sources. By being cited in both machine learning venues and tourism venues, your work is exposed to a much larger combined audience from both fields. This amplifies the visibility and potential influence of your research. You have the opportunity to connect both with machine learning experts and tourism experts, which could lead to interesting interdisciplinary collaborations generating innovative new ideas. Effective interdisciplinary work requires researchers from distinct fields to come together. An influential interdisciplinary publication that accumulates many citations can help to define the scope, boundaries, and topics of an emerging combined research domain, like "machine learning in tourism". Your work may be pivotal in shaping how this domain develops. Citations from different fields may point to unique limitations or open questions raised by each group of readers. This points to possible new research directions to explore in order to bridge machine learning and tourism more effectively. Addressing issues from multiple angles will result in more robust, comprehensive work. If cited by researchers focused on applied work, or in industry publications, your theoretical research may be influencing real-world practice. This demonstrates the usefulness and potential for the real-world impact of interdisciplinary work. That's, interdisciplinary research requires reaching, influencing and connecting distinct communities. An article that combines machine learning and tourism through accumulating a diversity of citations across fields will achieve this most effectively. Such influence shapes the growth of this interdisciplinary domain in a way that benefits both theory and practice. Citations point to issues to address across boundaries and possibilities for ground-breaking collaborative work. Table 3 and Table 4 outline the articles with the most citations obtained by SCOPUS and Google Scholar, respectively.

Table 3. *The most cited studies related to machine learning and tourism obtained by SCOPUS*

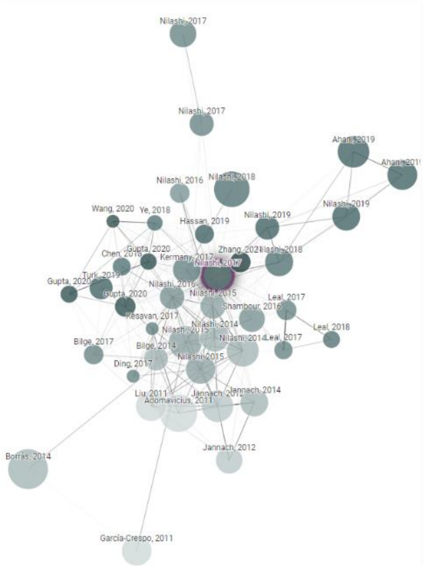
Ref.	Cites	Title	Year
37	144	A recommender system for tourism industry using cluster ensemble and prediction machine learning techniques	2017
194	97	Machine learning of robots in tourism and hospitality: interactive technology acceptance model (iTAM)–cutting edge	2020
181	83	Forecasting Chinese cruise tourism demand with big data: An optimized machine learning approach	2021
19	49	Combination forecasts of tourism demand with machine learning models	2016
201	47	Developing tourism demand forecasting models using machine learning techniques with trend, seasonal, and cyclic components	2015

50	42	Multi-objective hub-spoke network design of perishable tourism products using combination machine learning and meta-heuristic algorithms	2022
136	31	Machine learning in internet search query selection for tourism forecasting	2021
193	30	Exploring China's 5A global geoparks through online tourism reviews: A mining model based on machine learning approach	2021
153	28	Modelling tourism demand to Spain with machine learning techniques. The impact of forecast horizon on model selection	2018
46	24	A human-guided machine learning approach for 5G smart tourism IoT	2020
202	22	Tourism demand forecasting using machine learning methods	2008
203	16	Machine Learning in Tourism: A Brief Overview: Generation of Knowledge from Experience	2022
173	14	International tourism demand forecasting with machine learning models: The power of the number of lagged inputs	2022
204	14	Twitter data sentiment analysis of tourism in Thailand during the COVID-19 pandemic using machine learning	2022
205	14	Structural review of relics tourism by text mining and machine learning	2022
42	14	Proposing a systematic approach for integrating traditional research methods into machine learning in text analytics in tourism and hospitality	2021
206	13	Machine learning in tourism	2020
207	11	Performance of raspberry pi micro clusters for edge machine learning in tourism	2019
208	10	Tourism recommendation using machine learning approach	2018
209	10	Machine learning methods in tourism demand forecasting: Some evidence from Greece	2017
210	10	A machine learning approach to named entity recognition for the travel and tourism domain	2016
211	10	Regional tourism demand forecasting with machine learning models: Gaussian process regression vs. neural network models in a multiple-input multiple-output setting	2017

Table 4. *The most cited studies related to machine learning and tourism obtained by Google Scholar*

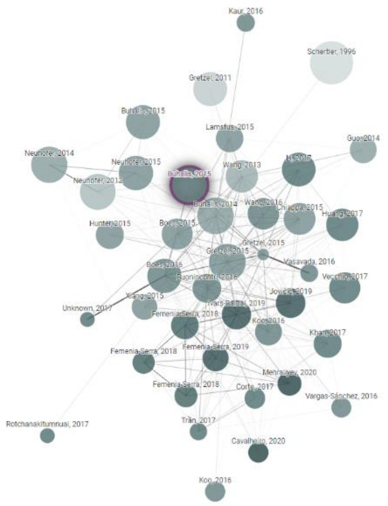
Ref.	Cites	Title	Year
212	881	Smart tourism destinations enhancing tourism experience through personalisation of services	2015
54	855	Sentiment classification of online reviews to travel destinations by supervised machine learning approaches	2009
213	741	Ontology matching: A machine learning approach	2004
175	727	A comparative analysis of major online review platforms: Implications for social media analytics in hospitality and tourism	2017
214	651	Hospitality and tourism online reviews: Recent trends and future directions	2015
215	646	Technology in tourism-from information communication technologies to e-Tourism and smart tourism towards ambient intelligence tourism: a perspective article	2020
216	544	Ontology learning and its application to automated terminology translation	2003
217	545	Technological disruptions in services: lessons from tourism and hospitality	2019
218	524	Real-time co-creation and nowness service: lessons from tourism and hospitality	2019
133	494	Sentiment analysis in tourism: capitalizing on big data	2019
219	477	Support vector regression with genetic algorithms in forecasting tourism demand	2007
220	441	User-generated content as a research mode in tourism and hospitality applications: Topics, methods, and software	2015
221	437	Tourism information technology	2019
222	396	The good, the bad and the ugly on COVID-19 tourism recovery	2021
223	391	Big data analytics for knowledge generation in tourism destinations–A case from Sweden	2014
224	358	A review of research into automation in tourism: Launching the Annals of Tourism Research Curated Collection on Artificial Intelligence and Robotics in Tourism	2020
225	343	Forecasting tourism demand with composite search index	2017
226	323	Business intelligence and big data in hospitality and tourism: a systematic literature review	2018
227	293	The digital revolution in the travel and tourism industry	2020
228	275	Tourism demand forecasting: A deep learning approach	2019
6	269	Forecasting tourist arrivals with machine learning and internet search index	2019
229	262	New technologies in tourism: From multi-disciplinary to anti-disciplinary advances and trajectories	2018
230	242	From digitization to the age of acceleration: On information technology and tourism	2018
231	225	SPETA: Social pervasive e-Tourism advisor	2009

Based on Table 3 and Table 4, the most cited papers are observed as [37] and [212] via SCOPUS and Google Scholar, respectively. The prior and derived works of [37] and [212] as given in Figure 3.



Title	Last author	Year	Citations	Graph citations
New Recommendation Techniques for Multicriteria Rating Systems	YoungOk Kwon	2007	500	32
Toward the next generation of recommender systems: a survey of the state-of-the-art and possible extensions	A. Tuzhilin	2005	10018	24
Improving personalized services in mobile commerce by a novel multicriteria rating approach	Guanggang Geng	2008	65	17
Analysis and Classification of Multi-Criteria Recommender Systems	C. Costopoulou	2007	211	14
Multi-criteria Ratings for Recommender Systems: An Empirical Analysis in the Tourism Domain	M. Zanker	2012	49	13
Research Note - The Halo Effect in Multicomponent Ratings and Its Implications for Recommender Systems: The Case of...	Jamie Callan	2012	86	13
Item-based collaborative filtering recommendation algorithms	J. Riedl	2001	8801	13
Empirical Analysis of Predictive Algorithms for Collaborative Filtering	C. Kadie	1998	5795	13
Experimental Analysis of Design Choices in multiattribute Utility Collaborative Filtering	C. Costopoulou	2007	97	11
Multicriteria User Modeling in Recommender Systems	A. Tsoukiás	2011	169	10

a)



Title	Last author	Year	Citations	Graph citations
Progress in information technology and tourism management: 20 years on and 10 years after the Internet - the state of...	R. Law	2008	2949	17
Marketing the competitive destination of the future.	Dimitrios Buhalis	2000	2799	12
Mediating tourist experiences: access to places via shared videos.	D. Fesenmaier	2009	571	11
The Role of Smartphones in Mediating the Touristic Experience	D. Fesenmaier	2012	623	10
eTourism: Information technology for strategic tourism management	Dimitrios Buhalis	2003	997	10
Smart Cities in Europe	P. Nijkamp	2011	3088	10
A Smart City Initiative: the Case of Barcelona	J. Wareham	2013	816	9
Role of social media in online travel information search	U. Gretzel	2010	2569	8
SMART Destinations: new strategies to manage tourism industry	G. Chiappa	2013	28	8
Agenda for Co-Creation Tourism Experience Research	Teun den Dekker	2009	544	8

b)

Figure 3. *The derived and prior works of a) [37] and b) [212]*

By analyzing the published studies through Google Scholar and Scopus in terms of most citations, the first authors of the studies are determined as given in Table 5. The main reason is to determine these authors that the expertise of the authors defines the extended credibility and validity of the work. Authors with expertise in both machine learning and tourism will produce work grounded in knowledge and experience from both domains. They will have a deeper understanding of how methods and concepts from each field can be connected and integrated effectively. The authors will have access to separate networks in the machine learning and tourism research communities. This exposes the work to more researchers and provides more opportunities to stimulate interest and new collaborations across boundaries. Established authors with large networks will have an easier time bridging between fields. The reputation and recognition of the authors affect the initial and ongoing impact of the work. Well-known authors can draw more attention and citations to the article, helping to speed up its diffusion between research communities. Their reputation also lends more credibility to the work, making researchers from other fields more inclined to cite and build upon it. Authors familiar with both source domains are better equipped to frame and communicate their interdisciplinary work in a way that resonates with multiple audiences. They understand how to convey key machine learning concepts and methods to tourism researchers, and vice versa. This helps to overcome potential barriers when connecting disparate groups. Authors with expertise and connections in both machine learning and tourism are in an ideal position to continue conducting meaningful follow-up research that bridges these domains. They can further develop concepts and methods jointly in innovative ways. This results in a cohesive, progressive research stream rather than isolated publications. Authors linked to industry or applied research may be motivated to combine machine learning and tourism towards achieving a practical real-world goal. Their work will thus be aimed at solving concrete problems, rather than being purely theoretical. Applied authors can better assess where and how machine learning capabilities could transform and improve tourism practices. As a result, authors' interdisciplinarity, expertise, networks and motivations are all significant factors that determine the potential for connecting machine learning and tourism. While single authors may integrate these domains, teams that collectively span multiple communities are better equipped for sustained, high-impact interdisciplinary work. The backgrounds and goals of authors shape how, and how far, the integration between source fields progresses.

Table 5. *The first author of the studies with the most cited*

Authors		
Order	**Google Scholar**	**Scopus**
1.	M Nilashi	M. Nilashi
2.	H Go	H. Go
3.	G Xie	G. Xie
4.	O Claveria	O. Claveria
5.	S Cankurt	A.P. Chobar
6.	AP Chobar	X. Li
7.	X Li	Y. Luo
8.	Y Luo	O. Claveria
9.	O Claveria	J. Huh
10.	R Peng	A. Imsombut
11.	N Kamel	F. Afsahhosseini
12.	R Egger	Y. Tverdokhlib
13.	JW Bi	A. Dewangan
14.	N Leelawat	J. Vijay
15.	S Das	A. Komninos
16.	TH Le	F.A. Lisi
17.	F Afsahhosseini	D. Yang
18.	A Komninos	J.W. Bi
19.	A Dewangan	C. Srisawatsakul
20.	A Karakitsiou	T. Imam

The increasing number of publications and the presence of ML research in tourism-focused journals suggest a growing recognition of the potential benefits that ML can bring to the tourism industry. ML methods can enable the processing and analysis of large datasets, extraction of meaningful features, and generation of personalized recommendations, among other tasks. The integration of ML in tourism research opens up new possibilities for understanding tourist behaviour, optimizing tourism experiences, and improving decision-making processes in the industry. Feature engineering and feature selection are crucial steps in ML as good features form the backbone of any ML model. The quality of the model relies on the quality of the data it was trained on, and using bad data can lead to significant errors. Therefore, it is important to select only those features that have a meaningful impact on the model's quality. After preparing the data and selecting features, the algorithm is trained using the training data. The data is typically divided into two parts as such training and testing sets, where t training section is applied to educate the algorithm, and the testing data is used to evaluate its performance. Unsupervised learning tasks do not require the separated data, therefore, do not involve cross-validation. As soon as the model is educated, it is evaluated. Depending on supervised technique, the efficacy of the algorithm can be assessed, providing insights for optimizing data processing and hyperparameters. ML systems include hyperparameters that can be adjusted to affect the algorithm's performance, and finding the best settings often involves an iterative process of data preparation, model fitting, hyperparameter tuning, and model evaluation. The validated model is then applied to real-world tasks, such as making predictions, and the results are interpreted and contextualized within the specific domain.

Three main types of ML algorithms which are the kind of learning as such unsupervised, supervised, and reinforcement. Unsupervised learning is covered in detail in chapters on clustering and dimensionality reduction, while supervised learning is discussed in chapters on classification and regression. Reinforcement learning, although less relevant for tourism cases, is another type of ML algorithm. Additionally, natural language processing (NLP) is a specialized ML case, including algorithms for text classification, topic modelling, and sentiment analysis, among others. ML approaches can be classified based on the type of data and the availability of labels for the dependent variable. Supervised algorithms are used when labels are available for either continuous or discrete dependent variables, while unsupervised methods are applied when no labels are given. In addition to the traditional supervised, unsupervised, and reinforcement learning paradigms, several other ML paradigms have evolved in recent years. These include model-based learning, memory-based learning, and deep learning. Deep learning, particularly with neural networks, has played a significant role in the current ML renaissance. It represents a distinct subfield within ML and has the ability to scale with large amounts of data, often yielding superior results compared to traditional approaches. However, it is important to note that neural networks are not always superior to classical ML approaches.

The choice between deep learning and traditional ML methods depends on the specific problem and the available data. For a more comprehensive discussion on neural networks and deep learning, further literature such as Aggarwal [232] or Ekman [233] can provide detailed insights. Machine learning, as a subset of artificial intelligence, can be applied to various types of data in the tourism industry across different stages of a tourist's journey. In fact, there are ML techniques specifically designed for scenarios with limited data, such as transfer learning and few-shot learning. Transfer learning enables the knowledge gained from training on one dataset to be transferred and applied to a related task or domain with smaller amounts of data. Few-shot learning focuses on training models with minimal data instances by leveraging prior knowledge or by utilizing techniques like data augmentation. Even with smaller datasets, ML approaches can still uncover patterns and relationships within complex data. These patterns can then be utilized to make predictions and informed decisions. ML models can generalize from the available data to identify underlying patterns, which enables them to make predictions on new, unseen data points. In scientific research projects, where data collection might be limited or resource-intensive, ML techniques can still be valuable. By employing ML algorithms, researchers can explore their data, identify patterns, and gain insights that may not be immediately apparent through traditional statistical analysis methods. ML can assist in automating the analysis process, saving time and effort, and enabling researchers to focus on interpreting the results and formulating hypotheses. In summary, while the availability of large datasets has undoubtedly expanded the possibilities and potential of ML, it is not a strict requirement for successful application. ML techniques can still yield valuable insights and predictions even with smaller datasets, making it a versatile tool for various domains, including scientific research. Commonly used data types in the literature as given in Table-6. As given in Table 6, a wealth of data types related to tourism exist for fuelling machine learning applications. When integrated and analysed collectively, these diverse data sources provide a multifaceted understanding of destination appeal, tourist behaviour, trends, patterns, experiences, needs, and opportunities for innovation. Machine learning is crucial for harnessing the potential of such data towards more personalized, seamless, and sustainable tourism development.

Table 6. *Key Data Types for Machine Learning and Tourism Applications*

Data Types	Ref.	Examples
Online reviews	[35,54,79,87, 90,92,98,129, 139,158,160, 169,192,214]	Reviews from platforms like TripAdvisor, Yelp, Expedia, etc. provide valuable data for machine learning in tourism. Data includes review text, review sentiment, review ratings, and information about the reviewer and destination. This data is useful for applications like sentiment analysis, recommendation systems, extractive summarization, and predictive analytics.
Images	[39,60,71,80, 89,104,115,1 82,186,187]	Images of tourist destinations, attractions, hotels, etc. from platforms like Instagram or posted with online reviews can be used for machine learning tasks such as image classification, object detection, visual semantic embedding, and automatic hashtag generation. These capabilities can enhance recommendation systems and social media analytics.
Ratings	[36]	The ratings (especially 5-star ratings) that tourists provide on various review and booking platforms represent useful quantitative data for machine learning. Ratings can be analyzed for tasks such as ranking and benchmarking destinations or anticipating peak travel seasons. They provide an indicator of overall tourist satisfaction and experience.
Search data	[88]	Search data from platforms like Google, Bing, Kayak, and Skyscanner contain valuable information about tourist interests, preferences, and intent. Analyzing search query terms, search frequencies, and other metadata through machine learning can uncover patterns to improve recommendation and personalization capabilities. Search data is useful for gaining broad market insights.
Location data	[197]	The location data generated from tourists' mobile devices and wearables as they travel provides significant data for machine learning applications. Analyzing location data can reveal patterns related to how tourists navigate a destination, visit points of interest, choose hotels or dining locations, and more. This data fuels location-aware applications and context-based personalization.
Demograph ic data	[2]	Basic demographic information about tourists such as age, gender, country of origin, income level, family size, etc. represents useful data for machine learning in tourism. Analyzing how different segments of visitors interact with and experience a destination leads to models that provide tailored, targeted recommendations and personalization of services for specific demographic groups.

Transportation data	[149,185,196, 197,198]	Data related to how tourists get around a destination, such as public transport usage, taxi services, walking or biking, vehicle rental or ownership, etc. gives insight into visitor flows and how infrastructure supports tourism. Machine learning analysis of transportation data aims to gain efficiencies, reduce environmental impact, and ensure high quality of experience regardless of transportation mode choice.

ML can be described as a field of study that enables computers to learn from experience and data without being explicitly programmed. It involves the use of computational methods and algorithms that learn patterns and relationships from examples, with the goal of improving performance and making accurate predictions. In ML, datasets consist of examples that contain features, where each row represents an instance and each column represents a feature. Features are measurable pieces of data that are fed into an ML algorithm to help solve a problem or make predictions. By training an ML algorithm with the dataset, a model is created, which represents the learned patterns and knowledge derived from the data. For example, a random forest algorithm can be trained with training data to generate a random forest model. Once the model is trained, it can be used to make predictions on new, unseen data. This predictive model takes in new data and produces predictions or classifications based on the patterns and knowledge it has learned during the training process.

Machine learning contributes a diverse range of techniques to gain insight from data, predict and optimize outcomes, personalize the customer experience and innovate services within tourism. The capabilities offered by machine learning can transform both strategic and operational aspects, with the potential for significant efficiency, sustainability and economic gains. Some key machine learning terms and techniques relevant to tourism as given in Table 7.

Table 7. *Machine Learning Techniques Used in Tourism Settings*

ML Techniques	Reference	The Purpose of Usage
Sentiment analysis	[1,9,10,22,35,54,69,93,107, 113,133,134,161,187,204]	Analyses the emotional tone of text data like onlin reviews to determine whether the sentiment is positive negative or neutral. Useful for analyzing touris satisfaction.
Topic modelling	[195]	Identifies latent topics within unstructured text data Can uncover trends and themes in tourism domains lik reviews, news articles, blogs, etc.
Classification	[1,22,54,69,71,85,152]	Assigns items to categories based on patterns in the data Useful for tasks like segmenting visitors into marke segments, classifying images, or filtering onlin reviews.
Regression	[24,55,157,211,219]	Predicts a continuous numeric value based on input data Can be used for tourism forecasting and prediction, e.g predicting hotel revenue or numbers of visitors
Clustering	[73]	Groups similar items together without pre-define categories. Used for visitor segmentation and als identifying groups of interesting points-of-interes dining venues, events, etc.
Recommender systems	[2,7,12,34,37,65]	Provide personalized recommendations based o analysis of user profiles, interests and behaviors. Play a important role in personalization and destinatio promotion.
Neural networks	[11,47,117]	Identify complex patterns in very large data sets. Use for tourism tasks such as advanced personalization image recognition, forecasting and predictiv modelling. Require huge amounts of data to b effective.
Naïve Bayes	[98, 235, 236]	A probabilistic classifier based on Bayes' theorem tha calculates the probability of an item belonging to particular category. Despite its simplicity, effective fo tasks like sentiment analysis, topic modelling an classification.
Support Vector Machines (SVM)	[1,77,117,219]	Identify patterns that separate categories in the data Effective at handling high-dimensional spaces an widely used for tasks such as text classification forecasting, regression and anomaly detection withi tourism.
Contextual modelling	[154, 234]	Incorporates information about the surrounding contex situation or environment. Important for implementin

		machine learning in complex, real-world applications. Could include incorporating knowledge about seasons, events, companion, location, time, etc. for tourism personalization.
Decision trees	[38,61,81,86]	Create a flowchart-like model of decisions and their possible consequences. Useful for tourism applications such as optimizing marketing campaigns, transportation networks and staff scheduling.
Computer Vision	[68,105]	Enables machine learning models to identify and analyse visual content like images or videos. Techniques include image classification, object detection, visual search and automated image tagging. Useful for applications such as analysing tourism photos to determine point of interest density or popularity.

This covers some of the major machine learning techniques and terms that apply to tourism and hospitality. When integrated together, these diverse methods provide a powerful basis for building machine learning applications within the tourism industry

3. Discussion

Considering the article most cited and published along with the different databases namely SCOPUS, Web of Science, and Google Scholar, three of them are detailed to understand the trend of the machine learning application in tourism. Initially, [37] proposes a recommender system for the tourism industry using a combination of clustering and predictive modelling with machine learning. The system provides personalized recommendations for locations and activities to visitors based on their profiles and preferences. The recommender system has two main components:

- Clustering: The cluster ensemble technique is used to group visitors into segments based on demographic attributes like age, gender, occupation and behavioural attributes like interests, preferred locations, and activities. The K-means, hierarchical, and DBSCAN clustering algorithms were used in the ensemble. Ensemble clustering aims to improve robustness and accuracy.
- Predictive Modelling: Machine learning models including kNN, naive Bayes, decision trees, and random forests are trained on visitor profiles and location/activity preference data to make predictions for new visitors based on their cluster segment. The models provide a list of recommendations tailored to visitors in that cluster group.

The paper evaluates the performance of the proposed recommender system using metrics like precision, recall, F-measure, and accuracy. Experimental results show the ensemble cluster model achieved superior performance over individual clustering algorithms and the predictive models enhanced recommendation accuracy compared to basic recommender techniques. The recommender system can provide more personalized and tailored suggestions to visitors in the tourism domain compared to generic or "one-size-fits-all" recommendations. Clustering visitors into meaningful segments allows for targeted recommendations based on shared attributes and preferences within each group. And machine learning predictive models can continue learning and improving over time as new data is collected. Limitations include the need for large amounts of data on visitor profiles, preferences, and behaviours to properly train the machine learning models. Data may be difficult and expensive to obtain from some tourism organizations. Scalability and computational complexity are also challenging as the volume of visitors and locations/activities increase. Future work could explore how to gain additional data to further enhance the models, alternative or hybrid machine learning techniques to improve accuracy and user satisfaction, and how to deploy the recommender system in a way that is customized and valuable for individual tourism destinations and businesses.

[194] proposes an interactive technology acceptance model (iTAM) to explain how factors related to human-robot interaction and machine learning influence the adoption of service robots in the tourism and hospitality industry. The iTAM builds upon the original technology acceptance model (TAM) that focuses on perceived usefulness and ease of use. The interactive technology acceptance model (iTAM) includes 3 additional components:

- Interactivity: The ability of robots to engage in meaningful, responsive, and active social interactions with people. Interactivity contributes to perceived social presence, parasocial relationships, and enjoyment.
- Adaptability: How robots can learn, improve, and modify their knowledge and skills through machine learning based on new data and interactions. Adaptability enhances perceived intelligence, customization, and usefulness.

• Anthropomorphism: Giving human-like qualities and attributes to robots through their design and interactivity. Anthropomorphism positively impacts perceived enjoyment, social presence, and parasocial relationships with robots.

These 3 components, along with perceived usefulness and ease of use from the original TAM, influence people's attitudes toward service robots and their willingness to adopt and engage with them. Positive attitudes and experiences then also further contribute to machine learning as new data is collected to improve the robots. The paper proposes and evaluates a survey instrument to measure the iTAM components and model. Data was collected from over 500 survey respondents on their perspectives related to robot service in tourism and hospitality contexts like hotels, airports, and restaurants. Structural equation modelling validated the proposed interactive technology acceptance model and the relationships between its key factors. The iTAM provides a novel framework for understanding how machine learning-enabled social robots can be designed and improved to maximize acceptance, adoption, and continued use in service environments. A robot's ability to meaningfully interact, adapt to users, and exhibit human-like qualities are key to its success. Applying the iTAM could help researchers and practitioners develop robots that not only have practical, task-oriented benefits but also social and experiential value. Limitations include the need for empirical research with actual long-term human-robot interactions to supplement survey findings. The complexity of real-world service contexts may also challenge the implementation of social robots and machine learning in some situations. Privacy and ethical concerns related to data collection and use are additional considerations. Continued progress in natural language processing, computer vision, and other areas of artificial intelligence would further enhance interactive, learning-based robot services.

[181] aims to forecast demand for cruise tourism in China using an optimized machine learning approach with big data. Cruise tourism is a fast-growing sector, but there is limited research on methods for forecasting emerging cruise markets like China. The study obtains online search query data related to cruise tourism as a proxy for public interest and potential demand. The data consists of weekly search volumes for 120 keywords on the Baidu search engine from 2005 to 2017. The large dataset qualifies as "big data" due to its high volume, velocity, and variety. An optimized machine learning model is proposed that combines feature selection, hyperparameter tuning, and ensemble learning techniques to maximize forecast accuracy:

• Feature selection using Random Forest importance scores reduced the 120 keywords to the 30 most relevant for predicting cruise demand. This simplifies the model and reduces noise.

• Hyperparameter tuning using Random Search optimized settings for the XGBoost (eXtreme Gradient Boosting) algorithm. XGBoost is a highly effective tree ensemble method suitable for large datasets. Optimization helps maximize the power of the model.

• Ensemble learning combines forecasts from XGBoost, Random Forest, and Holt-Winters exponential smoothing to balance machine learning and statistical methods. The ensemble approach aims to improve robustness and accuracy.

The model is evaluated using root mean square error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE), and R-squared for different forecast horizons up to 12 weeks ahead. Results show the optimized machine learning model achieved significantly better accuracy than any single approach alone and, especially, compared to the basic trend forecast. The study demonstrates the potential of using big data and sophisticated machine learning techniques for forecasting in complex domains like tourism where traditional statistical methods may be limited. Cruise tourism appears strongly affected by search and digital trends, so online behaviour can tap into public interest before demand is realized. However, online factors alone may not capture all drivers of emerging cruise demand, especially long-term impacts. Integrating additional variables related to the economy, demographics, and tourism infrastructure with web data could further enhance forecasting performance. Practically, forecasts of cruise tourism demand could help strategic decision-making related to marketing, investment, operations, and management in the cruise industry. More accurate predictions enable stronger preauction and preparation to optimize opportunities related to changes in demand. But policymakers and businesses should also consider that machine learning models may reflect and even amplify biases or inequities in the data. So professional judgment still plays an important role in utilizing AI-enabled forecasts.

All 3 papers [37,181,194] apply machine learning to address key opportunities and challenges related to personalization, acceptance of emerging technologies, and forecasting in the tourism domain. Clustering, predictive modelling, robotics, and big data analytics are promising for industry progress but require consideration of limitations involving data quality, customization, complexity, and human judgment. A mix of methods may maximize benefits. Survey and performance metrics provide initial evaluation but longitudinal, real-world studies most insightful. Progress in neural networks, computer vision, NLP and other AI could greatly enhance techniques while raising additional concerns related to bias or job disruption that researchers are beginning to explore.

The paper of [212] focuses on an important trend: smart tourism and personalization and proposes a conceptual framework for smart destinations that can enhance the tourism experience. This paper covers a very broad, comprehensive scope at a destination level. However, it has some pros, which lack technical depth or empirical evaluation as it takes a more conceptual approach. In [54], machine learning methods (naive Bayes, SVM, neural network) are applied to a tourism-related problem (analysing online reviews), and the performance of different ML techniques is empirically evaluated and compared for the task. This paper could have useful industry applications for review analysis and customer insight. On the other hand, this paper only analyses reviews for tourist destinations in China, limiting wider insight. In [213], a machine learning-based method is proposed for ontology matching that could apply to the tourism domain. The method and approach in significant technical depth are explained. The performance against other existing methods is evaluated for demonstrating good results. However, this study is not tourism-specific and lacks a tourism example application, very theoretically and technically complex. Therefore, it may lack accessibility for some readers and the scope is narrow focusing on just one ML task and method. In summary, the articles take quite different approaches. The first takes a broad conceptual scope but lacks technical depth. The second applies ML to a specific tourism task but has a narrow empirical focus. The third proposes an ML method at a high technical level but lacks a tourism grounding. So, there are trade-offs in terms of scope, application, accessibility and technical proficiency. The articles could be combined by, for example, applying and evaluating the method from the third article on the review analysis task from the second article, set within the smart destination context of the first. This could result in an article with significant scope, technical merit, empirical evidence, and tourism relevance. The diverse citations of these articles, then, point to the potential and need for this type of integrated, in-depth work.

4. Near Future Aspects

Depending on the seminal research in this review paper, A myriad of key gaps and limitations in current machine learning applications for tourism is included as follows:

- **Lack of large datasets:** Many machine learning techniques require huge amounts of data to be effective, especially deep learning methods. Limited availability of large, multidimensional tourism datasets constraints model performance. More open data sharing between industry stakeholders and further integration of diverse data sources could help address this.
- **Narrow focus:** Most studies apply machine learning to a single data type (e.g. online reviews) or for one specific task (e.g. sentiment analysis). A more holistic approach that combines multiple data sources and machine learning techniques is needed. This could provide a broader, multifaceted understanding of tourists and tourism systems.
- **Theoretical rather than practical:** The majority of studies propose a methodological framework or evaluate machine learning techniques on a tourism dataset. There is a lack of real-world implementations and analysis of business metrics to demonstrate practical value. More collaboration with industry is required.
- **Static rather than dynamic:** Machine learning models are often built on static snapshots of data. There is little work on developing models able to adapt in real time based on continuous data streams. This limits the ability to detect and respond to sudden changes or events. Online learning and continuous model evaluation techniques could be explored.
- **Limited personalization:** While significant research exists on recommendation systems, machine learning is limitedly applied to gain a deep, multifaceted understanding of tourists that could enable truly personalized experiences across platforms and vendors. Integrating diverse data types and testing in real usage contexts may progress this capability.
- **Reactively rather than proactively:** Machine learning in tourism largely aims to analyse what has already occurred to gain insights and make predictions. Techniques have not been widely explored to anticipate tourists' future needs and desires before they are explicitly expressed. Proactive personalization will rely on gaining a deeper understanding of individuals.
- **Lack of transparency:** Many of the most advanced machine learning techniques (especially deep learning) act as "black boxes" - their inner workings are opaque. This lack of explainability is problematic when inaccurate or potentially biased predictions have a real impact on people. Approaches are needed to increase transparency and enable the auditing of machine learning systems.
- **Ethical issues:** The collection and use of tourist data by private companies raise ethical concerns related to privacy, consent and data ownership. There is a lack of consistent guidelines for the ethical use of

machine learning and resulting applications within the tourism industry. Frameworks for addressing ethical risks are required to gain trust and encourage adoption.

To conclude, gaps exist in data, scope, real-world integration, dynamic modelling, personalization, proactivity, transparency and ethics for machine learning in tourism. A more holistic, multifaceted approach that addresses both opportunities and risks will be needed to fulfil the potential benefits of moving to AI and data-driven tourism. Overall, greater collaboration between researchers and industry will be key.

References

[1] Zheng, Wenying, and Ye, Qiang (2009). Sentiment Classification of Chinese Traveler Reviews by Support Vector Machine Algorithm. *2009 Third International Symposium On Intelligent Information Technology Application, Vol 3, Proceedings*, 335-338, ISSN 978-0-7695-3859-4, https://dx.doi.org/10.1109/IITA.2009.457.

[2] Wang, Yuanyuan, Chan, Stephen Chi-Fai, and Ngai, Grace (2012). Applicability of Demographic Recommender System to Tourist Attractions: A Case Study on TripAdvisor. *2012 Ieee/Wic/Acm International Conference On Web Intelligence And Intelligent Agent Technology Workshops (Wi-Iat Workshops 2012), Vol 3*, 97-101, https://dx.doi.org/10.1109/WI-IAT.2012.133.

[3] Salman, Man Galih, Kanigoro, Bayu, Heryadi, Yaya, and IEEE (2015). Weather Forecasting using Deep Learning Techniques. *2015 International Conference On Advanced Computer Science And Information Systems (Icacsis)*, 281-285, ISSN 2330-4588

[4] Chang, Yu-Wei, and Tsai, Chih-Yung (2017). Apply deep learning neural network to forecast number of tourists. *2017 31st Ieee International Conference On Advanced Information Networking And Applications Workshops (Ieee Waina 2017)*, 259-264, https://dx.doi.org/10.1109/WAINA.2017.125

[5] Luong, Thai-Le, Cao, Minh-Son, Le, Duc-Thang, and Phan, Xuan-Hieu (2017). Intent Extraction from Social Media Texts Using Sequential Segmentation and Deep Learning Models. *2017 9th International Conference On Knowledge And Systems Engineering (Kse 2017)*, 215-220, ISSN 2164-2508

[6] Sun, Shaolong, Wang, Shouyang, Wei, Yunjie, Yang, Xianduan, and Tsui, Kwok-Leung (2017). Forecasting Tourist Arrivals with Machine Learning and Internet Search Index. *2017 Ieee International Conference On Big Data (Big Data)*, 4165-4169, ISSN 2639-1589

[7] Kbaier, Mohamed Elyes Ben Haj, Masri, Hela, Krichen, Saoussen, and IEEE (2017). A personalized hybrid tourism recommender system. *2017 Ieee/Acs 14th International Conference On Computer Systems And Applications (Aiccsa)*, 244-250, ISSN 2161-5322, https://dx.doi.org/10.1109/AICCSA.2017.12

[8] Son, Kyoungho, Byun, Yungcheol, Lee, Sangjoon, and IEEE (2018). Prediction of Visitors using Machine Learning. *2018 International Conference On Intelligent Informatics And Biomedical Sciences (Iciibms)*, 138-139, ISSN 2189-8723

[9] Ramanathan, Vallikannu, Meyyappan, T., and IEEE (2019). Twitter Text Mining for Sentiment Analysis on People's Feedback about Oman Tourism. *2019 4th Mec International Conference On Big Data And Smart City (Icbdsc)*, 30-34

[10] Yadav, Mukesh, and Bhojane, Varunakshi (2019). Semi-Supervised Mix-Hindi Sentiment Analysis using Neural Network. *2019 9th International Conference On Cloud Computing, Data Science and Engineering (Confluence 2019)*, 309-314

[11] Folgieri, Raffaella, Baldigara, Tea, and Mamula, Maja (2017). Artificial Neural Networks-Based Econometric Models For Tourism Demand Forecasting. *4th International Scientific Conference: Tosee - Tourism In Southern And Eastern Europe 2017, 4*, 169-182, ISSN 1848-4050, https://dx.doi.org/10.20867/tosee.04.10

[12] Deldjoo, Yashar, Schedl, Markus, Cremonesi, Paolo, and Pasi, Gabriella (2020). Recommender Systems Leveraging Multimedia Content. *Acm Computing Surveys, 53*(5), ISSN 0360-0300, https://dx.doi.org/10.1145/3407190

[13] Siricharoen, Waralak V. (2008). Learning semantic web from e-tourism. *Agent And Multi-Agent Systems: Technologies And Applications, Proceedings*, *4953*, 516-525, ISSN 0302-9743

[14] Birim, Sule, Kazancoglu, Ipek, Mangla, Sachin Kumar, Kahraman, Aysun, and Kazancoglu, Yigit (2022). The derived demand for advertising expenses and implications on sustainability: a comparative study using deep learning and traditional machine learning methods. *Annals Of Operations Research*, ISSN 0254-5330, https://dx.doi.org/10.1007/s10479-021-04429-x

[15] Rice, William L., Park, So Young, Pan, Bing, and Newman, Peter (2019). Forecasting campground demand in US national parks. *Annals Of Tourism Research*, *75*, 424-438, ISSN 0160-7383, https://dx.doi.org/10.1016/j.annals.2019.01.013

[16] Yu, Joanne, and Egger, Roman (2021). Color and engagement in touristic Instagram pictures: A machine learning approach. *Annals Of Tourism Research*, *89*, ISSN 0160-7383, https://dx.doi.org/10.1016/j.annals.2021.103204

[17] Zhang, Chen, and Huang, Zhenfang (2015). Mining Tourist Motive for Marketing Development via Twice-Learning. *Applied Artificial Intelligence*, *29*(2), 119-133, ISSN 0883-9514, https://dx.doi.org/10.1080/08839514.2015.993554

[18] Starosta, Kejo, Budz, Sonia, and Krutwig, Michael (2019). The impact of German-speaking online media on tourist arrivals in popular tourist destinations for Europeans. *Applied Economics*, *51*(14), 1558-1573, ISSN 0003-6846, https://dx.doi.org/10.1080/00036846.2018.1527463

[19] Claveria, Oscar, Monte, Enric, and Torra, Salvador (2016). Combination forecasts of tourism demand with machine learning models. *Applied Economics Letters*, *23*(6), 428-431, ISSN 1350-4851, https://dx.doi.org/10.1080/13504851.2015.1078441

[20] Tsai, Yu Hsin, Stow, Douglas, An, Li, Chen, Hsiang Ling, Lewison, Rebecca, and Shi, Lei (2019). Monitoring land-cover and land-use dynamics in Fanjingshan National Nature Reserve. *Applied Geography*, *111*, ISSN 0143-6228, https://dx.doi.org/10.1016/j.apgeog.2019.102077

[21] Li, Qin, Li, Shaobo, Zhang, Sen, Hu, Jie, and Hu, Jianjun (2019). A Review of Text Corpus-Based Tourism Big Data Mining.

Applied Sciences-Basel, *9*(16), https://dx.doi.org/10.3390/app9163300

[22] Chen, Wen, Xu, Zhiyun, Zheng, Xiaoyao, Yu, Qingying, and Luo, Yonglong (2020). Research on Sentiment Classification of Online Travel Review Text. *Applied Sciences-Basel*, *10*(15), https://dx.doi.org/10.3390/app10155275

[23] Crivellari, Alessandro, and Beinat, Euro (2019). Identifying Foreign Tourists' Nationality from Mobility Traces via LSTM Neural Network and Location Embeddings. *Applied Sciences-Basel*, *9*(14), https://dx.doi.org/10.3390/app9142861

[24] Lv, Sheng-Xiang, Peng, Lu, and Wang, Lin (2018). Stacked autoencoder with echo-state regression for tourism demand forecasting using search query data. *Applied Soft Computing*, *73*, 119-133, ISSN 1568-4946, https://dx.doi.org/10.1016/j.asoc.2018.08.024

[25] Yilmaz, Mustafa K., Kusakci, Ali Osman, Aksoy, Mine, and Hacioglu, Umit (2022). The evaluation of operational efficiencies of Turkish airports: An integrated spherical fuzzy AHP/DEA approach. *Applied Soft Computing*, *119*, ISSN 1568-4946, https://dx.doi.org/10.1016/j.asoc.2022.108620

[26] Guerra-Montenegro, Juan, Sanchez-Medina, Javier, Lana, Ibai, Sanchez-Rodriguez, David, Alonso-Gonzalez, Itziar, and Ser, Javier Del (2021). Computational Intelligence in the hospitality industry: A systematic literature review and a prospect of challenges. *Applied Soft Computing*, *102*, ISSN 1568-4946, https://dx.doi.org/10.1016/j.asoc.2021.107082

[27] Spiliotis, Evangelos, Abolghasemi, Mahdi, Hyndman, Rob J., Petropoulos, Fotios, and Assimakopoulos, Vassilios (2021). Hierarchical forecast reconciliation with machine learning. *Applied Soft Computing*, *112*, ISSN 1568-4946, https://dx.doi.org/10.1016/j.asoc.2021.107756

[28] Bayliss, Christopher (2021). Machine learning based simulation optimisation for urban routing problems. *Applied Soft Computing*, *105*, ISSN 1568-4946, https://dx.doi.org/10.1016/j.asoc.2021.107269

[29] Gajdosik, Tomas, and Marcis, Matus (2019). Artificial Intelligence Tools for Smart Tourism Development. *Artificial Intelligence Methods In Intelligent Algorithms*, *985*, 392-402, ISSN 2194-5357, https://dx.doi.org/10.1007/978-3-030-19810-7_39

[30] Refanidis, Ioannis, Emmanouilidis, Christos, Sakellariou, Ilias, Alexiadis, Anastasios, Koutsiamanis, Remous-Aris, Agnantis, Konstantinos, Tasidou, Aimilia, Kokkoras, Fotios, and Efraimidis, Pavlos S. (2014). MYVISITPLANNER(GR): Personalized Itinerary Planning System for Tourism. *Artificial Intelligence: Methods And Applications*, *8445*, 615-629, ISSN 0302-9743

[31] Deo, Ravinesh C., and Sahin, Mehmet (2015). Application of the Artificial Neural Network model for prediction of monthly Standardized Precipitation and Evapotranspiration Index using hydrometeorological parameters and climate indices in eastern Australia. *Atmospheric Research*, *161*, 65-81, ISSN 0169-8095, https://dx.doi.org/10.1016/j.atmosres.2015.03.018

[32] Monkman, Graham G., Kaiser, Michel J., and Hyder, Kieran (2018). Text and data mining of social media to map wildlife recreation activity. *Biological Conservation*, *228*, 89-99, ISSN 0006-3207, https://dx.doi.org/10.1016/j.biocon.2018.10.010

[33] Peng, Lu, Wang, Lin, Ai, Xue-Yi, and Zeng, Yu-Rong (2021). Forecasting Tourist Arrivals via Random Forest and Long Short-term Memory. *Cognitive Computation*, *13*(1), 125-138, ISSN 1866-9956, https://dx.doi.org/10.1007/s12559-020-09747-z

[34] Altulyan, May, Yao, Lina, Wang, Xianzhi, Huang, Chaoran, Kanhere, Salil S., and Sheng, Quan Z. (2022). A Survey on Recommender Systems for Internet of Things: Techniques, Applications and Future Directions. *Computer Journal*, *65*(8), 2098-2132, ISSN 0010-4620, https://dx.doi.org/10.1093/comjnl/bxab049

[35] Jain, Praphula Kumar, Pamula, Rajendra, and Srivastava, Gautam (2021). A systematic literature review on machine learning applications for consumer sentiment analysis using online reviews. *Computer Science Review*, *41*, ISSN 1574-0137, https://dx.doi.org/10.1016/j.cosrev.2021.100413

[36] Gaur, Loveleen, Afaq, Anam, Solanki, Arun, Singh, Gurmeet, Sharma, Shavneet, Jhanjhi, N. Z., My, Hoang Thi, and Le, Dac-Nhuong (2021). Capitalizing on big data and revolutionary 5G technology: Extracting and visualizing ratings and reviews of global chain hotels. *Computers and Electrical Engineering*, *95*, ISSN 0045-7906, https://dx.doi.org/10.1016/j.compeleceng.2021.107374

[37] Nilashi, Mehrbakhsh, Bagherifard, Karamollah, Rahmani, Mohsen, and Rafe, Vahid (2017). A recommender system for tourism industry using cluster ensemble and prediction machine learning techniques. *Computers and Industrial Engineering*, *109*, 357-368, ISSN 0360-8352, https://dx.doi.org/10.1016/j.cie.2017.05.016

[38] Nilashi, Mehrbakhsh, Samad, Sarminah, Ahani, Ali, Ahmadi, Hossein, Alsolami, Eesa, Mahmoud, Marwan, Majeed, Hamsa D., and Alarood, Ala Abdulsalam (2021). Travellers decision making through preferences learning: A case on Malaysian spa hotels in TripAdvisor. *Computers and Industrial Engineering*, *158*, ISSN 0360-8352, https://dx.doi.org/10.1016/j.cie.2021.107348

[39] Sun, Yeran, Fan, Hongchao, Bakillah, Mohamed, and Zipf, Alexander (2015). Road-based travel recommendation using geo-tagged images. *Computers Environment And Urban Systems*, *53*, 110-122, ISSN 0198-9715, https://dx.doi.org/10.1016/j.compenvurbsys.2013.07.006

[40] Weerdenburg, Demi van, Scheider, Simon, Adams, Benjamin, Spierings, Bas, and Zee, Egbert van der (2019). Where to go and what to do: Extracting leisure activity potentials from Web data on urban space. *Computers Environment And Urban Systems*, *73*, 143-156, ISSN 0198-9715, https://dx.doi.org/10.1016/j.compenvurbsys.2018.09.005

[41] Antonio, Nuno, Almeida, Ana de, and Nunes, Luis (2019). Big Data in Hotel Revenue Management: Exploring Cancellation Drivers to Gain Insights Into Booking Cancellation Behavior. *Cornell Hospitality Quarterly*, *60*(4), 298-319, ISSN 1938-9655, https://dx.doi.org/10.1177/1938965519851466

[42] Le, Truc H., Arcodia, Charles, Novais, Margarida Abreu, and Kralj, Anna (2021). Proposing a systematic approach for integrating traditional research methods into machine learning in text analytics in tourism and hospitality. *Current Issues In Tourism*, *24*(12), 1640-1655, ISSN 1368-3500, https://dx.doi.org/10.1080/13683500.2020.1829568

[43] Zhao, Erlong, Du, Pei, Azaglo, Ernest Young, Wang, Shouyang, and Sun, Shaolong (2023). Forecasting daily tourism volume: a hybrid approach with CEMMDAN and multi-kernel adaptive ensemble. *Current Issues In Tourism*, *26*(7), 1112-1131, ISSN 1368-3500, https://dx.doi.org/10.1080/13683500.2022.2048806

[44] Kim, Jina, Jang, Yeonju, Bae, Kunwoo, Oh, Soyoung, Jeong, Nam Jeong, Park, Eunil, Han, Jinyoung, and Pobil, Angel P. del (2021). Between comments and repeat visit: capturing repeat visitors with a hybrid approach. *Data Technologies And Applications*, *55*(4), 542-557, ISSN 2514-9288, https://dx.doi.org/10.1108/DTA-06-2020-0123

[45] Mingotto, Erica, Montaguti, Federica, and Tamma, Michele (2021). Challenges in re-designing operations and jobs to embody AI and robotics in services. Findings from a case in the hospitality industry. *Electronic Markets*, *31*(3), 493-510, ISSN 1019-6781, https://dx.doi.org/10.1007/s12525-020-00439-y

[46] Peng, Rongqun, Lou, Yingxi, Kadoch, Michel, and Cheriet, Mohamed (2020). A Human-Guided Machine Learning Approach for 5G Smart Tourism IoT. *Electronics*, *9*(6), https://dx.doi.org/10.3390/electronics9060947

[47] Livieris, Ioannis E., Pintelas, Emmanuel, Kotsilieris, Theodore, Stavroyiannis, Stavros, and Pintelas, Panagiotis (2019). Weight-Constrained Neural Networks in Forecasting Tourist Volumes: A Case Study. *Electronics*, *8*(9), https://dx.doi.org/10.3390/electronics8091005

[48] Sidorov, Denis, Panasetsky, Daniil, Tomin, Nikita, Karamov, Dmitriy, Zhukov, Aleksei, Muftahov, Ildar, Dreglea, Aliona, Liu, Fang, and Li, Yong (2020). Toward Zero-Emission Hybrid AC/DC Power Systems with Renewable Energy Sources and Storages: A Case Study from Lake Baikal Region. *Energies*, *13*(5), https://dx.doi.org/10.3390/en13051226

[49] Brzustewicz, Pawel, and Singh, Anupam (2021). Sustainable Consumption in Consumer Behavior in the Time of COVID-19: Topic Modeling on Twitter Data Using LDA. *Energies*, *14*(18), https://dx.doi.org/10.3390/en14185787

[50] Chobar, Adel Pourghader, Adibi, Mohammad Amin, and Kazemi, Abolfazl (2022). Multi-objective hub-spoke network design of perishable tourism products using combination machine learning and meta-heuristic algorithms. *Environment Development And Sustainability*, ISSN 1387-585X, https://dx.doi.org/10.1007/s10668-022-02350-2

[51] Gomez, Diego, Salvador, Pablo, Sanz, Julia, and Casanova, Jose Luis (2021). A new approach to monitor water quality in the Menor sea (Spain) using satellite data and machine learning methods*. *Environmental Pollution*, *286*, ISSN 0269-7491, https://dx.doi.org/10.1016/j.envpol.2021.117489

[52] Martin-Gutierrez, Jorge, Mora, Carlos Efren, Anorbe-Diaz, Beatriz, and Gonzalez-Marrero, Antonio (2017). Virtual Technologies Trends in Education. *Eurasia Journal Of Mathematics Science And Technology Education*, *13*(2), 469-486, ISSN 1305-8215, https://dx.doi.org/10.12973/eurasia.2017.00626a

[53] Kirkos, Efstathios (2022). Airbnb listings' performance: determinants and predictive models. *European Journal Of Tourism Research*, *30*, ISSN 1994-7658

[54] Ye, Qiang, Zhang, Ziqiong, and Law, Rob (2009). Sentiment classification of online reviews to travel destinations by supervised machine learning approaches. *Expert Systems With Applications*, *36*(3), 6527-6535, ISSN 0957-4174, https://dx.doi.org/10.1016/j.eswa.2008.07.035

[55] Wu, Qi, Law, Rob, and Xu, Xin (2012). A sparse Gaussian process regression model for tourism demand forecasting in Hong Kong. *Expert Systems With Applications*, *39*(5), 4769-4774, ISSN 0957-4174, https://dx.doi.org/10.1016/j.eswa.2011.09.159

[56] Belmonte-Fernandez, Oscar, Montoliu, Raul, Torres-Sospedra, Joaquin, Sansano-Sansano, Emilio, and Chia-Aguilar, Daniel (2018). A radiosity-based method to avoid calibration for indoor positioning systems. *Expert Systems With Applications*, *105*, 89-101, ISSN 0957-4174, https://dx.doi.org/10.1016/j.eswa.2018.03.054

[57] Li, Xixi, Kang, Yanfei, and Li, Feng (2020). Forecasting with time series imaging. *Expert Systems With Applications*, *160*, ISSN 0957-4174, https://dx.doi.org/10.1016/j.eswa.2020.113680

[58] King, Michael A., Abrahams, Alan S., and Ragsdale, Cliff T. (2014). Ensemble methods for advanced skier days prediction. *Expert Systems With Applications*, *41*(4), 1176-1188, ISSN 0957-4174, https://dx.doi.org/10.1016/j.eswa.2013.08.002

[59] Yao, Yuan, Cao, Yi, Ding, Xuemei, Zhai, Jia, Liu, Junxiu, Luo, Yuling, Ma, Shuai, and Zou, Kailin (2018). A paired neural network model for tourist arrival forecasting. *Expert Systems With Applications*, *114*, 588-614, ISSN 0957-4174, https://dx.doi.org/10.1016/j.eswa.2018.08.025

[60] Lee, Chung-Hong, and Wang, Shih-Hao (2012). An information fusion approach to integrate image annotation and text mining methods for geographic knowledge discovery. *Expert Systems With Applications*, *39*(10), 8954-8967, ISSN 0957-4174, https://dx.doi.org/10.1016/j.eswa.2012.02.028

[61] Nilashi, Mehrbakhsh, Minaei-Bidgoli, Behrouz, Alrizq, Mesfer, Alghamdi, Abdullah, Alsulami, Abdulaziz A., Samad, Sarminah, and Mohd, Saidatulakmal (2021). An analytical approach for big social data analysis for customer decision-making in eco-friendly hotels. *Expert Systems With Applications*, *186*, ISSN 0957-4174, https://dx.doi.org/10.1016/j.eswa.2021.115722

[62] Sun, Shaolong, Li, Mingchen, Wang, Shouyang, and Zhang, Chengyuan (2022). Multi-step ahead tourism demand forecasting: The perspective of the learning using privileged information paradigm. *Expert Systems With Applications*, *210*, ISSN 0957-4174, https://dx.doi.org/10.1016/j.eswa.2022.118502

[63] Lennox, Robert J., Brownscombe, Jacob W., Cooke, Steven J., and Danylchuk, Andy J. (2018). Post-release behaviour and survival of recreationally-angled arapaima (Arapaima cf. arapaima) assessed with accelerometer biologgers. *Fisheries Research*, *207*, 197-203, ISSN 0165-7836, https://dx.doi.org/10.1016/j.fishres.2018.05.007

[64] Lisi, Francesca A., and Straccia, Umberto (2013). A Logic-based Computational Method for the Automated Induction of Fuzzy Ontology Axioms. *Fundamenta Informaticae*, *124*(4), 503-519, ISSN 0169-2968, https://dx.doi.org/10.3233/FI-2013-846

[65] Santamaria-Granados, Luz, Mendoza-Moreno, Juan Francisco, and Ramirez-Gonzalez, Gustavo (2021). Tourist Recommender Systems Based on Emotion Recognition-A Scientometric Review. *Future Internet*, *13*(1), https://dx.doi.org/10.3390/fi13010002

[66] Do, Hai-Ninh, Shih, Wurong, and Ha, Quang-An (2020). Effects of mobile augmented reality apps on impulse buying behavior: An investigation in the tourism field. *Heliyon*, *6*(8), https://dx.doi.org/10.1016/j.heliyon.2020.e04667

[67] Buckley, S., Ettl, M., Jain, P., Luss, R., Petrik, M., Ravi, R. K., and Venkatramani, C. (2014). Social media and customer behavior analytics for personalized customer engagements. *Ibm Journal Of Research And Development*, *58*(5), ISSN 0018-8646,

https://dx.doi.org/10.1147/JRD.2014.2344515

[68] Bonin-Font, Francisco, Burguera, Antoni, and Lisani, Jose-Luis (2017). Visual Discrimination and Large Area Mapping of Posidonia Oceanica Using a Lightweight AUV. *Ieee Access*, *5*, 24479-24494, ISSN 2169-3536, https://dx.doi.org/10.1109/ACCESS.2017.2764998

[69] Afzaal, Muhammad, Usman, Muhammad, and Fong, Alvis (2019). Tourism Mobile App With Aspect-Based Sentiment Classification Framework for Tourist Reviews. *Ieee Transactions On Consumer Electronics*, *65*(2), 233-242, ISSN 0098-3063, https://dx.doi.org/10.1109/TCE.2019.2908944

[70] Navigli, R, and Velardi, P (2005). Structural semantic interconnections: A knowledge-based approach to word sense disambiguation. *Ieee Transactions On Pattern Analysis And Machine Intelligence*, *27*(7), 1075-1086, ISSN 0162-8828

[71] Deglint, Jason L., Jin, Chao, and Wong, Alexander (2019). Investigating the Automatic Classification of Algae Using the Spectral and Morphological Characteristics via Deep Residual Learning. *Image Analysis And Recognition (Iciar 2019), Pt Ii*, *11663*, 269-280, ISSN 0302-9743, https://dx.doi.org/10.1007/978-3-030-27272-2_23

[72] Shin, Seunghun, Du, Qianzhou, and Xiang, Zheng (2019). What's Vs. How's in Online Hotel Reviews: Comparing Information Value of Content and Writing Style with Machine Learning. *Information And Communication Technologies In Tourism 2019*, 321-332, ISSN 978-3-030-05939-2, https://dx.doi.org/10.1007/978-3-030-05940-8_25

[73] Kaya, Kiymet, Yilmaz, Yaren, Yaslan, Yusuf, Oguducu, Sule Gunduz, and Cingi, Furkan (2022). Demand forecasting model using hotel clustering findings for hospitality industry. *Information Processing and Management*, *59*(1), ISSN 0306-4573, https://dx.doi.org/10.1016/j.ipm.2021.102816

[74] Huh, Jun-Ho, Kim, Han-Byul, and Kim, Jinmo (2017). A Method of Modeling of Basic Big Data Analysis for Korean Medical Tourism: A Machine Learning Approach Using Apriori Algorithm. *Information Science And Applications 2017, Icisa 2017*, *424*, 784-790, ISSN 1876-1100, https://dx.doi.org/10.1007/978-981-10-4154-9_91

[75] . Neidhardt, Julia, and Werthner, Hannes (2018). IT and tourism: still a hot topic, but do not forget IT. *Information Technology and Tourism*, *20*(1), 1-7, ISSN 1098-3058, https://dx.doi.org/10.1007/s40558-018-0115-x

[76] H., V Phan, Truong, and Do, Phuc (2020). BERT+vnKG: Using Deep Learning and Knowledge Graph to Improve Vietnamese Question Answering System. *International Journal Of Advanced Computer Science And Applications*, *11*(7), 480-487, ISSN 2158-107X

[77] Xu, Xin, Law, Rob, and Wu, Tao (2009). Support Vector Machines with Manifold Learning and Probabilistic Space Projection for Tourist Expenditure Analysis. *International Journal Of Computational Intelligence Systems*, *2*(1), 17-26, ISSN 1875-6891

[78] Ali, Faizan, Park, Eunhye (Olivia), Kwon, Junehee, and Chae, Bongsug (Kevin) (2019). 30 years of contemporary hospitality management Uncovering the bibliometrics and topical trends. *International Journal Of Contemporary Hospitality Management*, *31*(7), 2641-2665, ISSN 0959-6119, https://dx.doi.org/10.1108/IJCHM-10-2018-0832

[79] Gour, Alekh, Aggarwal, Shikha, and Erdem, Mehmet (2021). Reading between the lines: analyzing online reviews by using a multi-method Web-analytics approach. *International Journal Of Contemporary Hospitality Management*, *33*(2), 490-512, ISSN 0959-6119, https://dx.doi.org/10.1108/IJCHM-07-2020-0760

[80] Lin, Michael S., Liang, Yun, Xue, Joanne X., Pan, Bing, and Schroeder, Ashley (2021). Destination image through social media analytics and survey method. *International Journal Of Contemporary Hospitality Management*, *33*(6), 2219-2238, ISSN 0959-6119, https://dx.doi.org/10.1108/IJCHM-08-2020-0861

[81] Lee, Minwoo, Kwon, Wooseok, and Back, Ki-Joon (2021). Artificial intelligence for hospitality big data analytics: developing a prediction model of restaurant review helpfulness for customer decision-making. *International Journal Of Contemporary Hospitality Management*, *33*(6), 2117-2136, ISSN 0959-6119, https://dx.doi.org/10.1108/IJCHM-06-2020-0587

[82] Park, Eunhye (Olivia), Chae, Bongsug, and Kwon, Junehee (2018). Toward understanding the topical structure of hospitality literature: Applying machine learning and traditional statistics. *International Journal Of Contemporary Hospitality Management*, *30*(11), 3386-3411, ISSN 0959-6119, https://dx.doi.org/10.1108/IJCHM-11-2017-0714

[83] Filieri, Raffaele, D'Amico, Elettra, Destefanis, Alessandro, Paolucci, Emilio, and Raguseo, Elisabetta (2021). Artificial intelligence (AI) for tourism: an European-based study on successful AI tourism start-ups. *International Journal Of Contemporary Hospitality Management*, *33*(11), 4099-4125, ISSN 0959-6119, https://dx.doi.org/10.1108/IJCHM-02-2021-0220

[84] Ampountolas, Apostolos, and Legg, Mark P. (2021). A segmented machine learning modeling approach of social media for predicting occupancy. *International Journal Of Contemporary Hospitality Management*, *33*(6), 2001-2021, ISSN 0959-6119, https://dx.doi.org/10.1108/IJCHM-06-2020-0611

[85] Liu, Yiran, and Beldona, Srikanth (2021). Extracting revisit intentions from social media big data: a rule-based classification model. *International Journal Of Contemporary Hospitality Management*, *33*(6), 2176-2193, ISSN 0959-6119, https://dx.doi.org/10.1108/IJCHM-06-2020-0592

[86] Lee, Yejin, and Kim, Dae-Young (2021). The decision tree for longer-stay hotel guest: the relationship between hotel booking determinants and geographical distance. *International Journal Of Contemporary Hospitality Management*, *33*(6), 2264-2282, ISSN 0959-6119, https://dx.doi.org/10.1108/IJCHM-06-2020-0594

[87] Nilashi, Mehrbakhsh, Yadegaridehkordi, Elaheh, Ibrahim, Othman, Samad, Sarminah, Ahani, Ali, and Sanzogni, Louis (2019). Analysis of Travellers' Online Reviews in Social Networking Sites Using Fuzzy Logic Approach. *International Journal Of Fuzzy Systems*, *21*(5), 1367-1378, ISSN 1562-2479, https://dx.doi.org/10.1007/s40815-019-00630-0

[88] Kang, Junfeng, Guo, Xingyu, Fang, Lei, Wang, Xiangrong, and Fan, Zhengqiu (2022). Integration of Internet search data to predict tourism trends using spatial-temporal XGBoost composite model. *International Journal Of Geographical Information Science*, *36*(2), 236-252, ISSN 1365-8816, https://dx.doi.org/10.1080/13658816.2021.1934476

[89] Ma, Yufeng, Xiang, Zheng, Du, Qianzhou, and Fan, Weiguo (2018). Effects of user-provided photos on hotel review helpfulness:

An analytical approach with deep leaning. *International Journal Of Hospitality Management*, *71*, 120-131, ISSN 0278-4319, https://dx.doi.org/10.1016/j.ijhm.2017.12.008

[90] Kwok, Linchi, Tang, Yingying, and Yu, Bei (2020). Research Paper The 7 Ps marketing mix of home-sharing services: Mining travelers' online reviews on Airbnb. *International Journal Of Hospitality Management*, *90*, ISSN 0278-4319, https://dx.doi.org/10.1016/j.ijhm.2020.102616

[91] Sanchez-Medina, Agustin J., and C-Sanchez, Eleazar (2020). Using machine learning and big data for efficient forecasting of hotel booking cancellations. *International Journal Of Hospitality Management*, *89*, ISSN 0278-4319, https://dx.doi.org/10.1016/j.ijhm.2020.102546

[92] Le, Truc H., Arcodia, Charles, Novais, Margarida Abreu, and Kralj, Anna (2022). How consumers perceive authenticity in restaurants: A study of online reviews. *International Journal Of Hospitality Management*, *100*, ISSN 0278-4319, https://dx.doi.org/10.1016/j.ijhm.2021.103102

[93] Shi, Yong, Zhu, Luyao, Li, Wei, Gao, Kun, and Zheng, Yuanchun (2019). Survey on Classic and Latest Textual Sentiment Analysis Articles and Techniques. *International Journal Of Information Technology and Decision Making*, *18*(4), 1243-1287, ISSN 0219-6220, https://dx.doi.org/10.1142/S0219622019300015

[94] Perles-Ribes, Jose Francisco, Ramon-Rodriguez, Ana Belen, Moreno-Izquierdo, Luis, and Such-Devesa, Maria Jesus (2020). Machine learning techniques as a tool for predictingovertourism: The case of Spain. *International Journal Of Tourism Research*, *22*(6), 825-838, ISSN 1099-2340, https://dx.doi.org/10.1002/jtr.2383

[95] Zhu, Min, Wu, Jinran, and Wang, You-Gan (2021). Multi-horizon accommodation demand forecasting: A New Zealand case study. *International Journal Of Tourism Research*, *23*(3), 442-453, ISSN 1099-2340, https://dx.doi.org/10.1002/jtr.2416

[96] Moreno-Izquierdo, Luis, Egorova, Galina, Pereto-Rovira, Alexandre, and Mas-Ferrando, Adrian (2018). Exploring the use of artificial intelligence in price maximisation in the tourism sector: its application in the case of Airbnb in the Valencian Community. *Investigaciones Regionales-Journal Of Regional Research*(42), 113-128, ISSN 1695-7253

[97] Gu, Qiushi, Zhang, Haiping, Chen, Min, and Chen, Chongcheng (2019). Regionalization Analysis and Mapping for the Source and Sink of Tourist Flows. *Isprs International Journal Of Geo-Information*, *8*(7), https://dx.doi.org/10.3390/ijgi8070314

[98] Sanchez-Franco, Manuel J., Navarro-Garcia, Antonio, and Rondan-Cataluna, Francisco Javier (2019). A naive Bayes strategy for classifying customer satisfaction: A study based on online reviews of hospitality services. *Journal Of Business Research*, *101*, 499-506, ISSN 0148-2963, https://dx.doi.org/10.1016/j.jbusres.2018.12.051

[99] Garner, Benjamin, Thornton, Corliss, Pawluk, Anita Luo, Cortez, Roberto Mora, Johnston, Wesley, and Ayala, Cesar (2022). Utilizing text-mining to explore consumer happiness within tourism destinations. *Journal Of Business Research*, *139*, 1366-1377, ISSN 0148-2963, https://dx.doi.org/10.1016/j.jbusres.2021.08.025

[100] D'Amato, D., Droste, N., Allen, B., Kettunen, M., Laehtinen, K., Korhonen, J., Leskinen, P., Matthies, B. D., and Toppinen, A. (2017). Green, circular, bio economy: A comparative analysis of sustainability avenues. *Journal Of Cleaner Production*, *168*, 716-734, ISSN 0959-6526, https://dx.doi.org/10.1016/j.jclepro.2017.09.053

[101] Nilashi, Mehrbakhsh, Ahani, Ali, Esfahani, Mohammad Dalvi, Yadegaridehkordi, Elaheh, Samad, Sarminah, Ibrahim, Othman, Sharef, Nurfadhlina Mohd, and Akbari, Elnaz (2019). Preference learning for eco-friendly hotels recommendation: A multi-criteria collaborative filtering approach. *Journal Of Cleaner Production*, *215*, 767-783, ISSN 0959-6526, https://dx.doi.org/10.1016/j.jclepro.2019.01.012

[102] Nilashi, Mehrbakhsh, Ibrahim, Othman, Yadegaridehkordi, Elaheh, Samad, Sarminah, Akbari, Elnaz, and Alizadeh, Azar (2018). Travelers decision making using online review in social network sites: A case on TripAdvisor. *Journal Of Computational Science*, *28*, 168-179, ISSN 1877-7503, https://dx.doi.org/10.1016/j.jocs.2018.09.006

[103] Gabriel, I Penagos-Londono,, Rodriguez-Sanchez, Carla, Ruiz-Moreno, Felipe, and Torres, Eduardo (2021). A machine learning approach to segmentation of tourists based on perceived destination sustainability and trustworthiness. *Journal Of Destination Marketing and Management*, *19*, ISSN 2212-571X, https://dx.doi.org/10.1016/j.jdmm.2020.100532

[104] Arabadzhyan, Anastasia, Figini, Paolo, and Vici, Laura (2021). Measuring destination image: a novel approach based on visual data mining. A methodological proposal and an application to European islands. *Journal Of Destination Marketing and Management*, *20*, ISSN 2212-571X, https://dx.doi.org/10.1016/j.jdmm.2021.100611

[105] Tsang, Wai Kit, and Benoit, Dries F. (2020). Gaussian Processes for Daily Demand Prediction. *Journal Of Forecasting*, *39*(3), 551-568, ISSN 0277-6693, https://dx.doi.org/10.1002/for.2644

[106] Huang, Arthur, Chao, Ying, Velasco, Efren de la Mora, Bilgihan, Anil, and Wei, Wei (2022). When artificial intelligence meets the hospitality and tourism industry: an assessment framework to inform theory and management. *Journal Of Hospitality And Tourism Insights*, *5*(5), 1080-1100, ISSN 2514-9792, https://dx.doi.org/10.1108/JHTI-01-2021-0021

[107] Puh, Karlo, and Babac, Marina Bagic (2022). Predicting sentiment and rating of tourist reviews using machine learning. *Journal Of Hospitality And Tourism Insights*, ISSN 2514-9792, https://dx.doi.org/10.1108/JHTI-02-2022-0078

[108] Shehhi, Mohammed Al, and Karathanasopoulos, Andreas (2020). Forecasting hotel room prices in selected GCC cities using deep learning. *Journal Of Hospitality And Tourism Management*, *42*, 40-50, ISSN 1447-6770, https://dx.doi.org/10.1016/j.jhtm.2019.11.003

[109] Aggarwal, Shikha, and Gour, Alekh (2020). Peeking inside the minds of tourists using a novel web analytics approach. *Journal Of Hospitality And Tourism Management*, *45*, 580-591, ISSN 1447-6770, https://dx.doi.org/10.1016/j.jhtm.2020.10.009

[110] Ahani, Ali, Nilashi, Mehrbakhsh, Zogaan, Waleed Abdu, Samad, Sarminah, Aljehane, Nojood O., Alhargan, Ashwaq, Mohd, Saidatulakmal, Ahmadi, Hossein, and Sanzogni, Louis (2021). Evaluating medical travelers' satisfaction through online review analysis. *Journal Of Hospitality And Tourism Management*, *48*, 519-537, ISSN 1447-6770, https://dx.doi.org/10.1016/j.jhtm.2021.08.005

[111] Moro, Sergio, Rita, Paulo, Ramos, Pedro, and Esmerado, Joaquim (2019). Analysing recent augmented and virtual reality developments in tourism. *Journal Of Hospitality And Tourism Technology*, *10*(4), 571-586, ISSN 1757-9880, https://dx.doi.org/10.1108/JHTT-07-2018-0059

[112] Baggio, Rodolfo, Micera, Roberto, and Chiappa, Giacomo Del (2020). Smart tourism destinations: a critical reflection. *Journal Of Hospitality And Tourism Technology*, *11*(3), 559-574, ISSN 1757-9880, https://dx.doi.org/10.1108/JHTT-01-2019-0011

[113] Bagherzadeh, Sayeh, Shokouhyar, Sajjad, Jahani, Hamed, and Sigala, Marianna (2021). A generalizable sentiment analysis method for creating a hotel dictionary: using big data on TripAdvisor hotel reviews. *Journal Of Hospitality And Tourism Technology*, *12*(2), 210-238, ISSN 1757-9880, https://dx.doi.org/10.1108/JHTT-02-2020-0034

[114] Bilotta, Eleonora, Bertacchini, Francesca, Gabriele, Lorella, Giglio, Simona, Pantano, Pietro Salvatore, and Romita, Tullio (2021). Industry 4.0 technologies in tourism education: Nurturing students to think with technology. *Journal Of Hospitality Leisure Sport and Tourism Education*, *29*, ISSN 1473-8376, https://dx.doi.org/10.1016/j.jhlste.2020.100275

[115] Ren, Meng, Vu, Huy Quan, Li, Gang, and Law, Rob (2021). Large-scale comparative analyses of hotel photo content posted by managers and customers to review platforms based on deep learning: implications for hospitality marketers. *Journal Of Hospitality Marketing and Management*, *30*(1), 96-119, ISSN 1936-8623, https://dx.doi.org/10.1080/19368623.2020.1765226

[116] Jaseena, K. U., and Kovoor, Binsu C. (2022). Deterministic weather forecasting models based on intelligent predictors: A survey. *Journal Of King Saud University-Computer And Information Sciences*, *34*(6), 3393-3412, ISSN 1319-1578, https://dx.doi.org/10.1016/j.jksuci.2020.09.009

[117] Akman, Engin, Karaman, Abdullah S., and Kuzey, Cemil (2020). Visa trial of international trade: evidence from support vector machines and neural networks. *Journal Of Management Analytics*, *7*(2), 231-252, ISSN 2327-0012, https://dx.doi.org/10.1080/23270012.2020.1731719

[118] Rios-Morales, Ruth, Gamberger, Dragan, Jenkins, Ian, and Smuc, Tom (2011). Modelling investment in the tourism industry using the World Bank's good governance indicators. *Journal Of Modelling In Management*, *6*(3), 279-296, ISSN 1746-5664, https://dx.doi.org/10.1108/17465661111183694

[119] Sangkaew, Nichapat, and Zhu, Hongrui (2022). Understanding Tourists' Experiences at Local Markets in Phuket: An Analysis of TripAdvisor Reviews. *Journal Of Quality Assurance In Hospitality and Tourism*, *23*(1), 89-114, ISSN 1528-008X, https://dx.doi.org/10.1080/1528008X.2020.1848747

[120] Ahani, Ali, Nilashi, Mehrbakhsh, Yadegaridehkordi, Elaheh, Sanzogni, Louis, Tarik, A. Rashid, Knox, Kathy, Samad, Sarminah, and Ibrahim, Othman (2019). Revealing customers' satisfaction and preferences through online review analysis: The case of Canary Islands hotels. *Journal Of Retailing And Consumer Services*, *51*, 331-343, ISSN 0969-6989, https://dx.doi.org/10.1016/j.jretconser.2019.06.014

[121] Nilashi, Mehrbakhsh, Abumalloh, Rabab Ali, Minaei-Bidgoli, Behrouz, Zogaan, Waleed Abdu, Alhargan, Ashwaq, Mohd, Saidatulakmal, Azhar, Sharifah Nurlaili Farhana Syed, Asadi, Shahla, and Samad, Sarminah (2022). Revealing travellers' satisfaction during COVID-19 outbreak: Moderating role of service quality. *Journal Of Retailing And Consumer Services*, *64*, ISSN 0969-6989, https://dx.doi.org/10.1016/j.jretconser.2021.102783

[122] Pantano, Eleonora, and Dennis, Charles (2019). Store buildings as tourist attractions: Mining retail meaning of store building pictures through a machine learning approach. *Journal Of Retailing And Consumer Services*, *51*, 304-310, ISSN 0969-6989, https://dx.doi.org/10.1016/j.jretconser.2019.06.018

[123] Arora, Anuja, Srivastava, Aman, and Bansal, Shivam (2020). Business competitive analysis using promoted post detection on social media. *Journal Of Retailing And Consumer Services*, *54*, ISSN 0969-6989, https://dx.doi.org/10.1016/j.jretconser.2019.101941

[124] Agarwal, Pragati, Swami, Sanjeev, and Malhotra, Sunita Kumari (2022). Artificial Intelligence Adoption in the Post COVID-19 New-Normal and Role of Smart Technologies in Transforming Business: a Review. *Journal Of Science And Technology Policy Management*, ISSN 2053-4620, https://dx.doi.org/10.1108/JSTPM-08-2021-0122

[125] Filieri, Raffaele, Lin, Zhibin, Li, Yulei, Lu, Xiaoqian, and Yang, Xingwei (2022). Customer Emotions in Service Robot Encounters: A Hybrid Machine-Human Intelligence Approach. *Journal Of Service Research*, *25*(4), 614-629, ISSN 1094-6705, https://dx.doi.org/10.1177/10946705221103937

[126] Jain, Praphula Kumar, Pamula, Rajendra, and Yekun, Ephrem Admasu (2022). A multi-label ensemble predicting model to service recommendation from social media contents. *Journal Of Supercomputing*, *78*(4), 5203-5220, ISSN 0920-8542, https://dx.doi.org/10.1007/s11227-021-04087-7

[127] Rezapouraghdam, Hamed, Akhshik, Arash, and Ramkissoon, Haywantee (2021). Application of machine learning to predict visitors' green behavior in marine protected areas: evidence from Cyprus. *Journal Of Sustainable Tourism*, ISSN 0966-9582, https://dx.doi.org/10.1080/09669582.2021.1887878

[128] Hardy, Anne, and Aryal, Jagannath (2020). Using innovations to understand tourist mobility in national parks. *Journal Of Sustainable Tourism*, *28*(2), 263-283, ISSN 0966-9582, https://dx.doi.org/10.1080/09669582.2019.1670186

[129] Darko, Adjei Peter, and Liang, Decui (2023). A heterogeneous opinion-driven decision-support model for tourists' selection with different travel needs in online reviews. *Journal Of The Operational Research Society*, *74*(1), 272-289, ISSN 0160-5682, https://dx.doi.org/10.1080/01605682.2022.2035274

[130] Samala, Nagaraj, Katkam, Bharath Shashanka, Bellamkonda, Raja Shekhar, and Rodriguez, Raul Villamarin (2022). Impact of AI and robotics in the tourism sector: a critical insight. *Journal Of Tourism Futures*, *8*(1), 73-87, ISSN 2055-5911, https://dx.doi.org/10.1108/JTF-07-2019-0065

[131] Parvez, M. Omar (2021). Use of machine learning technology for tourist and organizational services: high-tech innovation in the hospitality industry. *Journal Of Tourism Futures*, *7*(2), 240-244, ISSN 2055-5911, https://dx.doi.org/10.1108/JTF-09-2019-0083

[132] Li, Gang, Law, Rob, Rong, Jia, and Vu, Huy Quan (2010). INCORPORATING BOTH POSITIVE AND NEGATIVE ASSOCIATION RULES INTO THE ANALYSIS OF OUTBOUND TOURISM IN HONG KONG. *Journal Of Travel and Tourism Marketing*, *27*(8), 812-828, ISSN 1054-8408, https://dx.doi.org/10.1080/10548408.2010.527248

[133] Alaei, Ali Reza, Becken, Susanne, and Stantic, Bela (2019). Sentiment Analysis in Tourism: Capitalizing on Big Data. *Journal Of Travel Research*, *58*(2), 175-191, ISSN 0047-2875, https://dx.doi.org/10.1177/0047287517747753

[134] Kirilenko, Andrei P., Stepchenkova, Svetlana O., Kim, Hany, and Li, Xiang (Robert) (2018). Automated Sentiment Analysis in Tourism: Comparison of Approaches. *Journal Of Travel Research*, *57*(8), 1012-1025, ISSN 0047-2875, https://dx.doi.org/10.1177/0047287517729757

[135] Hoepken, Wolfram, Eberle, Tobias, Fuchs, Matthias, and Lexhagen, Maria (2021). Improving Tourist Arrival Prediction: A Big Data and Artificial Neural Network Approach. *Journal Of Travel Research*, *60*(5), 998-1017, ISSN 0047-2875, https://dx.doi.org/10.1177/0047287520921244

[136] Li, Xin, Li, Hengyun, Pan, Bing, and Law, Rob (2021). Machine Learning in Internet Search Query Selection for Tourism Forecasting. *Journal Of Travel Research*, *60*(6), 1213-1231, ISSN 0047-2875, https://dx.doi.org/10.1177/0047287520934871

[137] Ma, Shihan (David), and Kirilenko, Andrei P. (2020). Climate Change and Tourism in English-Language Newspaper Publications. *Journal Of Travel Research*, *59*(2), 352-366, ISSN 0047-2875, https://dx.doi.org/10.1177/0047287519839157

[138] Zhang, Chengyuan, Li, Mingchen, Sun, Shaolong, Tang, Ling, and Wang, Shouyang (2022). Decomposition Methods for Tourism Demand Forecasting: A Comparative Study. *Journal Of Travel Research*, *61*(7), 1682-1699, ISSN 0047-2875, https://dx.doi.org/10.1177/00472875211036194

[139] Song, Yang, Wang, Runzi, Fernandez, Jessica, and Li, Dongying (2021). Investigating sense of place of the Las Vegas Strip using online reviews and machine learning approaches. *Landscape And Urban Planning*, *205*, ISSN 0169-2046, https://dx.doi.org/10.1016/j.landurbplan.2020.103956

[140] Koranga, Manisha, Pant, Pushpa, Kumar, Tarun, Pant, Durgesh, Bhatt, Ashutosh Kumar, and Pant, R. P. (2022). Efficient water quality prediction models based on machine learning algorithms for Nainital Lake, Uttarakhand. *Materials Today-Proceedings*, *57*, 1706-1712, ISSN 2214-7853, https://dx.doi.org/10.1016/j.matpr.2021.12.334

[141] Anglisano, Anna, Casas, Lluis, Anglisano, Marc, and Queralt, Ignasi (2020). Application of Supervised Machine-Learning Methods for Attesting Provenance in Catalan Traditional Pottery Industry. *Minerals*, *10*(1), https://dx.doi.org/10.3390/min10010008

[142] Thakker, Urvish, Patel, Ruhi, and Shah, Manan (2021). A comprehensive analysis on movie recommendation system employing collaborative filtering. *Multimedia Tools And Applications*, *80*(19), 28647-28672, ISSN 1380-7501, https://dx.doi.org/10.1007/s11042-021-10965-2

[143] Haklidir, Fusun S. Tut, and Haklidir, Mehmet (2020). Prediction of Reservoir Temperatures Using Hydrogeochemical Data, Western Anatolia Geothermal Systems (Turkey): A Machine Learning Approach. *Natural Resources Research*, *29*(4), 2333-2346, ISSN 1520-7439, https://dx.doi.org/10.1007/s11053-019-09596-0

[144] Hussain, Amir, and Cambria, Erik (2018). Semi-supervised learning for big social data analysis. *Neurocomputing*, *275*, 1662-1673, ISSN 0925-2312, https://dx.doi.org/10.1016/j.neucom.2017.10.010

[145] Pan, Yaoru, Flindt, Mogens, Schneider-Kamp, Peter, and Holmer, Marianne (2021). Beach wrack mapping using unmanned aerial vehicles for coastal environmental management. *Ocean and Coastal Management*, *213*, ISSN 0964-5691, https://dx.doi.org/10.1016/j.ocecoaman.2021.105843

[146] Aamer, Ammar Mohamed, Yani, Luh Putu Eka, and Priyatna, I. Made Alan (2021). Data Analytics in the Supply Chain Management: Review of Machine Learning Applications in Demand Forecasting. *Operations And Supply Chain Management-An International Journal*, *14*(1), 1-13, ISSN 1979-3561, https://dx.doi.org/10.31387/oscm0440281

[147] Haas, Andreas F., Guibert, Marine, Foerschner, Anja, Co, Tim, Calhoun, Sandi, George, Emma, Hatay, Mark, Dinsdale, Elizabeth, Sandin, Stuart A., Smith, Jennifer E., Vermeij, Mark J. A., Felts, Ben, Dustan, Phillip, Salamon, Peter, and Rohwer, Forest (2015). Can we measure beauty? Computational evaluation of coral reef aesthetics. *Peerj*, *3*, ISSN 2167-8359, https://dx.doi.org/10.7717/peerj.1390

[148] Wang, Meng (2020). Applying Internet information technology combined with deep learning to tourism collaborative recommendation system. *Plos One*, *15*(12), ISSN 1932-6203, https://dx.doi.org/10.1371/journal.pone.0240656

[149] Xue, Mingqiang, Wu, Huayu, Chen, Wei, Ng, Wee Siong, Goh, Gin Howe, and ACM (2014). Identifying Tourists from Public Transport Commuters. *Proceedings Of The 20th Acm Sigkdd International Conference On Knowledge Discovery And Data Mining (Kdd'14)*, 1779-1788, https://dx.doi.org/10.1145/2623330.2623352

[150] Tsai, Yu Hsin, Stow, Douglas, Chen, Hsiang Ling, Lewison, Rebecca, An, Li, and Shi, Lei (2018). Mapping Vegetation and Land Use Types in Fanjingshan National Nature Reserve Using Google Earth Engine. *Remote Sensing*, *10*(6), https://dx.doi.org/10.3390/rs10060927

[151] Sun, Yanwei, Gao, Chao, Li, Jialin, Wang, Run, and Liu, Jian (2019). Quantifying the Effects of Urban Form on Land Surface Temperature in Subtropical High-Density Urban Areas Using Machine Learning. *Remote Sensing*, *11*(8), https://dx.doi.org/10.3390/rs11080959

[152] Moya, Luis, Perez, Luis R. Marval, Mas, Erick, Adriano, Bruno, Koshimura, Shunichi, and Yamazaki, Fumio (2018). Novel Unsupervised Classification of Collapsed Buildings Using Satellite Imagery, Hazard Scenarios and Fragility Functions. *Remote Sensing*, *10*(2), https://dx.doi.org/10.3390/rs10020296

[153] Claveria, Oscar, Torra, Salvador, and Monte, Enric (2016). Modelling Tourism Demand To Spain With Machine Learning Techniques. The Impact Of Forecast Horizon On Model Selection. *Revista De Economia Aplicada*, *24*(72), 109-132, ISSN 1133-455X

[154] Hakim, Noorkholis Luthfil, Shih, Timothy K., Arachchi, Sandeli Priyanwada Kasthuri, Aditya, Wisnu, Chen, Yi-Cheng, and Lin, Chih-Yang (2019). Dynamic Hand Gesture Recognition Using 3DCNN and LSTM with FSM Context-Aware Model. *Sensors*, *19*(24), https://dx.doi.org/10.3390/s19245429

[155] Sagheer, Alaa, Hamdoun, Hala, and Youness, Hassan (2021). Deep LSTM-Based Transfer Learning Approach for Coherent Forecasts in Hierarchical Time Series. *Sensors*, *21*(13), https://dx.doi.org/10.3390/s21134379

[156] Crivellari, Alessandro, and Beinat, Euro (2020). Trace2trace-A Feasibility Study on Neural Machine Translation Applied to Human Motion Trajectories. *Sensors*, *20*(12), https://dx.doi.org/10.3390/s20123503

[157] Claveria, Oscar, Monte, Enric, and Torra, Salvador (2016). Modelling cross-dependencies between Spain's regional tourism markets with an extension of the Gaussian process regression model. *Series-Journal Of The Spanish Economic Association*, *7*(3), 341-357, ISSN 1869-4187, https://dx.doi.org/10.1007/s13209-016-0144-7

[158] Kesgin, Muhammet, and Murthy, Rajendran S. (2019). Consumer engagement: the role of social currency in online reviews. *Service Industries Journal*, *39*(7), 609-636, ISSN 0264-2069, https://dx.doi.org/10.1080/02642069.2018.1553237

[159] Saura, Jose Ramon, Reyes-Menendez, Ana, and Alvarez-Alonso, Cesar (2018). Do Online Comments Affect Environmental Management? Identifying Factors Related to Environmental Management and Sustainability of Hotels. *Sustainability*, *10*(9), https://dx.doi.org/10.3390/su10093016

[160] Nilashi, Mehrbakhsh, Mardani, Abbas, Liao, Huchang, Ahmadi, Hossein, Manaf, Azizah Abdul, and Almukadi, Wafa (2019). A Hybrid Method with TOPSIS and Machine Learning Techniques for Sustainable Development of Green Hotels Considering Online Reviews. *Sustainability*, *11*(21), https://dx.doi.org/10.3390/su11216013

[161] Tao, Yuguo, Zhang, Feng, Shi, Chunyun, and Chen, Yun (2019). Social Media Data-Based Sentiment Analysis of Tourists' Air Quality Perceptions. *Sustainability*, *11*(18), https://dx.doi.org/10.3390/su11185070

[162] Sun, Yao, Ma, Hang, and Chan, Edwin H. W. (2018). A Model to Measure Tourist Preference toward Scenic Spots Based on Social Media Data: A Case of Dapeng in China. *Sustainability*, *10*(1), https://dx.doi.org/10.3390/su10010043

[163] Lee, Jee Hoon, Wood, Jacob, and Kim, Jungsuk (2021). Tracing the Trends in Sustainability and Social Media Research Using Topic Modeling. *Sustainability*, *13*(3), https://dx.doi.org/10.3390/su13031269

[164] Pasvisheh, Roghayeh Sadeghi, Forio, Marie Anne Eurie, Ho, Long Tuan, and Goethals, Peter L. M. (2021). Evidence-Based Management of the Anzali Wetland System (Northern Iran) Based on Innovative Monitoring and Modeling Methods. *Sustainability*, *13*(10), https://dx.doi.org/10.3390/su13105503

[165] Arreeras, Tosporn, Arimura, Mikiharu, Asada, Takumi, and Arreeras, Saharat (2019). Association Rule Mining Tourist-Attractive Destinations for the Sustainable Development of a Large Tourism Area in Hokkaido Using Wi-Fi Tracking Data. *Sustainability*, *11*(14), https://dx.doi.org/10.3390/su11143967

[166] Cubric, Marija (2020). Drivers, barriers and social considerations for AI adoption in business and management: A tertiary study. *Technology In Society*, *62*, ISSN 0160-791X, https://dx.doi.org/10.1016/j.techsoc.2020.101257

[167] Yadegaridehkordi, Elaheh, Nilashi, Mehrbakhsh, Nasir, Mohd Hairul Nizam Bin Md, Momtazi, Saeedeh, Samad, Sarminah, Supriyanto, Eko, and Ghabban, Fahad (2021). Customers segmentation in eco-friendly hotels using multi-criteria and machine learning techniques. *Technology In Society*, *65*, ISSN 0160-791X, https://dx.doi.org/10.1016/j.techsoc.2021.101528

[168] Zibarzani, Masoumeh, Abumalloh, Rabab Ali, Nilashi, Mehrbakhsh, Samad, Sarminah, Alghamdi, O. A., Nayer, Fatima Khan, Ismail, Muhammed Yousoof, Mohd, Saidatulakmal, and Akib, Noor Adelyna Mohammed (2022). Customer satisfaction with Restaurants Service Quality during COVID-19 outbreak: A two-stage methodology. *Technology In Society*, *70*, ISSN 0160-791X, https://dx.doi.org/10.1016/j.techsoc.2022.101977

[169] Nilashi, Mehrbakhsh, Abumalloh, Rabab Ali, Alghamdi, Abdullah, Minaei-Bidgoli, Behrouz, Alsulami, Abdulaziz A., Thanoon, Mohammed, Asadi, Shahla, and Samad, Sarminah (2021). What is the impact of service quality on customers' satisfaction during COVID-19 outbreak? New findings from online reviews analysis. *Telematics And Informatics*, *64*, ISSN 0736-5853, https://dx.doi.org/10.1016/j.tele.2021.101693

[170] Nilashi, Mehrbakhsh, Asadi, Shahla, Minaei-Bidgoli, Behrouz, Abumalloh, Rabab Ali, Samad, Sarminah, Ghabban, Fahad, and Ahani, Ali (2021). Recommendation agents and information sharing through social media for coronavirus outbreak. *Telematics And Informatics*, *61*, ISSN 0736-5853, https://dx.doi.org/10.1016/j.tele.2021.101597

[171] Tang, Ling, Zhang, Chengyuan, Li, Tingfei, and Li, Ling (2021). A novel BEMD-based method for forecasting tourist volume with search engine data. *Tourism Economics*, *27*(5), 1015-1038, ISSN 1354-8166, https://dx.doi.org/10.1177/1354816620912995

[172] Schwartz, Zvi, Webb, Timothy, Jean-Pierre, I van der Rest,, and Koupriouchina, Larissa (2021). Enhancing the accuracy of revenue management system forecasts: The impact of machine and human learning on the effectiveness of hotel occupancy forecast combinations across multiple forecasting horizons. *Tourism Economics*, *27*(2), 273-291, ISSN 1354-8166, https://dx.doi.org/10.1177/1354816619884800

[173] Bi, Jian-Wu, Han, Tian-Yu, and Li, Hui (2022). International tourism demand forecasting with machine learning models: The power of the number of lagged inputs. *Tourism Economics*, *28*(3), 621-645, ISSN 1354-8166, https://dx.doi.org/10.1177/1354816620976954

[174] Sun, Shaolong, Li, Yanzhao, Guo, Ju-e, and Wang, Shouyang (2022). Tourism demand forecasting: An ensemble deep learning approach. *Tourism Economics*, *28*(8), 2021-2049, ISSN 1354-8166, https://dx.doi.org/10.1177/13548166211025160

[175] Xiang, Zheng, Du, Qianzhou, Ma, Yufeng, and Fan, Weiguo (2017). A comparative analysis of major online review platforms: Implications for social media analytics in hospitality and tourism. *Tourism Management*, *58*, 51-65, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2016.10.001

[176] Sun, Shaolong, Wei, Yunjie, Tsui, Kwok-Leung, and Wang, Shouyang (2019). Forecasting tourist arrivals with machine learning

and internet search index. *Tourism Management*, *70*, 1-10, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2018.07.010

[177] Taecharungroj, Viriya, and Mathayomchan, Boonyanit (2019). Analysing TripAdvisor reviews of tourist attractions in Phuket, Thailand. *Tourism Management*, *75*, 550-568, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2019.06.020

[178] Giglio, Simona, Bertacchini, Francesca, Bilotta, Eleonora, and Pantano, Pietro (2019). Using social media to identify tourism attractiveness in six Italian cities. *Tourism Management*, *72*, 306-312, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2018.12.007

[179] Rong, Jia, Vu, Huy Quan, Law, Rob, and Li, Gang (2012). A behavioral analysis of web sharers and browsers in Hong Kong using targeted association rule mining. *Tourism Management*, *33*(4), 731-740, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2011.08.006

[180] Kaczmarek, Tomasz, Perez, Katarzyna, Demir, Ender, and Zaremba, Adam (2021). How to survive a pandemic: The corporate resiliency of travel and leisure companies to the COVID-19 outbreak. *Tourism Management*, *84*, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2020.104281

[181] Xie, Gang, Qian, Yatong, and Wang, Shouyang (2021). Forecasting Chinese cruise tourism demand with big data: An optimized machine learning approach. *Tourism Management*, *82*, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2020.104208

[182] Arefieva, Veronika, Egger, Roman, and Yu, Joanne (2021). A machine learning approach to cluster destination image on Instagram. *Tourism Management*, *85*, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2021.104318

[183] Law, Rob, Rong, Jia, Vu, Huy Quan, Li, Gang, and Lee, Hee Andy (2011). Identifying changes and trends in Hong Kong outbound tourism. *Tourism Management*, *32*(5), 1106-1114, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2010.09.011

[184] Brida, Juan Gabriel, Lanzilotta, Bibiana, Moreno, Leonardo, and Santinaque, Florencia (2018). A non-linear approximation to the distribution of total expenditure distribution of cruise tourists in Uruguay. *Tourism Management*, *69*, 62-68, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2018.05.006

[185] Zheng, Weimin, Liao, Zhixue, and Lin, Zhibin (2020). Navigating through the complex transport system: A heuristic approach for city tourism recommendation. *Tourism Management*, *81*, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2020.104162

[186] Payntar, Nicole D., Hsiao, Wei-Lin, Covey, R. Alan, and Grauman, Kristen (2021). Learning patterns of tourist movement and photography from geotagged photos at archaeological heritage sites in Cuzco, Peru. *Tourism Management*, *82*, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2020.104165

[187] Li, Hengyun, Ji, Haipeng, Liu, Hongbo, Cai, Danting, and Gao, Huicai (2022). Is a picture worth a thousand words? Understanding the role of review photo sentiment and text-photo sentiment disparity using deep learning algorithms. *Tourism Management*, *92*, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2022.104559

[188] Chen, Shui-xia, Wang, Xiao-kang, Zhang, Hong-yu, Wang, Jian-qiang, and Peng, Juan-juan (2021). Customer purchase forecasting for online tourism: A data-driven method with multiplex behavior data. *Tourism Management*, *87*, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2021.104357

[189] Li, Peizhe, Xiao, Xiao, and Seekamp, Erin (2022). Climate adaptation planning for cultural heritages in coastal tourism destinations: A multi-objective optimization approach. *Tourism Management*, *88*, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2021.104380

[190] Ramos-Henriquez, Jose M., Gutierrez-Tano, Desiderio, and Diaz-Armas, Ricardo J. (2021). Value proposition operationalization in peer-to-peer platforms using machine learning. *Tourism Management*, *84*, ISSN 0261-5177, https://dx.doi.org/10.1016/j.tourman.2021.104288

[191] Zhang, Chengyuan, Wang, Shouyang, Sun, Shaolong, and Wei, Yunjie (2020). Knowledge mapping of tourism demand forecasting research. *Tourism Management Perspectives*, *35*, ISSN 2211-9736, https://dx.doi.org/10.1016/j.tmp.2020.100715

[192] Khorsand, Ramina, Rafiee, Majid, and Kayvanfar, Vahid (2020). Insights into TripAdvisor's online reviews: The case of Tehran's hotels. *Tourism Management Perspectives*, *34*, ISSN 2211-9736, https://dx.doi.org/10.1016/j.tmp.2020.100673

[193] Luo, Yuyan, He, Jinjie, Mou, Yu, Wang, Jun, and Liu, Tao (2021). Exploring China's 5A global geoparks through online tourism reviews: A mining model based on machine learning approach. *Tourism Management Perspectives*, *37*, ISSN 2211-9736, https://dx.doi.org/10.1016/j.tmp.2020.100769

[194] Go, Hanyoung, Kang, Myunghwa, and Suh, SeungBeum Chris (2020). Machine learning of robots in tourism and hospitality: interactive technology acceptance model (iTAM) - cutting edge. Tourism Review, *75*(4), 625-636, ISSN 1660-5373, https://dx.doi.org/10.1108/TR-02-2019-0062

[195] Egger, Roman, and Yu, Joanne (2022). Identifying hidden semantic structures in Instagram data: a topic modelling comparison. *Tourism Review*, *77*(4), 1234-1246, ISSN 1660-5373, https://dx.doi.org/10.1108/TR-05-2021-0244

[196] Wang, Yuan, Zhang, Dongxiang, Liu, Ying, Dai, Bo, and Lee, Loo Hay (2019). Enhancing transportation systems via deep learning: A survey. *Transportation Research Part C-Emerging Technologies*, *99*, 144-163, ISSN 0968-090X, https://dx.doi.org/10.1016/j.trc.2018.12.004

[197] Hasnat, Md Mehedi, and Hasan, Samiul (2018). Identifying tourists and analyzing spatial patterns of their destinations from location-based social media data. *Transportation Research Part C-Emerging Technologies*, *96*, 38-54, ISSN 0968-090X, https://dx.doi.org/10.1016/j.trc.2018.09.006

[198] Gungor, Osman Erman, and Al-Qadi, Imad L. (2018). Developing Machine-Learning Models to Predict Airfield Pavement Responses. *Transportation Research Record*, *2672*(29), 23-34, ISSN 0361-1981, https://dx.doi.org/10.1177/0361198118780681

[199] Taecharungroj, Viriya (2022). An analysis of tripadvisor reviews of 127 urban rail transit networks worldwide. *Travel Behaviour And Society*, *26*, 193-205, ISSN 2214-367X, https://dx.doi.org/10.1016/j.tbs.2021.10.007

[200] Vonk, Erwin, Cirkel, Dirk Gijsbert, and Blokker, Mirjam (2019). Estimating Peak Daily Water Demand under Different Climate

Change and Vacation Scenarios. *Water*, *11*(9), https://dx.doi.org/10.3390/w11091874

[201] Cankurt, S., and Subasi, A. (2015). Developing tourism demand forecasting models using machine learning techniques with trend, seasonal, and cyclic components. Balkan Journal of Electrical and Computer Engineering, 3(1), 42-49.

[202] Kamel, N., Atiya, A. F., El Gayar, N., and El-Shishiny, H. (2008). Tourism demand foreacsting using machine learning methods. ICGST International Journal on Artificial Intelligence and Machine Learning, 8, 1-7.

[203] Egger, R. (2022). Machine Learning in Tourism: A Brief Overview: Generation of Knowledge from Experience. Applied Data Science in Tourism: Interdisciplinary Approaches, Methodologies, and Applications, 85-107.

[204] Leelawat, N., Jariyapongpaiboon, S., Promjun, A., Boonyarak, S., Saengtabtim, K., Laosunthara, A., and Tang, J. (2022). Twitter data sentiment analysis of tourism in Thailand during the COVID-19 pandemic using machine learning. Heliyon, 8(10), e10894.

[205] Das, S., Mondal, S., Puri, V., and Vrana, V. (2022). Structural review of relics tourism by text mining and machine learning. Marketing, 8(2), 25-34.

[206] Afsahhosseini, F., and Al-Mulla, Y. (2020, September). Machine learning in tourism. In 2020 The 3rd International Conference on Machine Learning and Machine Intelligence (pp. 53-57).

[207] Komninos, A., Simou, I., Gkorgkolis, N., and Garofalakis, J. (2019). Performance of raspberry pi microclusters for edge machine learning in tourism. Network (Mbps), 100(100), 100.

[208] Dewangan, A., and Chatterjee, R. (2018). Tourism recommendation using machine learning approach. In Progress in Advanced Computing and Intelligent Engineering: Proceedings of ICACIE 2016, Volume 2 (pp. 447-458). Springer Singapore.

[209] Karakitsiou, A., and Mavrommati, A. (2017). Machine learning methods in tourism demand forecasting: Some evidence from Greece. MIBES Transactions, 11(1), 92-105.

[210] Vijay, J., and Sridhar, R. (2016). A machine learning approach to named entity recognition for the travel and tourism domain. Asian Journal of Information Technology, 15(21), 4309-4317.

[211] Claveria, O., Monte, E., and Torra, S. (2017). Regional tourism demand forecasting with machine learning models: Gaussian process regression vs. neural network models in a multiple-input multiple-output setting. Neural Network Models in a Multiple-Input Multiple-Output Setting.

[212] Buhalis, D., and Amaranggana, A. (2015). Smart tourism destinations enhancing tourism experience through personalisation of services. In Information and Communication Technologies in Tourism 2015: Proceedings of the International Conference in Lugano, Switzerland, February 3-6, 2015 (pp. 377-389). Springer International Publishing.

[213] Doan, A., Madhavan, J., Domingos, P., and Halevy, A. (2004). Ontology matching: A machine learning approach. Handbook on ontologies, 385-403.

[214] Schuckert, M., Liu, X., and Law, R. (2015). Hospitality and tourism online reviews: Recent trends and future directions. Journal of Travel and Tourism Marketing, 32(5), 608-621.

[215] Buhalis, D. (2020). Technology in tourism-from information communication technologies to eTourism and smart tourism towards ambient intelligence tourism: a perspective article. Tourism Review, 75(1), 267-272.

[216] Navigli, R., Velardi, P., and Gangemi, A. (2003). Ontology learning and its application to automated terminology translation. IEEE Intelligent systems, 18(1), 22-31.

[217] Buhalis, D., Harwood, T., Bogicevic, V., Viglia, G., Beldona, S., and Hofacker, C. (2019). Technological disruptions in services: lessons from tourism and hospitality. Journal of Service Management.

[218] Buhalis, D., and Sinarta, Y. (2019). Real-time co-creation and nowness service: lessons from tourism and hospitality. Journal of Travel and Tourism Marketing, 36(5), 563-582.

[219] Chen, K. Y., and Wang, C. H. (2007). Support vector regression with genetic algorithms in forecasting tourism demand. Tourism management, 28(1), 215-226.

[220] Lu, W., and Stepchenkova, S. (2015). User-generated content as a research mode in tourism and hospitality applications: Topics, methods, and software. Journal of Hospitality Marketing and Management, 24(2), 119-154.

[221] Benckendorff, Pierre J., Zheng Xiang, and Pauline J. Sheldon. Tourism information technology. Cabi, 2019.

[222] Fotiadis, A., Polyzos, S., and Huan, T. C. T. (2021). The good, the bad and the ugly on COVID-19 tourism recovery. Annals of tourism research, 87, 103117.

[223] Fuchs, M., Höpken, W., and Lexhagen, M. (2014). Big data analytics for knowledge generation in tourism destinations–A case from Sweden. Journal of destination marketing and management, 3(4), 198-209.

[224] Tussyadiah, I. (2020). A review of research into automation in tourism: Launching the Annals of Tourism Research Curated Collection on Artificial Intelligence and Robotics in Tourism. Annals of Tourism Research, 81, 102883.

[225] Li, X., Pan, B., Law, R., and Huang, X. (2017). Forecasting tourism demand with composite search index. Tourism management, 59, 57-66.

[226] Mariani, M., Baggio, R., Fuchs, M., and Höepken, W. (2018). Business intelligence and big data in hospitality and tourism: a systematic literature review. International Journal of Contemporary Hospitality Management, 30(12), 3514-3554.

[227] Pencarelli, T. (2020). The digital revolution in the travel and tourism industry. Information Technology and Tourism, 22(3), 455-476.

[228] Law, R., Li, G., Fong, D. K. C., and Han, X. (2019). Tourism demand forecasting: A deep learning approach. Annals of tourism research, 75, 410-423.

[229] Sigala, M. (2018). New technologies in tourism: From multi-disciplinary to anti-disciplinary advances and trajectories. Tourism management perspectives, 25, 151-155.

[230] Xiang, Z. (2018). From digitization to the age of acceleration: On information technology and tourism. Tourism management perspectives, 25, 147-150.

[231] García-Crespo, A., Chamizo, J., Rivera, I., Mencke, M., Colomo-Palacios, R., and Gómez-Berbís, J. M. (2009). SPETA: Social pervasive e-Tourism advisor. Telematics and informatics, 26(3), 306-315.

[232] Aggarwal, C. C. (2018). Neural networks and deep learning. Springer, 10(978), 3.

[233] Ekman, M. (2021). Learning deep learning: theory and practice of neural networks, computer vision, NLP, and transformers using TensorFlow.

[234] Khan, M. A., Ali, M., and Khan, M. A. (2021). Systematic Review of Contextual Suggestion and Recommendation Systems for Sustainable e-Tourism. Sustainability, 13(15), 8141. https://doi.org/10.3390/su13158141.

[235] Putra, I. G. N. A. W., Kadyanan, I. G. A. G. A. (2021). Optimization Of Bali Tourism Recommendations Based On Personal Motivation Of Tourists Using the Naive Bayes Algorithm. JLK, 1(10), 83. https://doi.org/10.24843/jlk.2021.v10.i01.p11.

[236] J. Srisuan and A. Hanskunatai, "The ensemble of Naïve Bayes classifiers for hotel searching," 2014 International Computer Science and Engineering Conference (ICSEC), Khon Kaen, Thailand, 2014, pp. 168-173, doi: 10.1109

Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida

Vol. 3, No. 2, pp. 80-87, 2023
Research Article
Received: 19/06/2023 Accepted: 12/08/2023

Implementation of An Adaptive Filter on A Manifold Absolute Pressure (MAP) Sensor

Muhammet Furkan ÖZATA[1,*], Ali SERTKAYA[2], İlkay ERDENİZ[3]

Abstract

This study proposes an adaptive filter based on a manifold absolute pressure (MAP) sensor in order to control automotive engines. The proposed adaptive filter, which is based on the least mean squares (LMS) algorithm, is intended to reduce the impacts of sensor noise and nonlinearity, which can result in false readings and a subsequent decline in engine performance. The filter can be used for long-term engine control applications because it is implemented on a model-based system and can adapt to changes in the sensor's properties over time. The suggested filter efficiently decreases sensor noise and increases the accuracy of MAP sensor readings, according to experimental data, which also indicate a roughly 10% rise in mean absolute percentage error (MAPE) compared to the standard lowpass filter. The filter's versatility also enables reliable operation under a variety of operating conditions and sensor characteristics. Additionally, the filter's signal-to-noise ratio (SNR) enhancement is almost 10% greater than that of a traditional lowpass filter, resulting in enhanced engine performance and fuel economy. Overall, the suggested adaptive filter appears to be a viable option for improving the performance of MAP sensors in automotive engine control applications.

Keywords: Signal processing, digital filtering, adaptive filtering, manifold absolute pressure

1. Introduction

Automotive engines rely on accurate and reliable sensor measurements to ensure optimal performance and fuel efficiency. The Manifold Absolute Pressure (MAP) sensor, which gauges pressure inside the engine's intake manifold, is one of the crucial sensors used in contemporary internal combustion engines (ICE) [1]. However, noise and nonlinearity in MAP sensors can result in inaccurate readings and decreased engine performance. Adaptive filtering techniques have been used in a number of recent studies on signal processing and control systems to address a variety of problems. [2] is focused on Adaptive Filter design for Electrocardiogram (ECG) signal noise removal in order to obtain noiseless and pure embryo signals. During acquisition and transmission, various noise sources frequently contaminate ECG signals. To remove noise from the desired ECG signals and ultimately obtain noiseless and pure embryo signals, the researchers use the well-known Least Mean Square (LMS) algorithm as an adaptive filtering technique. The study offers a potential remedy to improve the accuracy and clinical applicability of ECG data in healthcare settings by showcasing promising results in noise reduction. The creation of a model-free adaptive filter with the goal of reducing actuator wear in engineering systems is the subject of [3]. Actuator wear is a common problem that shortens system lifespan and degrades performance. The proposed model-free approach successfully addresses uncertainties in system dynamics and model parameterization to address this problem. As a result, actuator wear is successfully mitigated, and the reliability and longevity of control systems are improved.

In this paper, an implementation of the proposed Adaptive Filter using the LMS algorithm on a MAP sensor is suggested. The filter is implemented on a model-based system to enable real-time operation and is intended to reduce the effects of sensor noise and nonlinearity. The filter is suitable for use in long-term engine control applications because its adaptability ensures robust performance over a variety of operating conditions and sensor characteristics. The recommended filter successfully reduces sensor noise and raises the accuracy of MAP sensor data, which enhances engine performance and fuel efficiency as measured by an improvement in Signal to Noise Ratio (SNR) [2]. Overall, this research offers a promising method for improving the performance of MAP sensors in applications involving automotive engine control.

Internal combustion engine supercharging has been used for a long time to increase engine power output, but a new trend is emerging to comply with fuel consumption and emission control. Increasing the mean effective pressure is the most preferred way to increase power output by providing air or a combination of air and fuel under pressure that is greater than atmospheric pressure. By increasing density, the engine's power output will rise

*Corresponding author

Muhammet Furkan ÖZATA; Türk Otomobil Fabrikası A.Ş., Türkiye; e-mail: muhammet.furkanozata@tofas.com.tr; 0000-0001-9186-1858

Ali SERTKATA; Türk Otomobil Fabrikası A.Ş., Türkiye; e-mail: ali.sertkaya@tofas.com.tr; 0000-0002-1293-9723

İlkay ERDENİZ; Türk Otomobil Fabrikası A.Ş., Türkiye; e-mail: ilkay.erdeniz@tofas.com.tr; 0000-0003-4011-972X

as a result [1]. To adjust the fuel and air pressures in the intake manifold of automotive engines, accurate and reliable sensor measurements are crucial, and the existence of a MAP sensor is a must. This sensor measures the pressure inside the engine's intake manifold, providing critical information to the engine control system to optimize fuel injection and air intake, ultimately ensuring optimal performance and fuel efficiency. Without the accurate readings from the MAP sensor, the engine control system would not be able to adjust the fuel and air pressures to the appropriate levels, leading to reduced engine performance and fuel efficiency, and potentially causing damage to the engine over time. Therefore, the MAP sensor plays a vital role in the operation and performance of modern automotive engines, making its accuracy and reliability a top priority for engine manufacturers and designers.

A type of MAP sensor, which is made of semiconductor piezo resistance. Its primary operating principle is the piezoresistive effect of semiconductors, as depicted in Figure 1. It consists of a pressure converter and a composite integrated circuit for signal amplification.

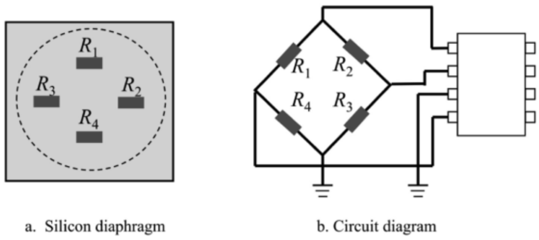


Figure 1. *Schematic of Manifold Absolute Pressure Sensor [4]*

Noise is present to variable degrees in practically all surroundings, and there are numerous varieties of noise, the most identifiable of which is Acoustic Noise, which occurs from moving, vibrating, or colliding sources. Electromagnetic noise may be found at all frequencies, including radio frequencies, whereas Processing Noise is caused by the processing of signals, such as quantization noise in digital coding or missing data packets in digital data transfer networks. A random white noise will be added and then a denoising technique, which is digital filtering, will be applied in order to clean up the noisy signal.

Using a limited number of data, the power spectrum (PS) of a signal in the temporal domain describes how the signal's power is distributed across various frequencies. The signal's frequency-domain form is frequently easier to examine than its time-domain counterpart. Several signal processing applications, including noise removal and system identification, rely on frequency-specific signal alterations. The purpose of power spectral estimation is to estimate a signal's power spectrum from a succession of time samples. Fourier transform methods, such as the Welch method and the filter bank approach, are used to estimate the power spectrum [5].

The signal can be entirely retrieved from noise if the spectra of the signal and noise do not overlap. Figure 2 depicts an example of a noisy signal with different signal and noise spectra. The signal and noise occupy separate parts of the frequency spectrum in this case, and a low-pass filter may be used to denoise the signal. Although, Figure 2(b) depicts a more common example in which the signal and noise spectra overlap. It is difficult to distinguish the signal from the noise in these instances. Nonetheless, using a filter approach can reduce the influence of noise to some amount. [3].

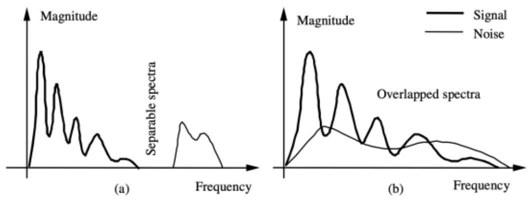


Figure 2. *Separability of a Signal*

Unit-delay elements, multipliers, and adders make form a digital FIR filter, sometimes referred to as a tapped-delay line filter or a transversal filter. The length of the impulse response is dependent on the amount of delay elements which is also called filter order. It is represented by M in Figure 3 depicts a filter made up of delay elements represented by the unit-delay operator z^{-1}. The delay elements operate on the input signal and produce delayed versions of it. The multipliers multiply the tap inputs by coefficients known as tap weights, resulting in a weighted sum of delayed inputs. The adders sum the outputs of the multipliers to produce the overall response of the filter. The Eq. (1) is a representation of the filter's output. It is important to notice that complex conjugation is indicated by the asterisk, and that complex valued inputs and tap weights are expected.

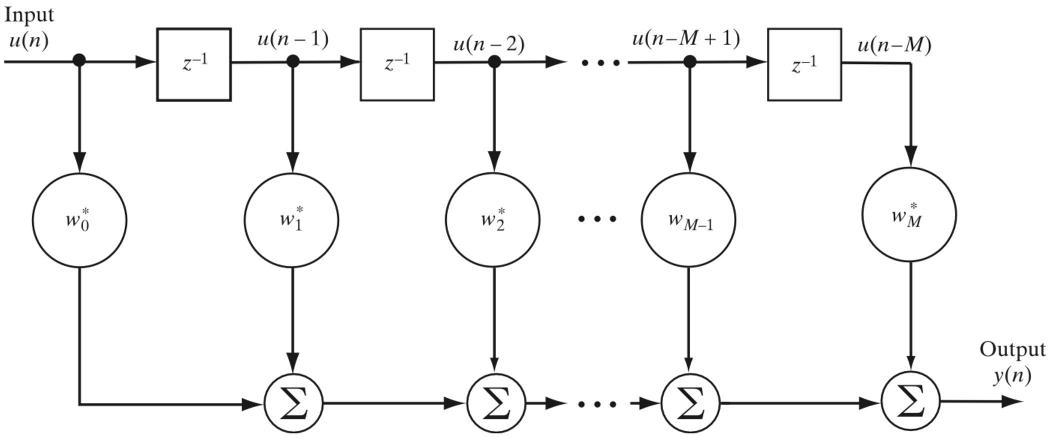


Figure 3. *Finite Impulse Response (FIR) Filter*

$$y(n) = \sum_{i=0}^{M} w_k^* u(n - k) \tag{1}$$

The Eq. (1) is representation of convolution sum since the process of convolution takes the impulse response of the filter, represented by w_k^*, and combines it with the filter input, represented by $u(n)$, to produce the filter output, represented by $y(n)$ [6].

Conventional digital filters such as a lowpass filter, or even a finite impulse response (FIR) may not be appropriate for accurate results due to their static structure. On contrary, recursive filters are better choices due to their dynamic structure. A type of recursive filter, which is adaptive filter, will be used to filter a noisy signal in this paper.

The concepts "signal" and "noise" are similar. The waveform that is of interest is typically referred to as the signal, and the remainder as the noise. The SNR is frequently used to calculate the relative amounts of signal and noise in a waveform. The SNR is often expressed in decibels (dB), where:

$$SNR = 20\, log \frac{Signal}{Noise} \tag{2}$$

RMS amplitude is the unit of measurement for signal and noise values [2].

2. Adaptive Filter

A system created to gather details about a specified quantity of interest from noisy data is commonly referred to as an estimator or filter [6]. There are two types of filters: digital and analog. Digital signals with discrete temporal components are processed by digital filters. The internal structure and parameters of time-invariant filters are fixed, and if they are linear, the output signal is a linear function of the input signal [7].

The Wiener Filter is a type of linear filter that can effectively remove noise from a signal, but its design requires prior knowledge of the statistical characteristics of the signal and noise, such as power spectral densities and cross-correlation functions. However, in real-world scenarios, this information may be incomplete or unavailable, making it challenging to design the Wiener Filter optimally. To address this issue, the "estimate and plug" procedure can be used, which involves estimating the statistical parameters of the signal and noise from the available data and then using these estimates to design the filter. However, this approach requires significant computational resources, making it unsuitable for real-time applications.

To overcome these limitations, an Adaptive Filter can be used. This filter is self-designing, meaning it can adjust its parameters based on the input data without requiring prior knowledge of the statistical characteristics of the signal and noise. The filter operates using a recursive algorithm that updates the filter coefficients in real-time, starting from a set of predetermined initial conditions. In a stationary environment, the adaptive filter converges to the optimum Wiener solution in a statistical sense, meaning that the filter coefficients approach the optimal values that would be obtained with complete knowledge of the signal and noise statistics. In a nonstationary environment, where the statistical characteristics of the input data may change over time, the adaptive filter can track the time variations by continuously updating the filter coefficients. However, this capability relies on the assumption that the variations in the input data statistics are sufficiently slow. If the variations are too rapid, the adaptive filter may not be able to track them accurately. Overall, the adaptive filter offers an effective and practical solution for removing noise from signals in real-time applications where prior knowledge of the signal and noise statistics may be incomplete or unavailable [6, 7, 8].

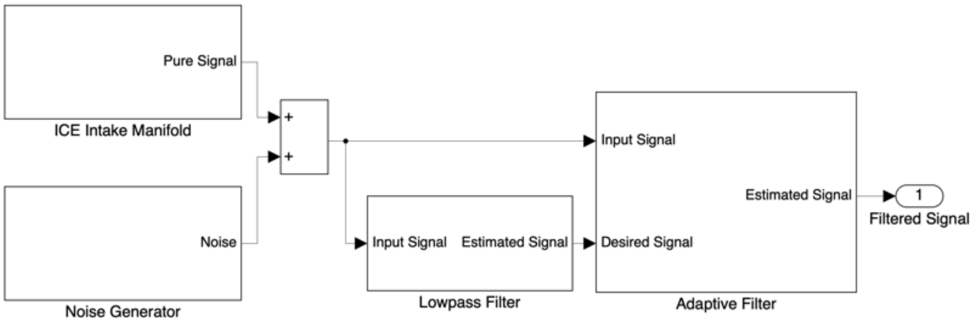


Figure 4. *Signal Processing Schematic of Adaptive Filtering*

Pure Signal is representing the ideal theoretical sensor response of intake manifold pressure without any noise. Noise is generated by using Uniform Random Number block in Simulink which gives a uniformly distributed random signal. Noise is added to this signal before summing it up with pure signal. This sum will be called as MAP sensor data. Noisy signal is the input of adaptive filter, desired signal is lowpass filtered signal and the output is filtered signal as shown in Figure 4.

To meet the performance requirement, the settings of the adaptive filters are continually changing (time variable).

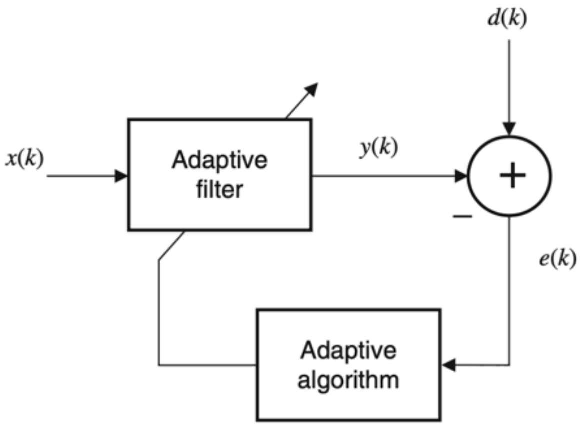


Figure 5. *Adaptive Filter Configuration [7]*

In Figure 5, the error between the filtered signal and the desired signal can be calculated as

$$e(k) = d(k) - y(k) \tag{3}$$

It is intended to closely resemble the desired signal, d(k), by using an adaptive filter to analyze the input signal, x(k). An error signal is created by subtracting the filtered signal, y(k), from the intended signal, d(k).

Due to a variety of characteristics, the LMS algorithm is often used in adaptive filtering. Its appeal stems mostly from its cheap computing complexity, shown convergence in stationary situations, unbiased convergence towards the Wiener solution, and steady behavior even when implemented with finite-precision arithmetic.

The resultant gradient-based approach, which minimizes the mean squared error, is referred to be the least-mean-square (LMS) algorithm, and its equation is shown below:

$$w(k+1) = w(k) + 2^{*}\mu^{*}e(k)^{*}x(k) \tag{4}$$

Where $w(k)$ is a set of adaptive filter coefficients. The convergence factor, which is μ, chosen from a range to assure convergence [7, 9].

The performance of a filter in a certain context can be measured by either the normalized cumulative squared error or the mean-squared error (MSE), which are equivalent metrics. The equation of MSE is: [10]

$$\frac{1}{n}\sum_{t=1}^{n}(x_t - \hat{\chi}_t(Y^t))^2 \tag{5}$$

$\hat{\chi}_t(Y^t)$is the causal estimator of x_t based on the noisy observation Y^t.

MMSE is an abbreviation for Minimum Mean Square Error. MMSE is used to calculate the difference between the original and filtered signals in such a way that the expected value of the square of the difference is minimized.

In practical applications, the MMSE can be used to compare different filtering algorithms or to optimize the parameters of a given filter. A lower MMSE value indicates better performance and higher accuracy of the filter in reproducing the original signal [6].

Mean Absolute Percentage Error (MAPE) is another performance metric that can be used to evaluate the accuracy of a digital filter. MAPE measures the average percentage difference between the actual values of a signal and the predicted values produced by the filter. It is commonly used in time series forecasting and other applications where the accuracy of predictions is critical. It was the major metric in the M-competition. Absolute percentage errors (APE) are referred to as the mean, or MAPE. Let A_t and F_t stand for the true and expected values, respectively, at data point t. Thus, MAPE is described as follows:

$$MAPE = \frac{1}{N}\sum_{t=1}^{N}\left|\frac{A_t - F_t}{A_t}\right| \tag{6}$$

N denotes the number of data points. That should be multiplied by 100 to be more precise [11].

3. Results

The Lowpass filter uses two parameters which are the cut-off frequency and minimum stopband attenuation As depicted in Table 1. The adaptive filter uses three parameters as initial conditions which are μ, N, and ε as shown in Table 2. These parameters are step size, filter order, and a small constant to prevent division by zero. Parameter optimization is done by using Parameter Estimator Toolbox in Simulink. The toolbox uses an MSE algorithm to optimize the initial parameters. As a result, the initial parameters are:

Table 1. *Lowpass Filter Parameters.*

Cut-off Frequency	Attenuation (dB)
24.5186	524.32

Table 2. *Adaptive Filter Parameters.*

μ (Step Size)	N (Filter Order)	ε (Small Const.)
0.05	20	0.001

By using MATLAB Simulink, the noise of the MAP sensor data is removed with the help of an adaptive filter, and the plots are shown in Figure 6.

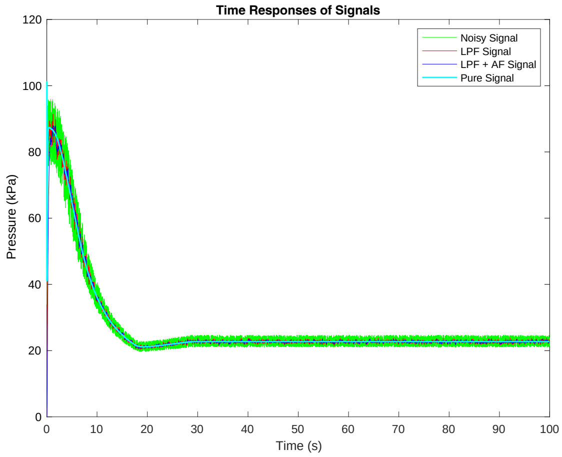


Figure 6. *Time Response of Noisy and Filtered Signal*

The error plot in Figure 7 generated from the adaptive filter implementation on the MAP sensor provides valuable insights into the filter's performance. The error plot shows a significant reduction in the magnitude of the error over time as the filter adapts to the changing signal. The error values gradually decrease, indicating that the filter effectively reduces sensor noise and improves the accuracy of MAP sensor readings.

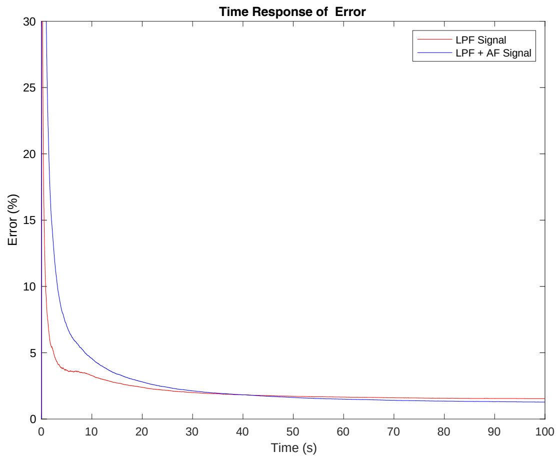


Figure 7. *Time Response of Error*

The MAPE errors of the Lowpass and Adaptive filters provide valuable insights into the performance of the two filters. In the Table 3, the MAPE error of the Lowpass filter is measured at 4.176, indicating a moderate level of error in the filter's ability to mitigate sensor noise and nonlinearity. On the other hand, the MAPE error of the Adaptive filter is measured at 3.762, indicating a lower level of error and thus superior performance compared to the Lowpass filter. This result suggests that the Adaptive Filter is more effective at reducing sensor noise and improving the accuracy of MAP sensor readings, leading to improved engine performance and fuel efficiency. Overall, the MAPE error results demonstrate the effectiveness of the proposed Adaptive filter implementation on the MAP sensor, outperforming the Lowpass filter in terms of accuracy and performance.

Table 3. *MAPE Values for MAP Signal.*

Filter	MAPE (%)

LPF	0.00
LPF + AF	1.14

The Power Spectrum of the Noisy and Filtered MAP Signal is depicted in Figure 8 as a consequence of the adaptive filter's recursion method. When the least mean square method is used, the filter cancels out the noise.

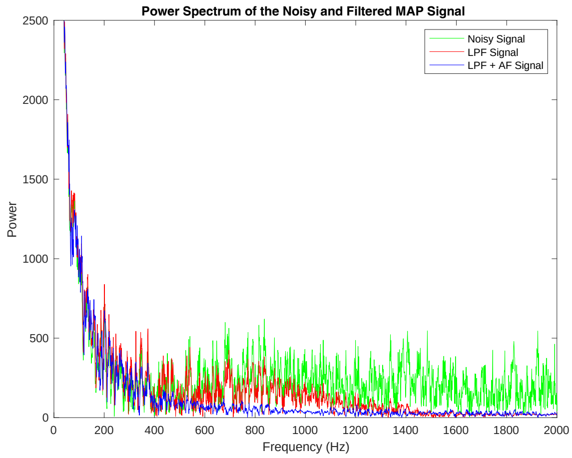


Figure 8. *Power Spectrum of the Noisy and Filtered MAP Signal*

Prior to filtering, the SNR was measured at -0.2641 as shown in the table, indicating that the noise in the signal was higher than the signal itself. However, after implementing the adaptive filter, the SNR increased to 35.2807, indicating a significant improvement in the quality of the signal. The adaptive filter SNR improvement is %10 higher than that the lowpass filter. This increase in SNR demonstrates that the filter effectively mitigates the effects of sensor noise and nonlinearity, leading to improved accuracy in MAP sensor readings. Overall, the SNR results provide strong evidence for the effectiveness of the proposed adaptive filter implementation on the MAP sensor in reducing sensor noise and improving the accuracy of MAP sensor readings.

Table 4. *SNR Values for MAP Signal.*

Filter	Noisy SNR	Filtered SNR	Improvement
LPF	-0.2641	32.1169	32.3810
LPF + AF	-0.2641	35.2807	35.5448

4. Conclusion

The adaptive filter implementation suggested in this study offers a potentially effective method for improving the functionality of MAP sensors in automotive engine control applications. The proposed adaptive filter implementation on a MAP sensor based on the LMS algorithm offers a promising solution for enhancing the performance of MAP sensors in automotive engine control applications. The filter is effective in overcoming the problems caused by sensor noise and nonlinearity, which may lead to more precise readings, better engine performance, and increased fuel efficiency. The MAPE results of the Lowpass and Adaptive filters demonstrate that the Adaptive filter outperforms the Lowpass filter in terms of accuracy and performance. The filter is a useful tool for long-term engine control applications because its adaptability ensures consistent performance under various operating conditions and sensor characteristics. The effect of the filter is also demonstrated by using the SNR algorithm, where the adaptive filter significantly improves the SNR compared to the lowpass filtered signal. This study makes a significant contribution toward improving MAP sensor measurements in automobile engines, which is essential for improving performance and minimizing environmental impact.

Declaration of Interest

The authors declare that there is no conflict of interest.

Acknowledgements

This paper was presented at the EAD 2023 Conference and another version of its abstract was published in its Proceedings (Title of the conference paper was “Adaptive Filter Implementation On Manifold Absolute Pressure (Map) Sensor”).

Author Contributions

The following authors affirm their contributions to the paper: Muhammet Furkan Özata, Ali Sertkaya, İlkay Erdeniz; data collection: Ali Sertkaya, İlkay Erdeniz; data analysis and interpretation: Muhammet Furkan Özata, Ali Sertkaya; draft manuscript preparation: Muhammet Furkan Özata, Ali Sertkaya. All authors examined the findings and approved the final paper version.

References

[1] V. Ganesan, IC Engines, 4th ed, New Delhi: Tata McGraw Hill Education Private Limited, 2012.

[2] M. A. J. Matos, "ECG Denoising Based on Adaptive Signal Processing Technique," M.S. thesis, Instituto Superior de Engenharia do Porto, November. 2011. [Online]. Available: https://core.ac.uk/download/pdf/302861698.pdf. [Accessed January 2023].

[3] L. F. Eugênio, M. G. Lucas, O. d. A. L. F. José, C. d. C. Mário, G. S. L. c. Luis, L. d. L. Marcelo and S. T. Eduardo, "Model-free adaptive filter to mitigate actuator wear," *ISA Transactions,* vol. 129, pp. 493-504, 2022.

[4] G. Xin, J. Changwei, S. Wang, H. Meng, K. Chang, J. Yang and C. Hong, "Monitoring of hydrogen-fueled engine backfires using dual manifold absolute pressure sensors," *International Journal of Hydrogen Energy,* vol. 47, no. 26, pp. 13134-13142, 2022.

[5] "Estimate the Power Spectrum in MATLAB," MATLAB, [Online]. Available: https://www.mathworks.com/help/dsp/ug/estimate-the-power-spectrum-in-matlab.html. [Accessed January 2023].

[6] S. Haykin, Adaptive Filter Theory, 5th ed, NJ: Prentice Hall, 2014.

[7] P. S. R. Diniz, Adaptive Filtering Algorithms and Practical Implementation, 4th Ed., Rio de Janeiro: Springer, 2013.

[8] S. C. Douglas, "Introduction to Adaptive Filters," in *Digital Signal Processing Handbook*, CRC Press LLC, 1999.

[9] S. Dixit and D. Nagaria, "LMS Adaptive Filters for Noise Cancellation: A Review," *International Journal of Electrical and Computer Engineering (IJECE),* vol. 7, no. 5, pp. 2520-2529, 2017.

[10] T. Moon and T. Weissman, "Universal FIR MMSE Filtering," *IEEE TRANSACTIONS ON SIGNAL PROCESSING,* vol. 57, no. 3, pp. 1068-1083, 2009.

[11] S. Kim and H. Kim, "A new metric of absolute percentage error for intermittent demand forecasts," *International Journal of Forecasting,* no. 32, pp. 669-679, 2016.

Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida

Vol. 3, No. 2, pp. 88-98, 2023
Research Article
Received: 06/09/2023 Accepted: 05/11/2023

Pixel Dungeon - Turn Based Game With Unity

Mehmet EROĞUL [1], Ömer Faruk CENİKLİ [2], Oğuzhan BİÇEN [3], Fidan NURİYEVA [4, *]

Abstract

Pixel Dungeon is a turn-based game developed using the C# programming language and the Unity game engine, targeting players who enjoy using strategic thinking skills to defeat their opponents. It is designed based on the Object-Oriented Programming concept and incorporates commonly used Design Patterns in game programming such as Observer, State, and Singleton. The objective of the game is to use the selected units (game characters) to battle against enemy units and emerge victorious, aiming to achieve the highest possible score. As we defeat the encountered enemies, we earn points and face new opponents. The game concludes when we lose all of our units. Each unit in the game possesses unique abilities (ranged attack, melee attack, healing, buffing or debuffing another unit, poisoning, etc.). Each character takes turns to make their moves and strategically utilizes their abilities to gain an advantage during the gameplay. This study serves as an example of how turn-based games can be designed using the Unity game engine. It not only provides an enjoyable gaming experience but also enhances players' strategic decision-making skills.

Keywords: Game development; object oriented programming; turn based game; unity.

1. Introduction

The gaming industry has witnessed remarkable growth in recent years, and Unity has emerged as one of the leading game development engines. Game development is a rapidly evolving field, and the use of the C# programming language in combination with the Unity game engine has become a predominant choice among developers. Unity offers several advantages to game developers, making it a popular choice in the industry [1, 2]. Unity is a powerful and versatile game development engine that has gained immense popularity among developers worldwide. Unity is a cross-platform game development engine that enables developers to create games for various platforms, including PC, consoles, mobile devices, and etc. It boasts an intuitive user interface and a vast array of tools, making it accessible to developers of all skill levels. Unity supports multiple programming languages like C#, JavaScript, with C# being the most widely used [3, 4]. C# has emerged as the scripting language of choice for Unity development. It strikes a balance between performance and ease of use. Developers appreciate C#'s versatility and strong support within the Unity ecosystem. C# and Unity have made significant inroads into various game genres, including action, adventure, simulation, strategy, and more. Beyond entertainment, Unity and C# have been employed in developing serious games, educational simulations, and applications in augmented and virtual reality.

There are numerous games developed using C# and Unity. Hollow Knight, Cuphead, Oxenfree, Inside, Cities: Skylines, Monument Valley, Crossy Road, Kerbal Space Program, Pillars of Eternity are some of them.

Pixel Dungeon is a turn-based game project. It is developed using the C# programming language and the Unity game engine. It is designed to challenge players' strategic thinking skills as they strive to defeat their opponents.

An earlier version of this paper was presented at the ICADA 2023 Conference and was published in its Abstract Book (Title of the conference paper: “Unity ile Sıra Tabanlı Oyun”).

The goal of the game is to use the selected units (game characters) to engage in battles against enemy units and emerge victorious to achieve the highest possible score. As players defeat their adversaries, they earn points

*Corresponding author

MEHMET EROĞUL; Dokuz Eylul University, Faculty of Science, Department of Computer Science, Türkiye; e-mail: mehmet_erogul@icloud.com; 0009-0005-3352-0365

ÖMER FARUK CENİKLİ; Dokuz Eylul University, Faculty of Science, Department of Computer Science, Türkiye; e-mail: omerfarukceniklii@gmail.com; 0009-0008-3607-7030

OĞUZHAN BİÇEN; Dokuz Eylul University, Faculty of Science, Department of Computer Science, Türkiye; e-mail: oguzhanbicen.b@gmail.com; 0009-0002-2345-0015

FİDAN NURİYEVA*; Dokuz Eylul University, Faculty of Science, Department of Computer Science, Türkiye; Institute of Control Systems of ANAS, Baku, Azerbaijan; e-mail: nuriyevafidan@gmail.com; 0000-0001-5431-8506

and encounter increasingly challenging new enemies. However, if all of their units are defeated, the game comes to an end.

In the game, there are four units controlled by the player and four units controlled by the computer. The turn-based system in the game manages the order of actions for each unit based on their individual speeds. The units of both the player and the computer are placed in a queue according to their speeds. The unit with the highest speed will be the first one to perform its action, while the unit with the lowest speed will be the last one to act. Each unit takes its turn to perform its action and is then removed from the queue. This process continues until there are no more units left in the queue. After all units have taken their turns, a new round begins, and the turn-based system creates a new queue for the upcoming actions. The game proceeds with the next unit in the queue, and the cycle continues.

This turn-based mechanism adds a strategic element to the game, as players need to carefully plan their unit's actions and consider the order in which they will act to gain an advantage over the computer-controlled units.

By utilizing the turn system and considering the speed of each unit, players can make tactical decisions to optimize their chances of victory in battles against the computer-controlled units.

Figure 1. *The game's screenshot* [5, 6]

In the game, each unit has different abilities or actions it can perform (ranged attack, melee attack, healing, buffing or debuffing another unit, poisoning, etc.). The usage of abilities can be restricted based on the team or position of the characters. For example, the healing ability can only be applied to characters within the same team, while the attack ability can only be used against characters in the opposing team. The Cavalry unit can attack any position of the opponent from any position on the player's side, whereas the Knight unit can only attack one of the opponent's front two positions when it is in one of the player's front two positions.

Additionally, units have status attributes such as health points, attack, and defense. These attributes determine how much damage the unit will deal to the opponent, how much damage it will ignore when attacked, or how much damage it needs to take to be defeated. Some units' buff and debuff abilities can affect these status attributes.

2. How to Play

To play Pixel Dungeon, you only need to use the left mouse button. The game starts with the player selecting four out of seven characters, each having different abilities. As the game begins, the player encounters waves of enemies, each consisting of four enemy units, which progressively increase in difficulty.

Being a turn-based game, both the player's units and the enemy units take their actions one by one. A unit must complete its action before another unit can perform its action. If it is the player's turn, they can select any action from their current unit's ability set, and choose a valid position to execute the action by clicking the left mouse button. The player then initiates the selected action.

When it is the enemy's turn, the computer randomly attacks any of the player's units. The player must strategically plan their moves to defeat the enemy waves and achieve the highest score possible.

In the game, the player earns points by destroying any of the enemy units. When all enemy units are destroyed, the current score is doubled, and the next enemy wave appears. If the player loses all of their units, the game ends. The objective is for the player to keep their units alive as much as possible and achieve the highest score.

Figure 2. *Sample ability set for the archer unit* [7, 8]

Figure 3. *Display image of suitable positions for the selected skill* [5]

3. Game Development Environment in Unity

Unity is a cross-platform game engine that supports scripting with C#. It allows developers to process 2D and 3D graphics in real-time, play audio and animations, and easily control events such as collision detection. Unity provides an environment where we can easily manage various aspects of our game. Additionally, Unity includes a physics engine, enabling us to simulate physics in our game environment closely resembling real-world physics. This allows for a more realistic and immersive gaming experience.

In Unity, our game is composed of scenes. Scenes are structures that contain the objects of the game, such as cameras, lights, 3D characters or environment models, canvases, 2D images, and more. The objects present in the current scene are visible in Unity's Hierarchy panel. Each object has its own unique components that determine its behavior. These components are visible in Unity's Inspector panel when we click on an object in the Hierarchy.

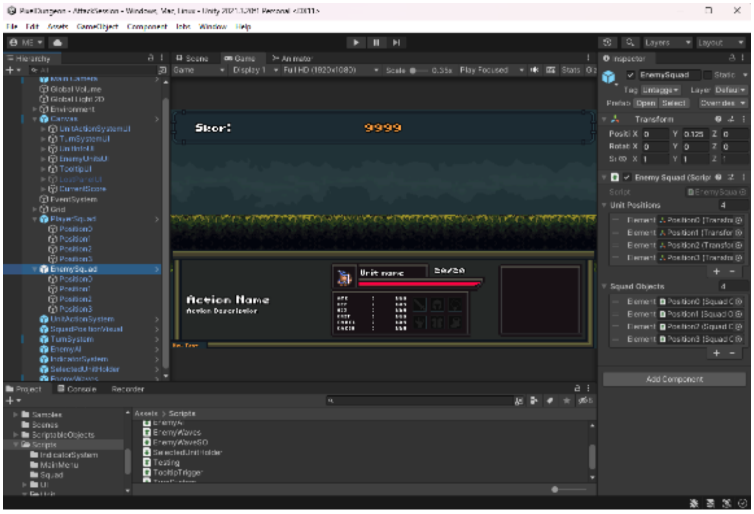


Figure 4. *Unity interface*

By default, a transform component is assigned to every object added to the scene. This component determines the object's position in the scene, its orientation, and its size.

When we want to play an audio file, we need to add the AudioSource component to the respective object. When we want to play an animation, we use the Animator component. For collision detection, we add the Collider component, and for applying physics, we add the Rigidbody component to the desired object. Unity provides many built-in components similar to these.

Additionally, we can create custom scripts and attach them as components to objects, allowing us to easily interact with other components of the object. By creating a custom script, we can play an audio clip through the AudioSource component of an object, move an object by changing the position values of its Transform component when a key is pressed, and decide which animation to play through the Animator component.

In summary, Unity offers a wide range of components that can be added to objects, and we can create custom scripts to control and manipulate these components efficiently. This flexibility allows for powerful and dynamic interactions within the game or application.

3.1. Pixel Dungeon scene structure

Scenes can be used to create the main menu or levels of the game. Pixel Dungeon consists of three scenes: the main menu, unit selection, and battle stages.

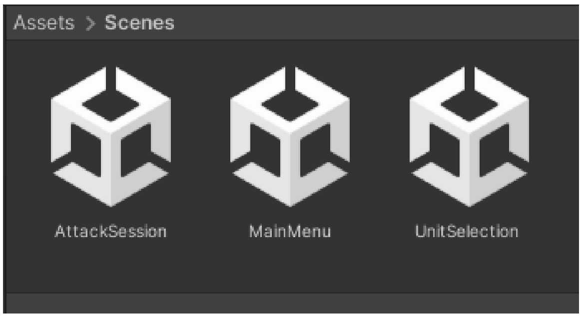


Figure 5. *Scenes of the game*

Figure 6. *Screenshot of the game's main menu scene*

When the player presses the "Play" button in the menu, the game transitions to the unit selection scene. In this scene, the player can choose four units with different abilities. After selecting the units, the player can click the "Start" button to transition to the battle scene.

Figure 7. *Screenshot of the game's unit selection scene*

When the battle scene is entered, the game starts. At this stage, pre-defined enemies appear in waves in front of the player. If the player loses the game, the losing panel, which is inactive on the canvas of the current scene, becomes active.

Figure 8. *Screenshot of the game's battle scene*

Figure 9. *Screenshot of the game's losing panel*

3.2. Objects and scripts in scenes

3.2.1. Main menu scene

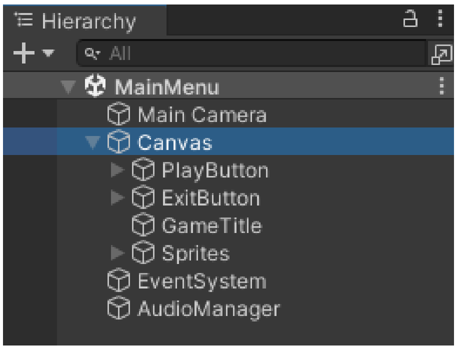


Figure 10. *Objects in the main menu scene*

In the main menu scene, there is one camera that displays a canvas containing text, images, and buttons to start the game or exit the game. In Unity, cameras are objects through which players view the world. Canvases, on the other hand, are structures that contain user interface elements.

In the scene, the canvas object has a script component named "MainMenu" attached to it. This script contains the functions "StartGame()" and "QuitGame()". These functions are called through the OnClick events of the "Play" and "Quit" buttons, respectively, enabling the player to proceed to the next scene or exit the game.

Additionally, there is an AudioManager object in the scene, which has an AudioSource component to play the background music of the game. The object is assigned a script with the same name. With this script, we use Unity's DontDestroyOnLoad() function to carry the object to the next scene. This ensures that the AudioManager persists across scene changes, allowing the background music to continue playing seamlessly as the player moves between scenes.

In Unity, data is lost when scenes are loaded. The DontDestroyOnLoad() function allows us to achieve scene-to-scene data persistence and transfer the background music to another scene without interruption. This ensures that the data associated with the object remains intact and carries over seamlessly as the player navigates between different scenes.

3.2.2. Unit selection scene

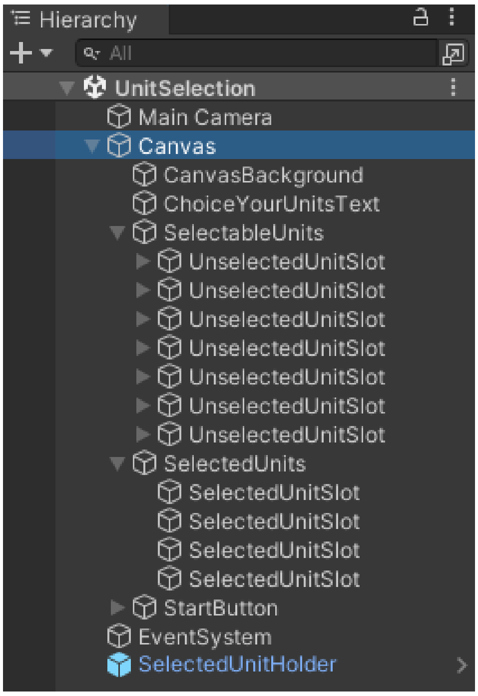


Figure 11. *Objects in the unit selection scene.*

In the unit selection scene, there is one camera and one canvas. The canvas has a script called "UnitSelectionManagerUI" attached to it, and this script allows the player to choose units and move them to slots. Within the canvas, there are seven slot objects (UnselectedUnitSlot) to hold unselected units and four slot objects (SelectedUnitSlot) to hold selected units. These objects have scripts with the same name, and these scripts store information about whether the slot is empty or which unit is assigned to that slot.

At the beginning, units are located under the UnselectedUnitSlot objects and they have a script called "UnitSelector". This script stores information about which slot the unit is assigned to and the unit's Prefab data. In Unity, Prefabs allow objects to be stored and reused, enabling efficient management and instantiation of objects throughout the game.

In the scene, there is also an object named "SelectedUnitHolder" which is assigned a script with the same name. This object is used to transfer the selected units to the Battle scene when the "Start" button is pressed. It collects the Prefab data from the UnitSelector scripts of the units assigned to the SelectedUnitSlot objects and stores them in a four-indexed Transform array. Then, it uses the DontDestroyOnLoad method to carry the data of the selected units to the next scene, ensuring their persistence and availability in the Battle scene.

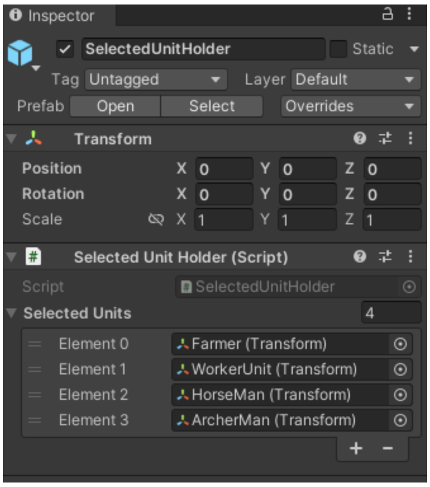


Figure 12. *The components of the "SelectedUnitHolder"*

3.2.3. Battle scene

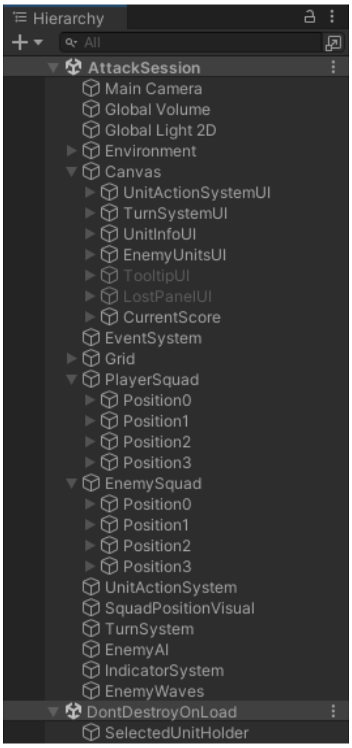


Figure 13. *Objects in the battle scene.*

In the battle scene, there is an object named "TurnSystem" which controls the entire game. When the scene is loaded, it receives the units sent from the "SelectedUnitHolder" object in the unit selection scene and passes them to the "PlayerSquad" object. The "PlayerSquad" object stores the position data where the units will be instantiated.

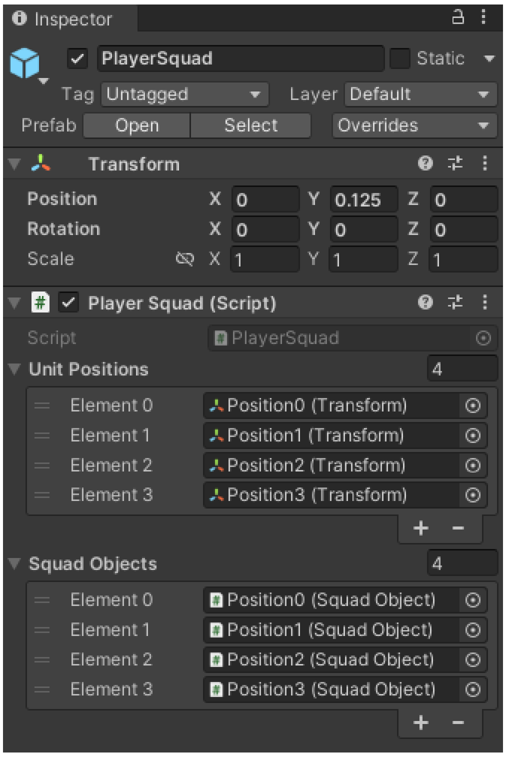


Figure 14. *The components of the "PlayerSquad"*

The "EnemySquad" object holds the position data for enemy units. When the "TurnSystem" is loaded or when the game transitions to the next enemy wave, it retrieves the relevant enemy units from the "EnemyWaves" object and sends them to the "EnemySquad" object. The "EnemyWaves" object stores enemy waves using Unity's ScriptableObject structure. ScriptableObject is a data container provided by Unity that can be used to save large amounts of data. In this example, ScriptableObjects are used to hold four enemy units each and are stored in an array of ScriptableObjects.

The TurnSystem, after sending the player and enemy units to the PlayerSquad and EnemySquad objects, respectively, organizes all units into a queue based on their speeds, creating a sequence in decreasing order of speed. It selects the unit with the highest speed, and if the unit belongs to the player, it assigns that unit to the UnitActionSystem object using the SetSelectedUnit() function of the object's UnitActionSystem script. If the next unit in the sequence is an enemy unit, it is sent to the EnemyAI object.

Each unit has a script called "Unit" associated with it. This script holds various data related to each unit. Additionally, units have scripts named "StatSystem" and "HealthSystem". These scripts store data such as the unit's attack, defense, and health points.

When a unit is assigned to the UnitActionSystem object, buttons are dynamically created on the canvas through the UnitActionSystemUI object for the abilities that the unit possesses. It also allows updating descriptions related to the player unit's abilities on the canvas. The OnClick event of the buttons calls the SetSelectedAction() function in the UnitActionSystem object, changing the selected action.

Specific command files such as MoveAction for the walking action and AttackAction for the attack action are created, each derived from the BaseAction class for every action. Valid positions are defined for each action. When the player clicks on the buttons, the valid positions for that action are visualized through the SquadPositionVisual object.

If the position clicked by the player is valid, the UnitActionSystem initiates the TakeAction() function of the selected unit's selected action, utilizing the data of the selected unit and action. After the action is completed, the TurnSystem comes into play, and the turn is passed to the next unit.

The IndicatorSystem object is used to create damage or healing numbers on the relevant unit whenever any unit takes damage or gets healed, providing feedback to the player.

The EnemyAI object is responsible for performing the attack action of the enemy unit it receives, targeting any of the player's units.

The UnitInfoUI object within the canvas updates data such as the selected player unit's attack, defense, and health points on the canvas. The EnemyUnityUI object is used to display and update enemy unit health on the canvas. The TooltipUI object displays data such as statuses, buffs, and debuffs of units when the mouse hovers over them.

The LostPanelUI object displays the score data on the screen if the player loses the game and contains a button to restart the game.

4. Used Design Patterns

Design patterns are standardized solutions created for commonly encountered problems in software development. Three design patterns were used while developing Pixel Dungeon: Singleton, Observer, and State design patterns.

4.1 Singleton design pattern

The Singleton design pattern ensures that only one instance of a class is created. The concept of an instance refers to allocating memory in the computer's memory for an object derived from a class. When we want to have only a single instance of an object, we use the Singleton design pattern.

In Figure 15, an example of a singleton used in Pixel Dungeon can be seen. A static instance is defined for the EnemyAI object. If there is no existing instance, assignment to the current instance is done within Unity's provided Awake function. If an instance has been assigned before, the current object is destroyed.

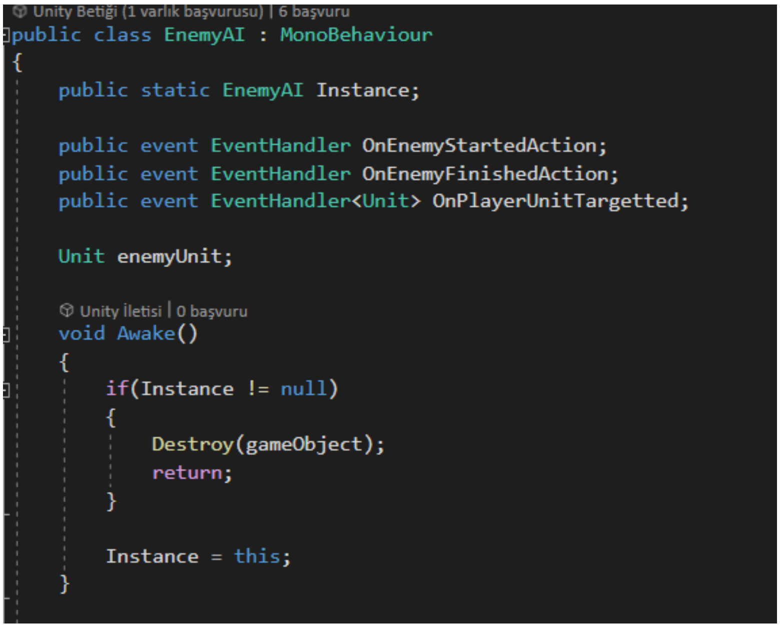


Figure 15. *Image of the EnemyAI object's EnemyAI script.*

When we create a script, we also create a class at the same time. By default, Unity inherits this class from the MonoBehaviour class. This allows us to attach that script as a component to an object. Additionally, the MonoBehaviour class provides us with various functions within the script that we can use, such as Awake, Start, LateUpdate, Update, FixedUpdate, OnEnable, and OnDestroy.

The Start and Update functions are automatically created in the class. They are called once when a scene is loaded. The only difference between the Awake and Start functions is that the Awake function is called before the Start function.

The Update function, on the other hand, works throughout the time our game is running and is called as many times as the computer's hardware allows (FPS - Frames Per Second).

The LateUpdate and FixedUpdate functions are similar to the Update function but have a different execution order, which is predetermined by Unity.

4.2 Observer design pattern

The Observer design pattern is used to easily notify all relevant objects when the state of an object changes. Its greatest benefit is minimizing the dependency between classes. The Observer design pattern can be implemented using C#'s event and delegate structures. In Pixel Dungeon, the ready-made delegate structure of C#, EventHandler, is used. Below is an example of the Observer design pattern used in Pixel Dungeon.

```
Unity Betiği (1 varlık başvurusu) | 25 başvuru
public class UnitActionSystem : MonoBehaviour
{
    public static UnitActionSystem Instance;

    public event EventHandler OnSelectedUnitChanged;
    public event EventHandler OnSelectedActionChanged;
    public event EventHandler<bool> OnBusyChanged;
    public event EventHandler OnActionStarted;
    public event EventHandler OnActionComplete;
```

Figure 16. *Events defined in the UnitActionSystem command line.*

In Figure 16, it can be observed that in the UnitActionSystem script, an event named OnSelectedActionChanged is defined to be used when the player's selected ability is changed.

In Figure 17, it shows how the event is invoked. The SetSelectedAction function is assigned to the OnClick events of buttons in the player's current unit's ability set. When the Invoke() function is called, other classes that have subscribed to this class's event will be notified about which ability the player has selected.

```
3 başvuru
public void SetSelectedAction(BaseAction baseAction)
{
    selectedAction = baseAction;

    OnSelectedActionChanged?.Invoke(this, EventArgs.Empty);
}
```

Figure 17. *The invocation method of the OnSelectedActionChanged event.*

```
public class UnitActionSystemUI : MonoBehaviour
{
    void Start()
    {
        tooltipContainer.SetActive(false);

        UnitActionSystem.Instance.OnSelectedUnitChanged += UnitActionSystem_OnUnitSelected;
        UnitActionSystem.Instance.OnSelectedActionChanged += UnitActionSystem_OnSelectedActionChanged;
        UnitActionSystem.Instance.OnBusyChanged += UnitActionSystem_OnBusyChanged;
        TurnSystem.Instance.OnUnitChanged += TurnSystem_OnUnitChanged;
        EnemyAI.Instance.OnEnemyStartedAction += EnemyAI_OnEnemyStartedAction;
```

Figure 18. *Subscribe to the OnSelectedActionChanged event from the UnityActionSystemUI script.*

In Figure 18, the way UnitActionSystemUI class subscribes to the OnSelectedActionChanged event of the UnitActionSystem class is shown. Inside the class, the function "UnitActionSystem_OnSelectedActionChanged" is defined, and whenever the event is called, this function will be called along with the event.

```
1 başvuru
private void UnitActionSystem_OnSelectedActionChanged(object sender, EventArgs e)
{
    UpdateSelectedVisual();
    UpdateActionTooltip(UnitActionSystem.Instance.GetSelectedAction());
}
```

Figure 19. *The UnitActionSystem_OnSelectedActionChanged function*

The "UnitActionSystem_OnSelectedActionChanged" function is used to change the background color of the selected ability and update the action's description text on the canvas based on the player's selection.

4.3 State design pattern

The State design pattern is a design pattern that allows an object to change its behavior when its internal state changes. It is closely related to finite state machines. Below is an example of the State design pattern used in Pixel Dungeon.

In Figure 20, it can be seen that in the AttackAction class, there is an enum named "State" created for states, and a variable named "state" is defined from this enum. Additionally, a counter named "stateTimer" is defined to determine the duration of each state.

```
public class AttackAction : BaseAction
{
    public event EventHandler OnAttack;
    public static event EventHandler OnAnyUnitStartedAttack;
    [SerializeField] AudioClip attackSound;

    10 başvuru
    private enum State
    {
        Aiming,
        Hitting,
        Cooloff,
    }

    private State state;
    private float stateTimer;
```

Figure 20. *Enumeration definition for states in the AttackAction class*

```
void Update()
{
    if(!isActive)
    {
        return;
    }

    stateTimer -= Time.deltaTime;

    float lerpSpeed = 8f;
    switch(state)
    {
        case State.Aiming:
            transform.position = Vector3.Lerp(transform.position, targetPosition, lerpSpeed * Time.deltaTime);
            break;
        case State.Hitting:
            if(canHitDamage)
            {
                Hit();
                canHitDamage = false;
            }
            break;
        case State.Cooloff:
            transform.position = Vector3.Lerp(transform.position, unitPosition, lerpSpeed * Time.deltaTime);
            break;
    }

    if(stateTimer <= 0f)
    {
        NextState();
    }
}
```

Figure 21. *Control of defined states within a switch.*

In Figure 21, it can be observed that the control of states is done using a switch inside the Update function. Using a switch is the simplest method to control states. When units perform an attack action, the AttackAction class comes into play. In the "Aiming" state, the attacking unit moves towards the position of the target unit.

In the "Hitting" state, the attack action is performed. In the "Cooldown" state, the unit returns to its previous position.

In the Update function, the value of the stateTimer counter variable is decreased over time using Unity's Time class. At the end of the function, if the time reaches zero, the NextState() function is called to transition to the next states.

```
1 başvuru
void NextState()
{
    switch(state)
    {
        case State.Aiming:
            state = State.Hitting;
            unit.GetAudioSource().PlayOneShot(attackSound);
            float hittingStateTime = 1f;
            stateTimer = hittingStateTime;
            break;
        case State.Hitting:
            state = State.Cooloff;
            float cooloffStateTime = 0.75f;
            stateTimer = cooloffStateTime;
            break;
        case State.Cooloff:
            ActionComplete();
            unit.SendSpriteBack();
            break;
    }
}
```

Figure 22. Control of state transitions in the NextState function.

In Figure 22, the content of the NextState function can be seen. When this function is called, it transitions to the next state and sets the value of the stateTimer counter. Additionally, it plays the attack sound effect of the unit and notifies relevant classes that the action is completed.

5. Conclusion

In this study, a game has been developed using the C# programming language and the Unity game engine. It caters to a niche of players who appreciate the intellectual challenge of strategic thinking and tactics. By incorporating the principles of Object-Oriented Programming and implementing well-established Design Patterns such as Observer, State, and Singleton, the game demonstrates a commitment to sound software engineering practices.

The core objective of proposed game project is to engage players in a battle of wits, utilizing a diverse array of in-game characters with unique abilities. This strategic depth adds a layer of complexity and intrigue to the gameplay, making each move a critical decision that can influence the outcome of the game. As players progress through the game, accumulating points and facing increasingly formidable opponents, they are continuously challenged to adapt their strategies and make the best use of their character's abilities. "Pixel Dungeon" not only offers an enjoyable gaming experience but also serves as an effective tool for enhancing players' strategic decision-making skills.

This study exemplifies how the Unity game engine can be harnessed to create turn-based games that not only entertain but also provide a platform for players to sharpen their cognitive and strategic abilities. "Pixel Dungeon" is a testament to the creative possibilities that arise from the fusion of innovative game design and state-of-the-art development technologies.

References

[1] J. K. Haas, "A history of the unity game engine", Diss. Worcester Polytechnic Institute, 2014.
[2] P. B. Addison, J. Manning, and T. Nugent, "Unity Game Development Cookbook: Essentials for Every Game", O'Reilly Media, 2019.
[3] H. Ferrone, "Learning C# by Developing Games with Unity: Get to grips with coding in C# and build simple 3D games in Unity 2022 from the ground up", 7th Edition.
[4] S. L. Kim, , H. J. Suk, , J. H. Kang, J. M.Jung, T. H. Laine and Westlin, J., "Using Unity 3D to facilitate mobile augmented reality game development". In 2014 IEEE World Forum on Internet of Things (WF-IoT), pp. 21-26, IEEE, 2014.
[5] LYASeeK, MiniFolks bundle. https://lyaseek.itch.io/
[6] Szadi art, Platformer Fantasy SET1. https://szadiart.itch.io/platformer-fantasy-set1
[7] M. Tohami, Pixel Art GUI Elements. https://mounirtohami.itch.io/pixel-art-gui-elements
[8] 7Soul, 7Soul's RPG Graphics - Icons. https://7soul.itch.io/7souls-rpg-graphics-pack-1-icons

Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida
Vol. 3, No. 2, pp. 99-106, 2023
Research Article
Received: 10/09/2023 Accepted: 01/12/2023

MitM Attacks and IoT Security: A Case Study on MQTT[1]

Serhat ÇELİK[1], Nesibe YALÇIN[2,*], Semih ÇAKIR[3]

Abstract
The number of devices connected to the Internet has increased with the development of Internet of Things (IoT) technologies. It is foreseen that this situation will increase daily, and the concept of the IoT will become more popular. However, security vulnerabilities in IoT devices have not been eliminated, and these devices are vulnerable to attacks because their resource-limited features increase security concerns. The security problem of the Message Queuing Telemetry Transport (MQTT) protocol, which is widely used in the IoT field, is of great importance. In this study, a smart-home system application that provides communication between devices using the MQTT protocol has been developed. A Man in the Middle (MitM) attack, which is one of the first attacks that come to mind when it comes to privacy violation, was carried out, targeting data packets between users with a temperature sensor used in the application.
Keywords: Attack Detection; IoT; IoT Security; MitM Attacks; MQTT.

1. Introduction

IoT is a technology that allows any “thing” that can connect to the internet so that things communicate (send/receive data) and work synchronously with other things [1]. With this definition, it would be incorrect to limit IoT devices to appliances, such as smart televisions or smartwatches. Printers, refrigerators, washing machines, air conditioners, home heating systems, and many similar or different devices can be defined as IoT devices. With the development of technologies such as IoT, the use of the Internet is increasing; however, the security of data sent and received via the Internet still poses a fundamental problem. According to analysts, the use of IoT technologies is expected to increase gradually, but owing to the security vulnerabilities of IoT devices, many companies still worry and take extra caution when investing in this field. The use of IoT poses security challenges [2]. Devices must communicate only with users that belong to them. Most devices do not have an authentication interface to enter a username and password. However, authorization must be achieved. Every device in an IoT environment should have guaranteed security. These devices must be capable of remote updates. The device and updates must be compatible. Furthermore, version control should be performed to prevent the device from being downgraded from its current version to older versions.

Information security, including IoT security, includes three main terms: confidentiality, integrity, and availability [3]. Confidentiality aims to ensure that information is accessible only to authorized persons. Because information is processed, stored, and shared, it must be protected. Integrity tries to prevent data corruption. These corruptions can occur by changing the information, adding to the information, and deleting some or all of its content. The goal of availability is to make information accessible to users anytime and for as long as they want. As an illustration of a situation in which some of these security terms are violated: have a baby camera for parent usage. This device can be a simple live tracking camera or a face analysis camera that uses artificial intelligence and image processing techniques. It is assumed that the login information of the home Internet used by this device for communication is captured by a malicious user. If the attackers are on the same network as the devices they intend to attack, they can execute a Man in the Middle (MitM) attack. In this way, an attacker can view or alter important data in network traffic. Therefore, confidentiality and integrity are violated.

*Corresponding author

SERHAT ÇELİK; Erciyes University, Faculty of Engineering, Department of Computer Engineering, Türkiye; e-mail: 1030510344@erciyes.edu.tr; 0000-0002-4717-1507

NESİBE YALÇIN; Erciyes University, Faculty of Engineering, Department of Computer Engineering, Türkiye; e-mail: nesibeyalcin@erciyes.edu.tr; 0000-0003-0324-9111

SEMİH ÇAKIR; Zonguldak Bülent Ecevit University, Karadeniz Ereğli Vocational School of Higher Education, Information Technology Security Program, Türkiye; e-mail: semih.cakir@beun.edu.tr; 0000-0003-3072-9532

[1]An earlier version of this paper was presented at the ICADA 2023 Conference and was published in its Abstract Book (Title of the conference paper: “MQTT Protokolü Tabanlı IoT Sistemine Yönelik Saldırı Uygulaması ve Güvenlik”).

Many studies have been conducted to examine and secure IoT technologies. This research focuses on the security of the Message Queuing Telemetry Transport (MQTT) protocol used in various IoT systems. In particular, MQTT contains a limited number of security elements [4]. A new design for the MitM attack against IoT devices using MQTT is presented in [5]. Experiments have been conducted in a test environment containing Mosquitto, Raspberry Pi, Pineapple, Wi-Fi, etc. The designed attack has successfully evaded various machine learning-based intrusion detection models. The study shows how difficult it is for MiTM attacks to be detected by traditional security defense mechanisms. In [6], the K-Nearest Neighbor approach has been adopted for attack detection in MQTT-based IoT systems. A basic smart home system has been developed in that study. Attacks have been conducted on a machine running Kali Linux and Wireshark has been used for packet listening on a machine with Windows installed. A switch has been utilized to interact with the device. An access point has been used for the communication of IoT devices, and a Raspberry Pi for control. Three different attacks have been performed to test the security of MQTT and security measures have been recommended by Şimşek and Atılgan [7] for systems using the MQTT protocol. In [8], a lightweight authentication system has been proposed to provide secure MQTT communication between IoT devices. The energy consumption and communication overhead have been analyzed using the Cooja simulator for optimal performance. A machine learning approach has been presented for an MQTT-based IoT platform in [9]. An attack is first carried out on the MQTT server of a smart-home network. MitM attacks are added when an attack is observed on the Wireshark. The post-attack data and MQTT dataset have been combined in a comma-separated value format. Training and test implementations have been performed separately, and the results are recorded as accuracy, F1 score, and training and test times. The authors in [10] have studied On-Off Attack (OOA) detection for IoT devices in a Contiki–Cooja simulation environment. Multilayer perceptron neural networks have been applied to improve the detection of OOA-based attacks. A real network environment has been created to record the on/off status of each node. Incoming radio messages have been captured simultaneously, and unstable conditions have been controlled. Varma and UniKrishnan [11] have carried out some experiments to evaluate the payload of MQTT when exposed to a MitM attack. ARP spoofing (via MitM attack) has been successfully conducted in the study. However, sniffing has failed because the payload has been secured using the AES encryption algorithm. To make the MQTT protocol more secure, it has been suggested that object-level security rather than Transport Layer Security (TLS) should be considered.

This study addresses the importance of MQTT security for IoT systems. The security requirements of IoT devices using MQTT have been discussed and the attack surface in IoT has been examined over the local network. We have also developed an IoT-based testbed with a particular focus on MitM attacks for MQTT security. So IoT security awareness can be improved specifically for MQTT. The next section presents general information about the MQTT protocol, and Section 3 provides details of the design and implementation of the testbed. The ARP-spoofing-based MitM attack and an example scenario are presented in Section 4. The results of the attack are discussed in Section 5, and the security risks and measures of MQTT are evaluated in the final section.

2. MQTT Protocol

The MQTT protocol [12] is a messaging protocol used for machine-to-machine communication. IoT is widely utilized [4] as the application layer protocol in data exchange [13]. The main reasons why they are preferred by a multitude of IoT devices [14], [15] are as follows.

- Resource efficiency: IoT devices do not consume a large amount of resources owing to their nature. Because the MQTT protocol is also lightweight, it is suitable for use with IoT devices. For example, an MQTT message can be as small as two bytes.
- Dynamic scalability: The coding difficulty required for MQTT is minimal. In addition, built-in features support IoT devices.
- Security: This allows message authentication with options such as OAuth, TLS, and personal certificates.
- Support: Many languages such as Python offer extensive library support for the MQTT protocol.

2.1. MQTT architecture

A publish/subscribe communication method is employed in the MQTT architecture. This publishing device is called a publisher. Publishers transmit data to specific topics. Subscribed devices, known as subscribers, can follow the content of a topic by subscribing to the topic. Figure 1 shows the basic structure of the MQTT architecture.

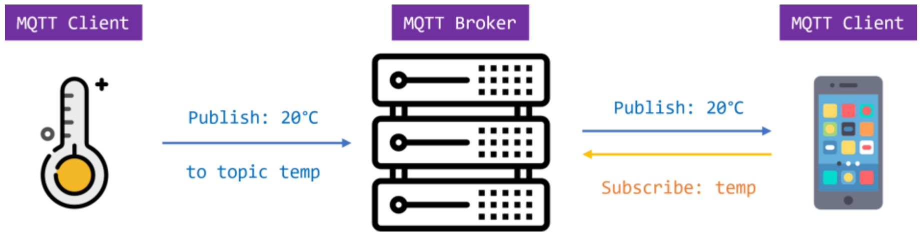


Figure 1. *MQTT architecture.*

The three key components in the architecture are the MQTT client, broker, and connection. MQTT clients can be defined as any device that sends/receives data in the network using the MQTT protocol. If this device sends data, it is referred to as the publisher. If it receives data by subscribing to a topic, it is called a subscriber. The MQTT broker is responsible for managing the messages among different clients. It performs the tasks of authorization, authentication, message filtering, and subscriber identification. Using an MQTT connection, clients communicate with each other. First, any client sends a CONNECT message to the MQTT broker. When a connection is established, the broker sends the CONNACK message to the client. Thus, clients communicate with each other only through the broker. There is no direct connection between the two.

2.2. MQTT broker

Many commercial and open-source MQTT brokers are available on the market. In this study, HiveMQ [16] has been used as the MQTT broker. The public HiveMQ MQTT broker offers some features (100 connectable devices for free, 10 GB data limit, etc.) required to build MQTT applications. This supports the latest MQTT version and fully managed cloud service. In addition, users can be created in this service, and their identities can be determined. User manuals and other documentation are available for multiple development environments including Arduino, NodeMCU, Raspberry Pi, and Python.

3. MQTT-Based IoT Platform

A smart home system has been developed as a testbed for the practical evaluation of IoT security. The software and hardware requirements for the design and implementation of a smart-home system are detailed in this section.

3.1. Software

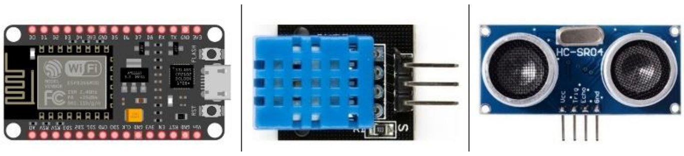
Arduino IDE, Fritzing, Wireshark, hARPy, and ARPspoof are used in the application testbed.

- The code written in C++ using the Arduino IDE is permanently loaded into the NodeMCU device memory.
- Fritzing is a tool for drawing hardware connections.
- The Wireshark software has been used as a network monitoring tool in this study. Wireshark is a free and open-source software for monitoring and listening/sniffing network traffic.
- hARPy is a tool developed in Python for active and passive Address Resolution Protocol (ARP) scanning. In this manner, the Internet Protocol (IP) addresses of the devices in the current network and their corresponding Media Access Control (MAC) addresses can be learned.
- ARPspoof is a tool for performing MitM attacks using the ARP poisoning technique in Python.

3.2. Hardware

The NodeMCU development kit, DHT11 humidity and temperature sensor, and HC-SR04 ultrasonic distance sensor shown in Figure 2 are used to develop the IoT platform.

- NodeMCU V3 ESP8266 ESP-12F Development Kit: Unlike Arduino devices, the NodeMCU is a development kit that allows developers to connect to the Internet with the built-in ESP8266 WiFi module. In addition, it is preferred, particularly in IoT applications, owing to its lower power consumption.
- DHT11: A Digital Humidity and Temperature (DHT) sensor is used to obtain the temperature information of the environment and is ideal for long-term use. The temperature measurement range is between 0-50 °C degrees, and the measurement accuracy is acceptable [17].
- HC-SR04 Ultrasonic Distance Sensor: It is utilized to measure the distance of the target with the ultrasonic sound waves it emits. With a minimum range of 2 cm and a maximum range of 400 cm, this sensor can measure with an accuracy of 3 mm [18].



(a) (b) (c)

Figure 2. *(a) NodeMCU, (b) DHT11, (c) HC-SR04.*

3.3. Application Testbed

To prepare the IoT environment, first, the access point setting is made so that the devices can communicate with each other via an Internet connection. The IP address of the default gateway is set at 192.168.43.1. The ESP8266 module is set as the publisher to share the information it receives from the temperature sensor and ultrasonic distance sensor with the MQTT protocol, and its IP address is determined as 192.168.43.229. The IP address of the computer with the Lubuntu Linux operating system used for the MitM attack is 192.168.43.10. This computer was also used to monitor the network traffic during an attack using the Wireshark tool. Figure 3 shows a representative view of the IoT platform obtained as a result of these adjustments.

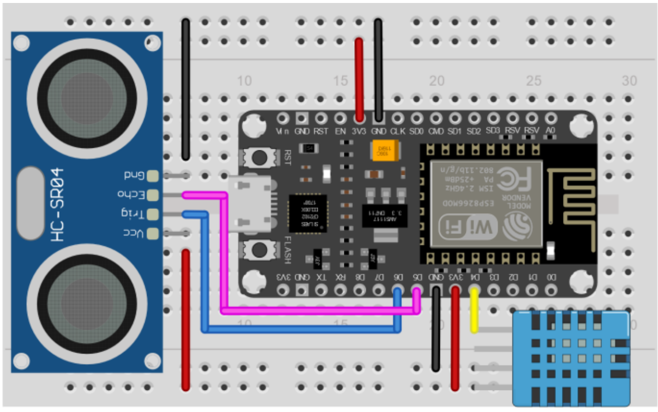


Figure 3. *Fritzing sketch of hardware connections.*

4. ARP Spoofing Based MitM Attack

A publisher/subscriber model is used by MQTT to enable messaging between devices. However, its protocol design has many security risks such as denial of service, poisoning, sniffing, tampering, MitM, elevation of privileges, and spam [4], [8]. A MitM attack is a cyberattack type that is possible if malicious users are on the same network as the devices they will attack. Multiple techniques can be used to carry out these attacks. ARP poisoning is one of these techniques. This section contains details on how the ARP works, the ARP poisoning technique, and how this technique is applied.

4.1. ARP

Before devices can communicate with other devices on the same network, they require their MAC addresses as well as their IP addresses. To accomplish this, the current device sends a who-is (request) packet to the other device that it wants to communicate with [19]. For example, if the device asks, "I am 192.168.0.1 and my MAC address is AA-BB-AA-11-11-11, what is the MAC address of the device 192.168.0.5?". After this request, the device that receives the message sends an is-at (response) packet. As shown in Figure 4, the device says "I am 192.168.0.5, and my MAC address is AA-BB-AA-55-55-55.

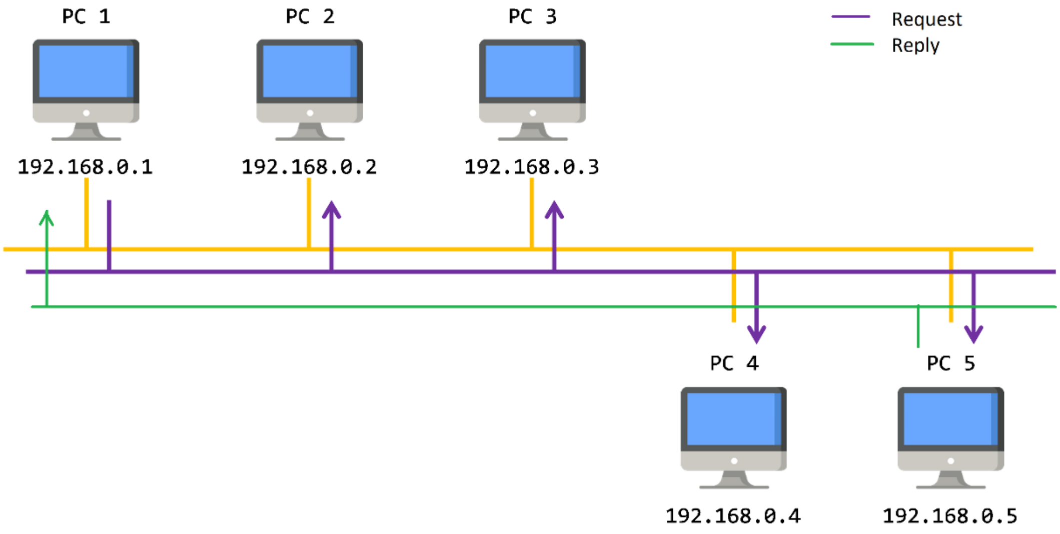


Figure 4. *ARP communication process.*

The process normally occurs in this example according to the definitions in the protocol. However, ARP is a vulnerable protocol, based on its nature. Because during the sending of these packets, it is not verified whether the incoming packets come from the original owner. Thus, ARP poisoning can be performed using this vulnerability.

4.2. ARP Poisoning

To perform MitM attacks with ARP poisoning [20]

a) The attacker sends a request packet to the victim device, meaning “I am the modem” as if the modem’s MAC address is its own.
b) The attacker sends a response packet to the modem that shows the MAC address of the victim device as if it is its own MAC address, meaning “I am a trusted device.”
c) Thus, the attacker becomes a man in the middle between the modem and the victim, and the traffic between these two devices flows over itself.

4.3. Attack Scenario

Before performing the attack, some setups are required on the Lubuntu Linux device used as the attack machine. The ARP discovery tool, hARPy, should be installed in the system to learn more about the devices connected to the network. To collect more detailed information about the network after an attack, Wireshark should be installed on the system. In addition, for the attack to be successful, the packets must be able to flow through the attack machine. IP forwarding must be implemented for this purpose. Following the completion of these preparations, a network scan is performed with hARPy for the MAC address information of the NodeMCU publisher that will be targeted by the attack. The data obtained as a result of the scanning is listed in Table 1.

Table 1. *IP and MAC address information of the devices before the attack.*

Address	NodeMCU	Access Point	Lubuntu Linux
IP	192.168.43.229	192.168.43.1	192.168.43.10
MAC	F4-CF-A2-XX-XX-XX	D8-5B-2A-XX-XX-XX	C0-4A-00-XX-XX-XX

ARPspoof has been used to perform the attack [21]. After this attack, it is aimed to get the MQTT topic, which contains important data. As with the network used in this application, the MQTT topic can be learned if the traffic is unencrypted. Figure 5 depicts the attacker’s position on the IoT platform in the case of a successful attack.

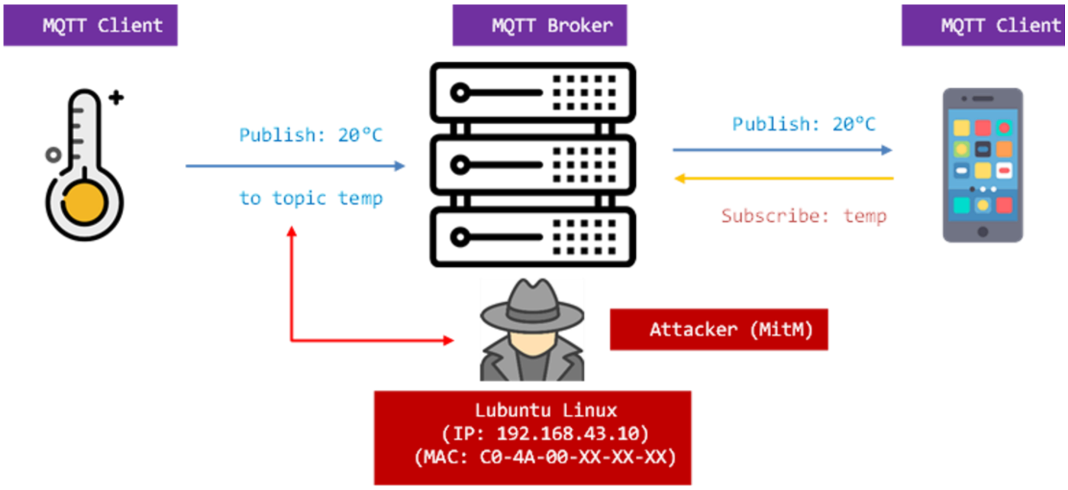


Figure 5. *The position of the attacker in the MitM attack.*

5. Results and Discussion

Table 2 presents the changes in device information after the attack. The MAC address of the Lubuntu Linux attack device remained the same, the MAC addresses of the NodeMCU publisher device and the access point are the same as the MAC address of the Lubuntu Linux device.

Table 2. *IP and MAC address information of the devices after the attack.*

Address	NodeMCU	Access Point	Lubuntu Linux
IP	192.168.43.229	192.168.43.1	192.168.43.10
MAC	C0-4A-00-XX-XX-XX	C0-4A-00-XX-XX-XX	C0-4A-00-XX-XX-XX

While the attack is in progress, it can be seen that the network traffic can be monitored using Wireshark. Figure 6 shows that the MQTT topic can be discovered by the attacker.

```
▾ MQ Telemetry Transport Protocol, Publish Message
  ▸ [Expert Info (Note/Protocol): Unknown version (missing the CONNECT packet?)]
    ▾ Header Flags: 0x30, Message Type: Publish Message, QoS Level: At most once delivery (Fire and Forget)
        0011 .... = Message Type: Publish Message (3)
        .... 0... = DUP Flag: Not set
        .... .00. = QoS Level: At most once delivery (Fire and Forget) (0)
        .... ...0 = Retain: Not set
    Msg Len: 33
    Topic Length: 24
    Topic: home/kitchen/temperature
    Message: 32362e37303030
```

Figure 6. *MQTT topic obtained by MitM attack.*

The MQTT message can be found following the Transmission Control Protocol flow. For instance, as can be seen in Figure 7, the temperature information is 26.7000 °C.

```
0!..home/kitchen/temperature26.7000!..home/kitchen/temperature26.7000!..home/kitchen/temperature26.7000!..home
/kitchen/temperature26.7000!..home/kitchen/temperature26.7000!..home/kitchen/temperature26.7000!..home/kitchen/
temperature26.7000!..home/kitchen/temperature26.7000!..home/kitchen/temperature26.7000....0!..home/kitchen/
temperature26.7000!..home/kitchen/temperature26.7000!..home/kitchen/temperature26.7000....home/kitchen/
temperature26.7000....0!..home/kitchen/temperature26.7000!..home/kitchen/temperature26.7000!..home/kitchen/
```

Figure 7. *Temperature information obtained by MitM attack.*

Various precautions must be taken in advance to prevent attackers from succeeding with such an ARP attack. Some of these measures are given below:

- All MAC addresses (on a home or enterprise network) can be statically mapped to their original IP addresses. This is quite effective in preventing ARP poisoning attacks but can be very workload-intensive. Because it requires manual updating of ARP tables for all computers after any changes are made to the network.
- ARP messages cannot be processed beyond a local subnetwork. Therefore, focusing important resources on a dedicated network segment that is well-segmented and has enhanced security may make the network less susceptible to ARP cache poisoning.
- Various software has been developed to observe suspicious IP and MAC matches on a network, for example, Arpwatch and X-ARP. These tools constantly monitor the network and can alert administrators if they detect any signs of an ARP attack. However, they can occasionally produce false positive results. Considering this possibility, the settings should be customized if necessary.
- Traffic can be encrypted. Although encryption does not technically prevent an ARP attack, it can reduce the potential damage. Connections encrypted with SSL/TLS will serve to defeat attackers' purposes.

If data is protected by encryption, when an attack occurs the resulting data will appear as encrypted text in the "Encrypted Application Data" section. Figure 8 shows that the data obtained as a result of the attack is encrypted.

```
▸ Transport Layer Security
  ▾ TLSv1.2 Record Layer: Application Data Protocol: mqtt
      Content Type: Application Data (23)
      Version: TLS 1.2 (0x0303)
      Length: 80
      Encrypted Application Data: b880302bfbddbff923ed58c647be0b86a17d49ad9e4155f200c9fe392b6d7365c2944374…
      [Application Data Protocol: mqtt]
```

Figure 8. *Encrypted data obtained as a result of a MitM attack on a secure network.*

6. Conclusion

This study focuses on the MQTT protocol and a case study has been conducted on the MitM attack. MitM attack is a powerful attack type and can cause serious damage that is hard to detect by typical defense mechanisms. In networks that lack security measures, the confidentiality of data can never be fully assured. Some precautions and counteractions to be taken to protect against this attack, including transport layer and application layer security are given as follows:

- The firewall must be active and updatable.
- Whenever possible, only devices that are on the whitelist should be allowed to join the network.
- By default, the MQTT protocol does not require a connection using a username and password. For this reason, it must be mandatory to establish a connection with a username and password.
- The current, most up-to-date version of the MQTT protocol should be preferred.
- MQTT brokers let clients create their own rules. Some of these rules are: publish only, subscribe only, publish only on a specific topic, and subscribe only on a specific topic. In this way, even if unauthorized users know about the MQTT topic, they will not be able to take any action because they are not authorized.
- Traffic should be encrypted using TLS technology. The HiveMQ service has explained how to implement certificates on NodeMCU devices. To achieve this, Distinguished Encoding Rules (DER) files are created via the Privacy Enhanced Mail (PEM) texts provided by the "Mozilla Trusted Certificate Authorities" page. PEM texts are simply Base64-encoded DER files. A DER file to be obtained in this way can be uploaded to the NodeMCU device, and the connections can be encrypted.

Encrypting payload data is the best option to secure MQTT. TLS must be offered to ensure the integrity of MQTT data and to prevent attacks on MQTT nodes. In addition, machine learning and blockchain technologies present promising solutions to deal with the MQTT security issues.

Declaration of Interest

The authors declare that there is no conflict of interest.

Author Contributions

Serhat Çelik: Conceptualization, Methodology, Software & Hardware of IoT Platform, Validation, Investigation, Results and Discussion, Visualization, and Writing - original draft.
Nesibe Yalçin: Conceptualization, Methodology, Writing - Review - Editing, and Supervision.
Semih Çakir: Methodology, Validation, Investigation, and Review - Editing.
All authors reviewed the manuscript.

References

[1] C. C. Sobin, "A Survey on Architecture, Protocols and Challenges in IoT," Wireless Personal Communications, vol. 112, pp. 1383-1429, 2020. doi: 0.1007/s11277-020-07108-5
[2] O. Yavuz, "Nesnelerin İnterneti (IoT) ve Güvenliği," btkakademi.gov.tr, 2023. [Online]. Available: https://www.btkakademi.gov.tr/portal/course/nesnelerin-interneti-iot-ve-guvenligi-10625. [Accessed July 2, 2023].
[3] M. B. Younes and N. N. El-Emam, "Information Security and Data Management for IoT Smart Healthcare," In Intelligent Internet of Things for Smart Healthcare Systems, CRC Press, pp. 69-80, 2023.
[4] A. J. Hintaw, S. Manickam, M. F. Aboalmaaly, and S. Karuppayah, "MQTT Vulnerabilities, Attack Vectors and Solutions in the Internet of Things (IoT)", IETE Journal of Research, vol. 69, no. 6, pp. 3368-3397, 2023. doi: 10.1080/03772063.2021.1912651
[5] H. Wong, L. Tuo, "Man-in-the-Middle Attacks on MQTT-based IoT Using BERTBased Adversarial Message Generation", KDD'20 Workshops: the 3rd International Workshop on Artificial Intelligence of Things (AIoT), 2020, San Diego, CA.
[6] B. Erdem and O. Yaman, "KNN Based Intrusion Detection Method for IoT Applications Using MQTT Protocol," Fırat University Journal of Science and Technology, vol. 1, no. 1, pp. 225-229, 2022.
[7] M. M. Şimşek and E. Atılgan, "Attacks on Availability of IoT Middleware Protocols: A Case Study on MQTT", Eskişehir Türk Dünyası Uygulama ve Araştırma Merkezi Bilişim Dergisi, vol. 4, no. 2, pp. 16-27, 2023. doi:10.53608/estudambilisim.1297052
[8] S. Tian, V. G. Vassilakis, "On the Efficiency of a Lightweight Authentication and Privacy Preservation Scheme for MQTT", Electronics, vol. 12, no. 14, 3085, 2023. doi: 10.3390/electronics12143085
[9] A. N. Kaya and E. N. Yolaçan, "Attacks nn The MQTT-Based IoT System Detection Using Machine Learning," Journal of Engineering and Architecture Faculty of Eskişehir Osmangazi University, vol. 30, no. 2, pp. 159-170, 2022.
[10] A. H. Farea and K. Küçük, "Enhancement Trust Management in IoT to Detect ON-OFF Attacks with Cooja," International Journal of Multidisciplinary Studies and Innovative Technologies, vol. 5, no. 2, pp. 123-128, 2021.
[11] A. Varma and S. UniKrishnan, "Effect of Payload Security in MQTT Protocol Over Transport and Application Layer", IOP Conference Series: Materials Science and Engineering, vol. 1166, 012019, 2021. doi:10.1088/1757-899X/1166/1/012019
[12] MQTT, "MQTT: The Standard for IoT Messaging," mqtt.org, 2022. [Online]. Available: https://mqtt.org. [Accessed July 2, 2023].
[13] F. Chen, Y. Huo, J. Zhu, and D. Fan, "A Review on the Study on MQTT Security Challenge," 2020 IEEE International Conference on Smart Cloud (SmartCloud), Washington, DC, USA, 2020, pp. 128-133, doi: 10.1109/SmartCloud49737.2020.00032.
[14] M. Bender, E. Kirdan, M. -O. Pahl, G. Carle, "Open-Source MQTT Evaluation," 2021 IEEE 18th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, pp. 1-4, 2021, doi: 10.1109/CCNC49032.2021.9369499.
[15] Amazon, "MQTT Protokolü Neden Önemli?," amazon.com, 2023. [Online]. Available: https://aws.amazon.com/tr/what-is/mqtt/. [Accessed July 22, 2023].
[16] HiveMQ, "HiveMQ | Public Broker | MQTT Dashboard," hivemq.com, 2023. [Online]. Available: https://broker.hivemq.com/. [Accessed July 22, 2023].
[17] ArduinoModules, "KY-015 Temperature and Humidity Sensor Module," arduinomodules.info, 2021. [Online]. Available: https://arduinomodules.info/ky-015-temperature-humidity-sensor-module/. [Accessed July 25, 2023].
[18] F. T. Akgul, "Ultrasonik (Ultrasonic) Sensör Nedir? Nasıl Çalışır?," robotistan.com, 2021. [Online]. Available: https://maker.robotistan.com/ultrasonic-sensor/. [Accessed July 25, 2023].
[19] IPCisco, "Address Resolution Protocol (ARP)," 2020. [Online]. Available: https://ipcisco.com/lesson/address-resolution-protocol-arp/. [Accessed Aug. 1, 2023].
[20] rauf, "[TR] ARP Nedir ve ARP Spoofing Nasıl Yapılır?," 2021. [Online]. Available: https://pwnlab.me/tr-arp-nedir-ve-arp-spoofing-nasil-yapilir/. [Accessed Aug. 2, 2023].
[21] M. Brown, "System Setup and Scripts For Various MitM Activities," 2022. [Online]. Available: https://github.com/nmatt0/mitmtools. [Accessed Aug. 2, 2023].

Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida

Vol. 3, No. 2, pp. 107-115, 2023
Research Article
Received: 11/09/2023 Accepted: 19/11/2023

An Analysis for Car Fuel Estimation with Regression Methods

Enes TAŞKIN [1], Vedat MARTTİN [2,*]

Abstract

Fuel consumption and efficiency have emerged as pressing concerns in the context of growing energy sources and increasing environmental awareness. Machine learning, a subset of artificial intelligence, leverages intricate data structures and variable information to make predictions. These algorithms play a pivotal role in modeling and forecasting across diverse industries like healthcare, finance, banking, and energy.

This study offers a comprehensive overview of a typical machine learning project flow, with a particular focus on fuel prediction. The project encompasses key stages such as data collection, data preparation, model development, and evaluation. The methodologies and algorithms employed in this research hold the potential for broader applications in various forecasting projects and industry sectors.

In this investigation, fuel estimation was carried out using a set of features from the Auto MPG Data Set, sourced from the University of California. These features included Mpg (fuel consumption), Number of Cylinders, Engine Volume, Horsepower, Vehicle Weight, Acceleration, Model Year, Vehicle Origin, and Vehicle Name. Various regression algorithms, namely Linear Regression, Ridge Regression, Lasso Regression, and XGBoost, were applied to predict fuel consumption. The study's outcomes were generated by splitting the dataset into training and test data subsets. In the study[1], it was observed that Lasso regression was generally a little more prominent than the others in terms of error metric (RMSE=0.132369, MSE=0.017522, MAE=0.099490) and R^2=0.834900. It was seen that Linear regression was slightly better in terms of training data (RMSE=0.065446, MSE=0.004283, MAE=0.054682, R^2 =0.949617).

Keywords: Artificial intelligence (AI), Machine learning (ML), Modelling, Prediction, Regression

1. Introduction

Fuel consumption and regression models are emerging as an important area of research and application today. Studies in this area emphasize the use of artificial intelligence (AI) and machine learning (ML) techniques. Modeling, forecasting and regression, analyzing fuel consumption data and future "Regression models help us understand and predict the relationship between dependent variables and independent variables. In this context, AI and machine learning offer powerful tools to model complex data structures and improve fuel consumption forecasts. Regression models are widely used in various fields such as marketing, energy, fuel consumption [1].

In the literature, prediction studies have been made with regression models. In the studies, marine vehicles were studied in terms of fuel consumption. In terms of price estimation studies, it has been seen that there are studies such as air ticket, car sales price. This research[2] focuses on the development of predictive models for estimating fuel consumption based on real-world data gathered from a cruise ship during its operation. The selection of input variables for these models was carried out through a combination of statistical analysis and domain knowledge expertise. The study investigated various prediction models, including Multiple Linear Regression (MLR), Decision Tree (DT) approach, Artificial Neural Network (ANN), and ensemble methods. In this research, a comparative analysis of various predictive modeling approaches was conducted across multiple studies. The first study [3] explored the effectiveness of penalized regression techniques, including Ridge, Lasso, and Elastic Net, in predicting flight ticket prices. In the subsequent investigation [4], the performance of Lasso and Linear Regression models was assessed for predicting used car prices. Similarly, another study [5] scrutinized

*Corresponding author

Enes TAŞKIN; Bilecik Seyh Edebali University, Faculty of Engineering, Department of Computer Engineering, Türkiye; e-mail: enestaskin938@gmail.com; 0009-0009-7533-9627

Vedat MARTTİN; Bilecik Seyh Edebali University, Faculty of Engineering, Department of Computer Engineering, Türkiye; e-mail vedat.marttin@bilecik.edu.tr; 0000-0001-5173-2349

[1] "An earlier version of this paper was presented at the ICADA 2023 Conference and was published in its Abstract Book (Title of the conference paper: "Fuel Estimation Study with Regression Algorithms")

the predictive capabilities of Lasso, Multiple Linear Regression (MLR), and Decision Tree methods. Furthermore, a separate study [6] involved a comparison between Linear Regression, Ridge Regression, and Lasso Regression. Meanwhile, in yet another study [7], car price prediction was tackled using Random Forest, K-Nearest Neighbors (KNN), Decision Tree, XGBoost, and Linear Regression models. Lastly, in the study denoted as [8], the performance of Support Vector Machine (SVM) was evaluated for predicting used car prices.

Collectively, these studies contribute to a broader understanding of predictive modeling methodologies in various fields. It is aimed to contribute to the literature by using regression models on car fuel consumption of the data set used in this study, which we have not seen used in the literature.

The subsequent sections of this paper are structured as follows: The succeeding chapter delves into the intricacies of data preparation and exploration, elucidating the processes involved in data processing and predictive modeling. The penultimate segment provides a comprehensive account of the findings, while the ultimate section encapsulates the conclusions drawn and offers recommendations for future research.

2. Methodology

2.1. Data Preparation and Exploration

In this section, Auto MPG Dataset is selected and this data is taken from University of California. This dataset is a slightly modified version of the dataset provided in the StatLib library. Derivatives of the dataset can be found on the kaggle web page [9]. It was used by Ross Quinlan to estimate the "mpg" attribute. For this purpose, 40 of 398 data (10%) were determined as training data, and the remaining 356 data (90%) were reserved as test data. The variables in the data set are multivariate, categorical and real data. Table 1 shows the variables in the data set.

Table 1. *The variables in data set*

Variables
Mpg(fuel consumption)
Cylinders(number of cylinders)
Displacement(inches of engine)
Horsepower
Weight(vehicle weight)
Acceleration
Model year
Origin(vehicle origin)
Car name(vehicle name)

There are missing values in this data set. These missing values were removed from the data set and processed. It has been observed that the chance of success decreases in models with missing data. Figure 1 shows the Correlation matrix of the variables in the data set.

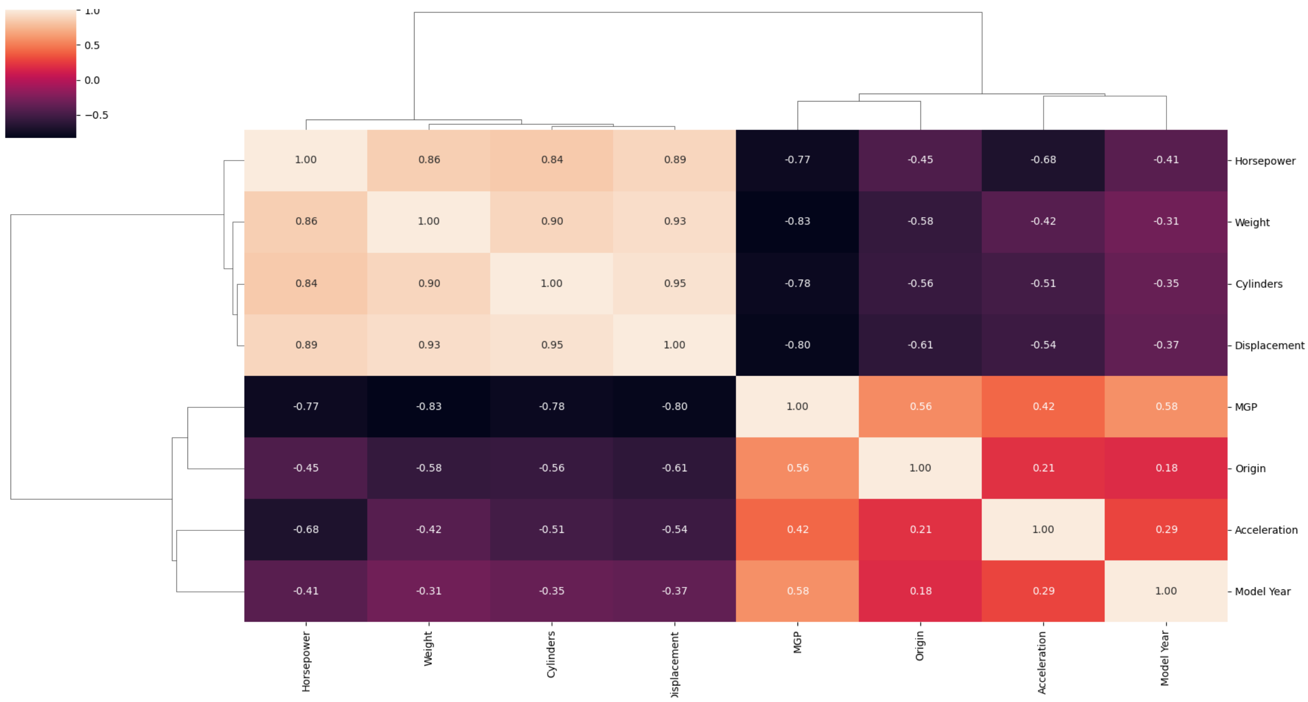


Figure 1. *Correlation matrix for MGP data set*

It is drawn as a 0.75 filter in the figure and when you look at this table, there is a correlation of -0.83 between MGP and cylinder. Likewise, there appears to be a -0.77 correlation between MGP and horsepower, a -0.83 correlation between MGP and vehicle weight, and a -0.80 correlation between MGP and engine inches. The features appearing in this table seem to be the features that have the most relationship with MPS.

2.2 Data Processing and Predictions

At this stage, real artificial intelligence and machine learning algorithms are used to process data and give predictions. The data set is divided into training/sample set and testing set. Training of algorithms is done with sample data set and the test set is used to verify the results. Evaluation of the results is done using . performance measurements and predictions are obtained. In the selection of these algorithms, regression methods that are expected to be main, effective and have high success rates were preferred, taking into account the size of the data set. Below, information is given about Linear, Lasso, Ridge equations and XGBoost, which is a decision tree structure.

Linear regression is a machine learning approach employed to establish a mathematical connection between dependent and independent variables. This method encompasses two primary categories: simple linear response variable based on a single predictor, while multiple linear regression is particularly useful when predicting a response variable utilizing multiple predictors [10]. The process of linear estimation is formally defined as follows in Eq.(1):

$$PRegLinear = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \epsilon \quad (1)$$

where the p th predictor is outlined by X_p, and also an association between a variable and the response is measured by β_p.

Rigde regression serves as a valuable tool for determining the coefficients in multiple-regression models, particularly when the independent variables are strongly correlated with one another. This technique often results in smaller variances and mean square estimators compared to those obtained through least square estimations [11]. The ridge estimate is formally defined as follows in Eq.(2):

$$PRegRidge = \sum_{i=1}^{n}\left(y_i - \beta_0 - \sum_{j=1}^{p}\beta_j x_{ij}\right)^2 + \lambda\sum_{j=1}^{p}\beta_j{}^2 \tag{2}$$

In this context, the parameter λ (where $\lambda \geq 0$) plays a crucial role as a tuning parameter, and the term $\lambda\sum_{j=1}^{p}\beta_j{}^2$ is known as a shrinkage penalty. This penalty serves the purpose of mitigating overfitting and addressing issues related to multidimensionality. Ridge regression constructs a model that involves all parameters without excluding any variables and simultaneously nudges the coefficients closer to zero. Consequently, it becomes essential to carefully determine an appropriate value for alpha (the penalty term) during the model-building process [12]. It's worth noting that utilizing ridge regression doesn't offer any advantages when λ equals zero.

Lasso regression simultaneously conducts variable selection and regularization to enhance the accuracy and interpretability of the statistical model being developed. Its primary objective is to identify coefficients that minimize the sum of squared errors while applying penalties to these coefficients [12]. The lasso regression function is outlined as follows in Eq.(3):

$$PRegLasso = \sum_{i=1}^{n}\left(y_i - \beta_0 - \sum_{j=1}^{p}\beta_j x_{ij}\right)^2 + \lambda\sum_{j=1}^{p}\left|\beta_j\right| \tag{3}$$

Unlike ridge regression, lasso regression differs in that it forces the coefficients of irrelevant variables to assume a value of zero. In more precise terms, the component $\beta_j{}^2$ in Eq.(2) is replaced with $|\beta_j|$ in Eq.(3) in the context of lasso regression.

XGBoost, stands for Extreme Gradient Boosting and stands for gradient boosting and decision tree It is a machine learning technique based on algorithms. Extreme gradient boosting (XGBoost) is an ensemble learning technique that creates a comprehensive model by combining a collection of individual models, typically decision trees. This method employs gradient-based optimization, akin to how neural networks utilize gradient descent for weight optimization [13]. It calculates second-order gradients of the loss function to minimize errors and incorporates advanced regularization techniques, including L_1 and L_2 regularization [14]. These regularization methods help reduce overfitting, ultimately enhancing the model's ability to generalize and perform well.

2.3 Performance Evaluation Methods

Several error metrics such as RMSE (Root Mean Square Error), MSE (Mean Squared Error), MAE (Mean Absolute Error), and R^2 (Coefficient of Determination) are employed to evaluate the predictive performance of the developed models. These reference error metrics provide insights into the extent of model training and the nature of errors. The metrics used for performance assessment are detailed as follows in Eqs.(4)-(7):

RMSE represents the standard deviation of prediction errors (residuals), indicating how tightly the data points cluster around the best-fitting line [15, 16]. RMSE estimate is defined by Eq.(4)

$$RMSE = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(P_i - T_i)^2} \tag{4}$$

MSE quantifies the average of the squared discrepancies between predicted values and actual observations [17]. It is alternatively referred to as mean squared deviation (MSD). MSE estimate is defined by Eq.(5).

$$MSE = \frac{1}{m}\sum_{i=1}^{m}(T_i - P_i)^2 \tag{5}$$

MAE assesses the absolute magnitude of discrepancies between pairs of data points, offering a direct comparison between predicted values and actual observations within the current context [15, 17]. MAE estimate is defined by Eq.(6).

$$MAE = \frac{1}{m}\sum_{i=1}^{m}|P_i - T_i| \quad (6)$$

R-squared (R^2) evaluates the fraction of the variability observed in the dependent variable that can be accounted for or predicted by the independent variable(s) [17]. This metric is commonly referred to as the Coefficient of Determination. R^2 estimate is defined by Eq.(7).

$$R^2 = 1 - \frac{\sum_{i=1}^{m}(Pi - Ti)^2}{\sum_{i=1}^{m}(Ti - T^*)^2} \quad (7)$$

where 'P_i' represents the predicted values, 'T_i' represents the actual or tested values, and '*m*' signifies the total number of data points. The mean value of all the tested values is calculated as the sum of the tested values divided by '*m*'.

2.4 K-Fold Cross-Validation

K-fold Cross Validation is not an error metric, but it is useful in training models and measuring performance. It helps to determine whether the high performance of the model is purely by chance [18]. This technique involves randomly dividing the dataset into '*k*' approximately equally sized subsets or multiples. During each iteration, *'k-1'* of these subsets are used to train the model while the remaining subset is reserved for testing. The process is repeated 'k' times and the average error value in these experiments serves as an indicator of the validity of the model. Typically '*k'* is chosen as 3 or 5, but can also be set to larger values such as 10 or 15.

2.5 Experimental Setup and Hyperparameter Tuning

In the study, we used the pandas library to draw the data set with the Python language, the seaborn and pairplot libraries to easily visualize the data in the form of plots, the scipy library to eliminate the skewed values in our data, and finally to standardize our data, perform cross-validation testing and regression. The sklearn library was used to perform the operations. The computer features and program information used are shown in the Table 2.

Table 2. *System Configuration*

Hardware and Sofware	Characteristics
Memory(RAM)	8 GB DDR4
Processor	Amd Ryzen5 2500U
Graphics	Readeon RX560
Operating System	MS Windows 10
Integrated Development Environment(IDE)	Anaconda Navigator, Spyder
Programming Languge	Python
Library	Pandas, Seaborn, Pairplot,Numpy, Matplotlib, Scipy, Sklearn.

The hyperparameters used to optimize the regression types used in the study are shown in the Table 3. The selected algorithm limits were determined by comparing the values that gave high success rates, which were used in many projects before, and the success rates obtained with various Monte Carlo methods used in the study.

Table 3. *Hyperparameters of Machine Learning Models*

Models	Hyperparameters	Optimal Values
Linear	Learning_rate	0.01
	Random State	42
	Max. Iteration	1000 epoch
Ridge	Learning_rate	0.001
	Random State	42
	Max. Iteration	1000 epoch
Lasso	Learning_rate	0.0001
	Random State	42
	Max. Iteration	1000 epoch
XGBRegressor	Criterion	Friedman
	Splitter	Random
	Min_sample_split	100

3. Results

The results of the regression models in the study according to performance metrics are shown in Table 4. It has been observed that the results of the regression models are close to each other according to the regression type. In regression performance analysis, error metrics such as RMSE, MSE, MAE are expected to be close to zero (0), while the R^2 value is desired to be close to one (1). As can be seen from Table 4, in the general case, Lasso regression is good in terms of RMSE, MSE, MAE, R^2 (0.132369-0.017522-0.099490-0.834900) values, respectively. It is seen that linear regression is slightly better in terms of training data, with RMSE, MSE, MAE, R^2 (0.065446-0.004283-0.054682-0.949617) values, respectively.

Table 4. *Performance evaluation measures for Regressions.*

Regression Types/Metrics	General				Train			
	RMSE	**MSE**	**MAE**	**R^2**	**RMSE**	**MSE**	**MAE**	**R^2**
Linear	0.143639	0.020632	0.106551	0.805590	0.065446	0.004283	0.054682	0.949617
Ridge	0.140447	0.019725	0.104693	0.814135	0.065554	0.004297	0.054940	0.949450
Lasso	0.132369	0.017522	0.099490	0.834900	0.068098	0.004637	0.057570	0.945451
XGBRegressor	0.021799	0.021799	0.111439	0.794593	0.087112	0.007589	0.070412	0.910735

The curves for regression models training and testing data is shown in Figure 2. The graph shows the following models based on the letters; a) Linear Regression applied to the training data, b) Linear Regression applied to the testing data, c) Ridge Regression applied to the training data, d) Ridge Regression applied to the testing data, e) Lasso Regression applied to the training data, f) Lasso Regression applied to the testing data, g) XGBoost Regression applied to the training data, h) XGBoost Regression applied to the testing data.

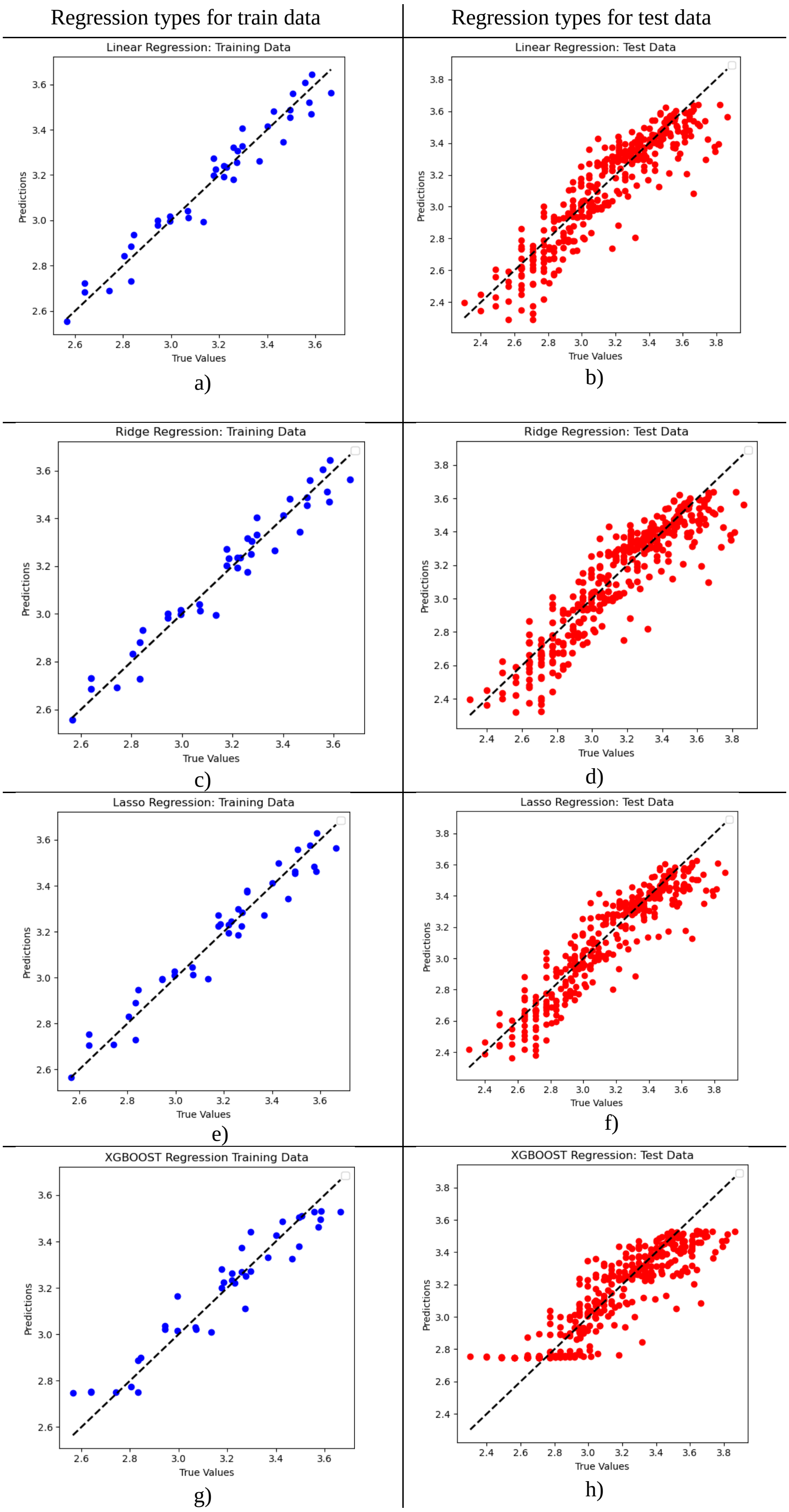


Figure 2. *The curves for regression models training and testing data*

In Figure 2, it is seen that the Linear, Ridge and Lassso curves of the regression models are concentrated in the regression curve region better than XGBoost in terms of training and test data.

4. Conclusions and Discussion

Predictions are made with the help of machine learning algorithms, using the complex structure of the data and the information accumulated in the variables. Today, machine learning algorithms play an important role in fields such as health, finance, banking and energy. Although electric vehicles have become widespread, fossil fuel and related fuel consumption estimates are still made due to reasons such as the widespread use of the service network of charging stations. In this study, the performance of a data set containing the data of cars that human beings need in life was examined using Linear Regression, Ridge Regression, Lasso Regression and XGBOOST algorithms. Auto MPG Data Set collected by the University of California was used as the data set. Application results were obtained by taking part of the data set as training data and the remaining part as test data. According to the research, academic fuel consumption studies have been conducted, but no studies similar to this study have been found. There are studies using different algorithms and variable parameters. In summary, in this study, the results obtained by applying various regression methods and algorithms to the vehicle data set are compared. In the study, it was observed that Lasso regression was generally a little more prominent than the others in terms of error metric and R^2 (RMSE=0.132369, MSE=0.017522, MAE=0.099490, R^2=0.834900). It was seen that Linear regression was slightly better in terms of training data (RMSE=0.065446, MSE=0.004283, MAE=0.054682, R^2 =0.949617). By applying different techniques and regression models to this data set, performance can be increased in future applications. In addition, this algorithm can be tested on different data sets and this study can be turned into an application that everyone can access and use via a website or a smart phone application.

Declaration of Interest

The authors declare that there is no conflict of interest.

Acknowledgements

An earlier version of this paper was presented at the ICADA 2023 Conference and was published in its Abstract Book (Title of the conference paper: "Fuel Estimation Study with Regression Algorithms")

Author Contributions

Enes Taşkın: Investigation, Modelling, Software. Vedat Marttin: Supervision, Conceptualization, Methodology, Visualization, Investigation, Modelling, Sofware, Writing - Original Draft, Writing - Review &Editing.

References

[1] I. H. Sarker, "Machine learning: Algorithms, real-world applications and research directions." SN computer science 2.3 ,2021: 160.

[2] Agand, Pedram, et al. "Fuel consumption prediction for a passenger ferry using machine learning and in-service data: A comparative study." Ocean Engineering 284 (2023): 115271.

[3] S. Buyrukoğlu, and Y.Yılmaz,"An Approach for Airfare Prices Analysis with Penalized Regression Methods." Veri Bilimi 4.2 pp.57-61, 2021.

[4] M. Asghar, K.Mehmood, S.Yasin and Z. M.Khan,"Used Cars Price Prediction using Machine Learning with Optimal Features". Pakistan Journal of Engineering and Technology, 4(2), pp:113-119, 2021.

[5] P. Venkatasubbu and M.Ganesh, "Used Cars Price Prediction using Supervised Learning Techniques". Int . J. Eng. Adv. Technol. (IJEAT), 9(1S3),2019.

[6] P. Rane, D.Pandya, D.Kotak," Used car price prediction "International Research Journal of Engineering and Technology (IRJET),2021.

[7] P. Gajera, A. Gondaliya, and J.Kavathiya, "Old Car Price Predict ion with Machine Learning". Int. Res. J. Mod. Eng. Technol. Sci, 3, pp:284-290,2021.

[8] S.Snehit, P.Borugadda, and N.Koshika. "Car Price Prediction: An Application of Machine Learning." 2023 International Conference on Inventive Computation Technologies (ICICT). IEEE, 2023.

[9] Kaggle [Online] Available: https://www.kaggle.com/datasets/uciml/autompg-dataset [Accessed Sept. 11, 2023].

[10] O. G., Uzut, S.Buyrukoglu, "Prediction of real estate prices with data mining algorithms". Euroasia Journal of Mathematics, Engineering, Natural and Medical Sciences.pp:77-84,2020, https://doi.org/10.38065/euroasiaorg.81

[11] T. Hastie, R.Tibshirani, J. H.Friedman and J. H Friedman. The elements of statistical learning: data mining, inference, and prediction (Vol. 2, pp. 1-758). New York: springer,2009.

[12] G. James,D.Witten,T. Hastie, and R.Tibshirani, An introduction to statistical learning, Vol. 112, pp: 18,. New York: springer, 2013.

[13] J. Han, J.Pei, M.Kamber. Data mining: concepts and techniques. Amsterdam: Elsevier; 2011.

[14] F.Pedregosa, G.Varoquaux, A. Gramfort,V.Michel, B.Thirion. O.Grisel,M. Blondel, P.Prettenhofer, R.Weiss,V.Dubourg et al."Scikit-learn: machine learning in python". J Mach Learn Res.12:2825–30, 2011.

[15] J. S.Chou, and , A. D.Pham. "Enhanced artificial intelligence for ensemble approach to predicting high performance concrete compressive strength.", Construction and Building Materials,49, pp:554-563,2013.

[16] P. N.Reddy and J. A. Naqash. "Strength prediction of high early strength concrete by artificial intelligence" Int J Eng Adv Technol, 8(3), pp:330-334,2019

[17] D. C.Feng, Z. T.Liu, X. D., Wang, Y .Chen, J. Q. Chang, D. F.Wei and Z. M. Jiang, "Machine learning-based compressive strength prediction for concrete: An adaptive boosting approach". Construction and Building Materials, 230, 117000, 2020.

[18] T. Fushiki," Estimation of prediction error by using K-fold cross-validation". Statistics and Computing, 21(2), pp:137-146, 2011.

Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida

Vol. 3, No. 2, pp. 116-123, 2023
Research Article
Received: 09/10/2023 Accepted: 26/11/2023

Time Series Forecasting of Solar Energy Production Data Using LSTM

Kadriye Filiz BALBAL[1,*], Özge ÇELİK [2] , Sebahattin İKİKARDEŞ [3]

Abstract

The fact that countries have increased the use of renewable energy resources in order to meet increasing energy demands has brought to light the fact that the components and energy production amounts of the solar energy systems to be installed must be estimated accurately. With the benefits provided by developing technology, forecasting calculations of these variable natural energy resources have become much more economical by using machine learning methods. In this context, this study proposes a deep learning-based methodology that includes LSTM-based tuned models for PV power forecasting, with univariate time series estimation of the amount of power obtained from a solar energy system integrated on a factory roof. When the created models are compared, the results show that the model approach named LSTM13 provides the most accurate prediction performance with the lowest RMSE metric value of 0.1470 among the other proposed models.

Key Words: Deep Learning, LSTM, Machine Learning, Renewable Energy, Solar Power Systems.

1. Introduction

Developing technology and increasing population cause the world's energy needs to increase day by day. Today, 70% of this energy need is met by fossil fuels. "Research since 1970 shows that the use of fossil fuels increases the emission of greenhouse gasses such as carbon dioxide (CO_2) and methane (CH_4) to the atmosphere. This increase thickens the ozone layer and causes global warming. To minimize the future effects of these phenomena, it is necessary to replace the use of fossil fuels with environmentally friendly, clean, and renewable energy sources as much as possible." [1]. Moreover, the fact that countries no longer want to depend on foreign energy has accelerated their orientation toward renewable clean energy sources.

The use of renewable energy sources, solar and wind energy, has been increasing in recent years. While the amount of electricity generated from solar energy in the world was 65,631 GWh in 2011, this value increased to 192 GWh in 2019 [2]. However, since solar energy is an energy source with daily, monthly, or annual inconsistencies, it is called an unstable renewable energy source. Therefore, unstable renewable resources differ in the amount of production compared with traditional energy sources. This situation has led to an increase in the importance of artificial intelligence in determining the potential of a renewable energy source with an unstable structure such as solar energy in solar energy systems, unlike traditional energy sources, and in predicting future characteristics.

The most important prerequisite for having a reliable and economic power source is determining the appropriate system design for the establishment and operation of new-generation renewable energy systems. However, for this, the capacity of these systems, which produce electricity from variable renewable energy sources, must be optimized and each component must be appropriately sized. The right choice of sizing techniques for these power systems, which are in relationship with smart network structures, can not only meet the required

*Corresponding author

KADRIYE FILIZ BALBAL; Dokuz Eylül University, Faculty of Science, Computer Science Department, Türkiye; e-mail: kadriyefiliz.balbal@deu.edu.tr ; 0000-0002-7215-9964

ÖZGE ÇELİK; Balıkesir University, The Graduate School of Natural and Applied Sciences, Mathematics Department, Türkiye; e-mail: ozgecelik2387@gmail.com ; 0009-0003-9565-8242

SEBAHATTIN İKİKARDEŞ; Balıkesir University, Faculty of Science, Mathematics Department, Türkiye; e-mail: skardes@balikesir.edu.tr ; 0000-0003-2924-5397

energy production amount but also contribute positively to the amount of energy that can be transferred to the connected grid with maximum efficiency.

Various algorithms are used to arrive at accurate estimates of renewable energy production. These algorithms are generally divided into four categories [3]: physical methods [4], [5], statistical models [6], artificial intelligence techniques [7], [8], and hybrid methods [9].

Renewable energy systems produce electricity using only solar energy, only wind energy, or both solar and wind energy. Many studies have been conducted to estimate the amount of electricity that can be obtained from these energy sources that change hourly, daily, monthly, or annually. The contribution of solar energy, which is considered an unstable renewable energy, to electricity production can be calculated with the predictions obtained by these algorithms using the climate regions, seasons, or meteorological data of the countries. There are many studies in the literature on photovoltaic (PV) power estimation using Deep Learning (DL) and Machine Learning (ML) approaches. Chaouachi et. al. [8] built the Recurrent Neural Network (RNN) ensemble model to predict short-term solar energy production. Tokgöz and Ünal [10] used RNN, LSTM, and GRU to estimate Turkey's electricity load in their study. Nam et al. [11] used SARIMA, GRU, LSTM, and MLR forecasting models to guide Korea's sustainable energy policy. Gao et al. [12] introduced the multi-strategy CNN-LSTM model to find the hourly solar irradiance forecast. Bişkin and Çiftci [13] used LSTM and GRU networks for forecasting Türkiye's electrical energy consumption one hour ahead and three hours ahead. Ünlü [14] found that LSTM showed the best performance in prediction of Türkiye's daily electricity load one hour ahead.

The aim of this study is to forecast solar power production using deep learning algorithm. For this purpose, a real photovoltaic plant production dataset is used in this study. The main objectives of this study are summarized as follows:

- First, this study provides Long Short-Term Memory (LSTM) models that forecast one hour ahead of real PV power production and comparative analysis.
- This study seeks to understand the relationship between time series input and forecasting accuracy.
- This study was conducted to evaluate the performance of LSTM models with univariate time series.

This paper is presented with its main headings as follows; The data used, the models created, and the accuracy measurements used are given in the Methodology section; forecasting results are discussed in the Results and Discussion section using graphics.

2. Methodology

Türkiye is the developing country that has plenty of solar power potential to produce own electricity independently. In order to ensure the widespread use of solar energy systems in the country, accurate estimates of the energy to be obtained must be made. In line with these ideals, the data collected, the pre-processing of the data, the introduction of the models planned to make consistent predictions and how they were created, and finally the metrics used are explained in this section. Figure 1 summarizes the framework of this study.

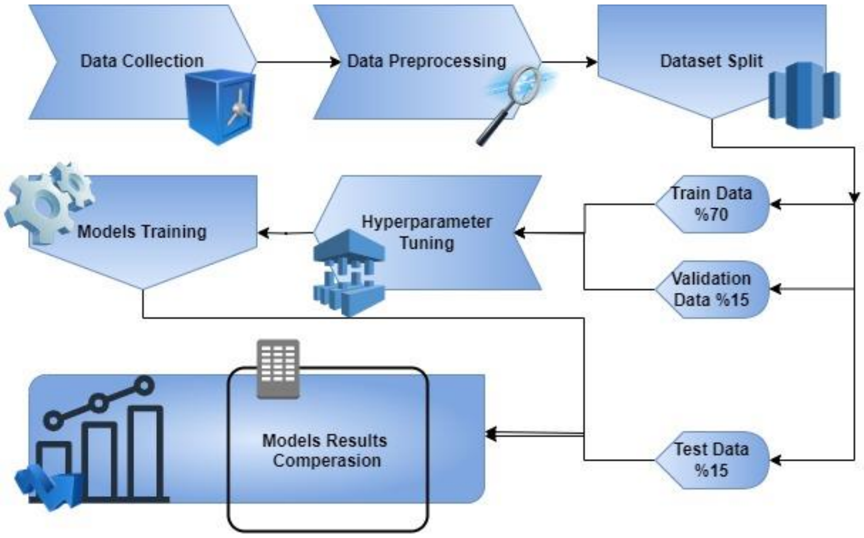


Figure 1: *Methodology of the study*

All calculations and visualizations were performed on the Colab (Collaborative) Platform [15] provided by Google. The GPU provided by the Colab Platform was also utilized to accelerate model training. For model training, TensorFlow v2.14.0 [16], Pandas v2.1.1 [17], and Keras v2.4.3 [18] and for visualizing Mathplotlib [19] libraries were used.

2.1 Data collection and preprocessing

Time series are data sets that can have a certain pattern, consisting of data with fixed time intervals. It enables the development of different forecasting approaches, depending on whether they are time-dependent or seasonal, to determine the underlying model in the data. If only one variable varies over time in the dataset, the time-series is named as "Univariate Time Series".

The selection and collection of input data are the primary factors that affect the consistency of the prediction. Researchers have used solar radiation amount, actual power plant production, and some meteorological data, especially in studies conducted for solar energy production estimates. In this study, inverter data of a roof-integrated solar energy system, which has been operating for two years, was used as input. Raw data are univariate time series data that are collected hourly production kW values that are not used before with 16464 lines. The factory whose data were used is located in Izmir, a city on the west coast of Türkiye. The city has a Mediterranean climate, with hot and dry summers and warm and rainy winters. With data visualization processes, the seasonality of the data can be clearly seen in Figure 2.

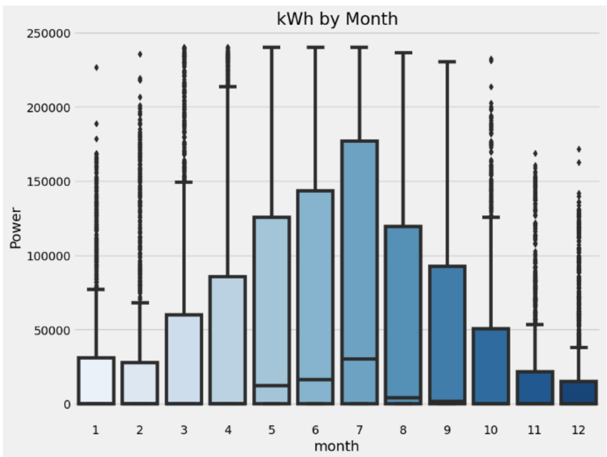


Figure 2: *Annual solar power production*

The seasonal difference in winter and summer production can be shown with one-week production amount graphs for February in Figure 3 and August in Figure 4.

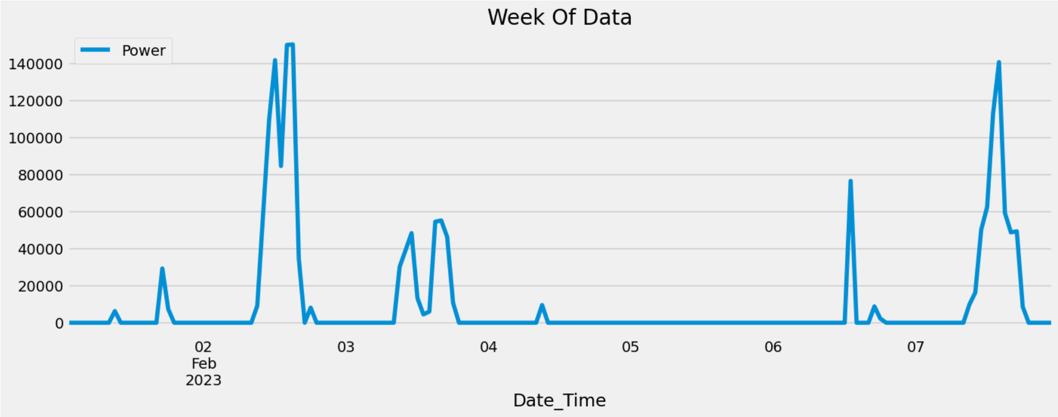


Figure 3: *Winter week of data*

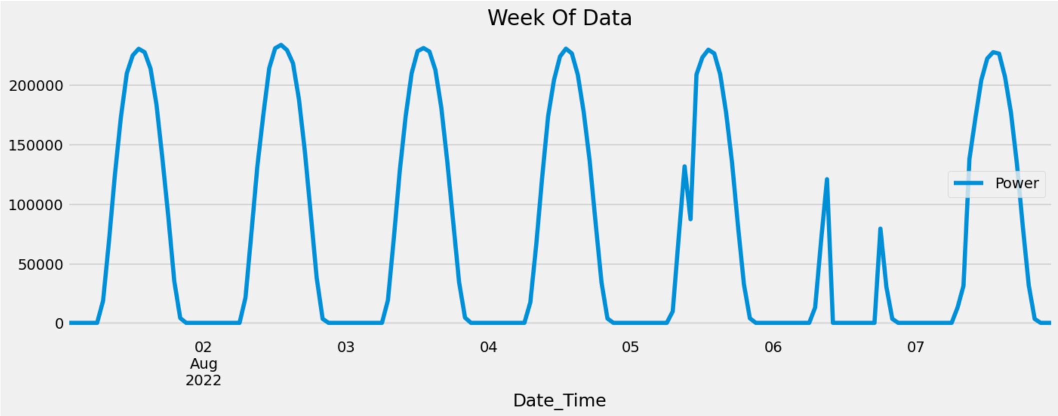


Figure 4: *Summer week of data*

For the DL method examined with the obtained time series dataset, it is necessary to configure a new dataset with transformed input and output variables. For this, after some Exploratory Data Analysis (EDA) were performed, sliding windows of size 7 were used and the dataset was transformed.

The newly transformed dataset was divided into training, validation, and test sets in the following proportions: 70%, 15%, and 15%.

2.2 Model development

Many machine learning and deep learning methods are used to forecast solar power production. For this study, Long Short-Term Memory (LSTM), which was proposed by Hochreiter & Schmidhuber [20] in 1997 and is known as a new generation Recurrent Neural Network (RNN) used in deep learning, was chosen because of its optimized architecture to easily capture patterns in time series data. Using a network such as LSTM provides benefits such as the ability to learn and remember over long sequences.

Table 1: *Model Structure*

	Hyperparameter	Value
MODELS	Hidden Layers	LSTM, Dense, Flatten
	Units	16, 32, 64, 128, 256
	Learning rates	0.01, 0.001, 0.0001, 0.00001
	Activation function	ReLu, Linear
	Optimizer	Adam
	Loss	Mean Squared Error
	Metric	Root Mean Squared Error
	Epochs	10, 50, 100

Table 1 demonstrates the construction of an LSTM network model for time series forecasting using Keras [18]. All models were constructed using different LSTM layers consisting of 16, 32, 64, 128, and 256 neurons. The activation function is the Rectified Linear Unit (ReLU) function used in the hidden layer, and the linear function is used in the output layer. The dropout probability was set to 0.2. The training epochs was chosen as 10, 50 and 100. To calculate the loss and weight in the compiler network, it is necessary to determine the loss function and optimization algorithm. For this purpose, in this study, Mean Squared Error (MSE) was selected as the loss function and Adaptive Moment Optimization (Adam) was selected as the optimization algorithm with learning rates as 0.01, 0.001, 0.0001, and 0.00001.

In this study, 30 different single and multilayer LSTM models were developed. Since the performances of 14 of the models created were higher than those of the others, only these fourteen models were compared in the Results and Discussion section.

3. Results and Discussion

The main purpose of this study is to investigate the consistency of LSTM models in univariate time series forecasting. For this purpose, different LSTM-based models have been developed using real PV power values obtained from a roof-integrated solar energy system for one hour ahead forecasting. Forecasting models use the sliding window method, which uses seven hours of data to learn and forecast electricity data for the next one hour. This sliding window technique has the advantage of increasing the time-dependent forecast performance of the developed models [11].

Models are trained using the 70% training set of the divided data after some EDA calculations and hyperparameter tuning transformations. After each training iteration on the 15% validation set, training errors and loss values are calculated using the MSE and RMSE metrics. The model with the lowest error in the validation set is selected for the final performance evaluation on the 15% test dataset. Table 2 lists the models' learning rate, epochs, loss, and RMSE values, respectively.

Table 2: *Statistical Test and Results of Models*

Model	Learning Rate	Epochs	Loss	RMSE
LSTM1	0.001	100	0.0323	0.1797
LSTM2	**0.001**	**100**	**0.0228**	**0.1510**
LSTM3	0.01	50	0.0303	0.1741
LSTM4	0.001	50	0.0371	0.1927
LSTM5	0.0001	50	0.0436	0.2088
LSTM6	0.001	50	0.0392	0.1981
LSTM7	0.00001	50	0.0525	0.2291
LSTM8	0.0001	10	0.0666	0.2580
LSTM9	0.001	50	0.0416	0.2039
LSTM10	**0.01**	**50**	**0.0250**	**0.1580**
LSTM11	0.01	50	0.0272	0.1650
LSTM12	**0.01**	**50**	**0.0245**	**0.1564**
LSTM13	**0.01**	**50**	**0.0216**	**0.1470**
LSTM14	0.01	50	0.0298	0.1726

All models use MSE as the loss function. Comparing the test data's loss and RMSE values in Figure 5, it is clearly noticeable how all loss and error values vary between models.

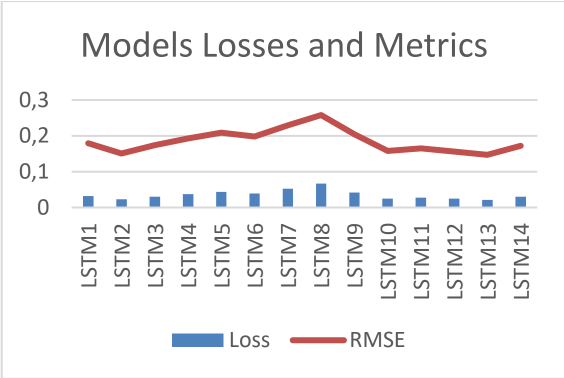
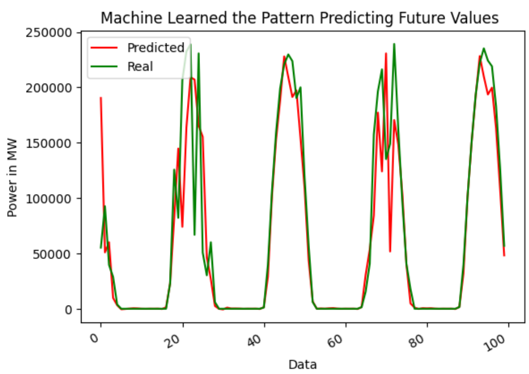


Figure 5: *Models Loss and Metrics changes*

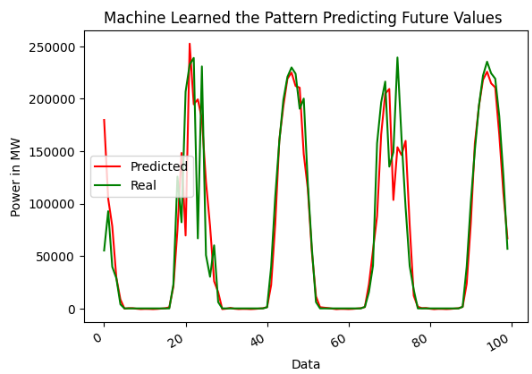
In Table 2, four models with higher performance are indicated in bold that are named LSTM2, LSTM10, LSTM12, and LSTM13. LSTM2 has hidden layers with 16, 32, 64, and 128 neurons; LSTM10 has hidden layers with two-64-neurons; LSTM12 has hidden layers with two-128-neurons; and LSTM13 has hidden layers with two-256-neurons; they were developed with two dense layers. These models were found to be the best four of fourteen proposed models.

Table 3 shows the PV power generation test set against the prediction results obtained under the conditions of using a two-year univariate time-series dataset and a single deep learning model. The results correspond to a 4-day period where actual and predicted PV power amounts perform scalability analysis.

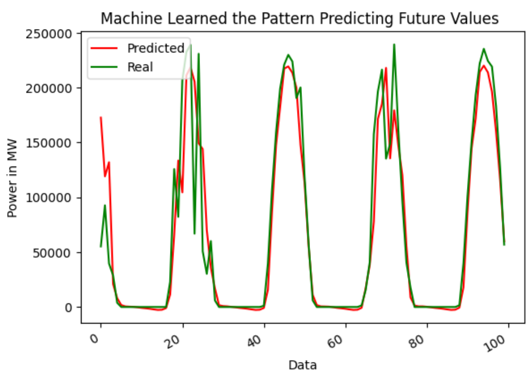
Table 3: *Visualizing the first 100 values of the test set by selected LSTM models*



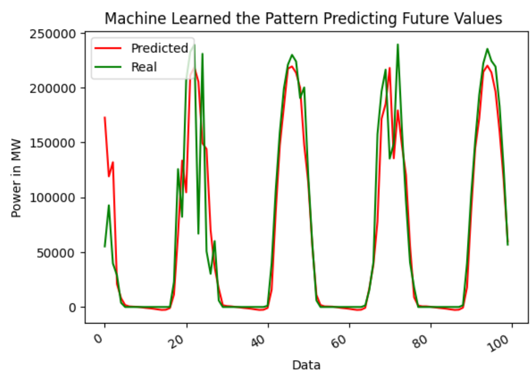
LSTM2



LSTM10



LSTM12



LSTM13

It is important to note that the choice of an LSTM model that will work using a univariate dataset will depend primarily on the characteristics of the time series data and the different requirements of the current forecasting problem [21]. Each type of univariate LSTM model has its own strengths and limitations. In particular, when forecasting horizons are considered, each model developed has different accuracy values for different forecasting horizons. The accuracy values of the model decrease as the forecasting horizons progress.

Considering the complexity of the preliminary calculations required for the widespread use of solar panels and the unstable nature of the renewable energy source to be used, research has shown many times that deep learning methods and hybrid models are the most appropriate method to eliminate these disadvantages. CEEMDAN and multi-strategy CNN-LSTM models RMSE performance improves 9.97% to 73.06% in [12], ConvLSTM1D is introduced by 0.0264 RMSE for 15 min ahead, 0.0273 RMSE for 30 min ahead and 0.0275 RMSE for 1h ahead in [22], averaged RMSE for Auto-LSTM is found 0.0713 in [23], plenty of GRU-LSTM models introduced in [24] with higher accuracies.

4. Conclusion

This article aims to develop deep learning models for forecasting on real PV output time series data. The studies argue that data-based forecasting increases the efficiency of renewable energies compared with other methods, and therefore it is emphasized that deep learning techniques should be investigated in solar energy forecasting [21]. In other words, the research underlines that each application is justified and that more efficient calculations can be made with significant improvements in the future. According to [21], a perfect estimate can save approximately 15%, while using an LSTM or a simple MLP can save approximately 12%. Therefore, the LSTM network, which is well-known for handling long sequence data effectively, is chosen to invest in accuracy while using univariate time series data. Although, it is unclear which structures could lead to the best forecasting performance. Several variations have been made to clarify the model structures. Different hidden layers, learning rates, epochs, and window sizes are used to build the model. However, using univariate time series data as a unique input has some limitations. To overcome such negative effects, using other deep learning methods or adding some independent varieties as inputs would be efficient.

For future works, studies using other deep learning methods such as GRU, CNN, and a built hybrid of these methods can be used to develop efficient power strategies to help PV power plant developers and countries to lead in dynamic energy markets.

Declaration of Interest

The authors declare that there are no conflicts of interest.

Author Contributions

Kadriye Filiz Balbal: Conceptualization, Methodology, Formal Analysis, Writing - Review & Editing, Supervision.
Özge Çelik: Conceptualization, Methodology, Data Generation, Writing - Review & Editing, Visualization.
Sebahattin İkikardeş: Conceptualization, Methodology, Validation, Writing - Review & Editing, Supervision.
All authors reviewed the manuscript.

References

[1] Z. Şen, "Solar energy in progress and future research trends," *Progress in Energy and Combustion Science 30,* p. 367–416, 2004.

[2] IRENA, "Renewable Energy Capacity Statistics 2023," International Renewable Energy Agency(IRENA), 2023.

[3] H. Wang, Z. Lei, X. Zhang, B. Zhou and J. Peng, "A review of deep learning for renewable energy forecasting," *Energy Conversion and Management,* no. 198, p. 111799, 2019.

[4] H. Bulut and O. Büyükalaca, "Simple model for the generation of daily global solar-radiation data in Turkey," *Applied Energy 84,* p. 477–491, 2007.

[5] M. Çınaroğlu and M. Nalbantoğlu, "Şebekeye Bağlı Üç Adet Fotovoltaik Enerji Santralinin PVsyst Programı ile Analizi; Kilis Örneği," *El-Cezerî Fen ve Mühendislik Dergisi,* vol. 8, no. 2, pp. 675-687, 2021.

[6] İ. T. Toğrul and H. Toğrul, "Global solar radiation over Turkey: comparison of predicted and measured data," *Renewable Energy ,* no. 25, p. 55–67, 2002.

[7] F. O. Hocaoğlu, Ö. N. Gerek and M. Kurban, "Hourly solar radiation forecasting using optimal coefficient 2-D linear filters and feed-forward neural networks," *Solar Energy,* vol. 82, pp. 714-726, 2008.

[8] A. Chaouachi, R. M. Kamel and K. Nagasaka, "Neural Network Ensemble-Based Solar Power Generation Short-Term Forecasting," *Journal of Advanced Computational Intelligence and Intelligent Informatics,* pp. 69-75, 2010.

[9] H. Demolli, *Makine Öğrenmesi Teknikleri Kullanılarak Yenilenebilir Enerji Güç Tahmini ve Optimum Hibrit güç sistemi Tasarımı(Doktora tezi),* Yükseköğretim Kurulu Ulusal Tez Merkezi veri tabanından erişildi (Tez No. 623617), 2020.

[10] A. Tokgöz and G. Ünal, "Türkiye Elektrik Tüketimi Tahmini ˙Için RNN Tabanlı Zaman Serisi Yaklaşımı," IEEE, 2018.

[11] K. Nam, S. Hwangbo and C. Yoo, "A deep learning-based forecasting model for renewable energy scenarios to guide sustainable energy policy: A case study of Korea," *Renewable and Sustainable Energy Reviews,* vol. 109725, no. 122, 2020.

[12] B. Gao, . X. Huang, J. Shi, . Y. Tai and J. Zhang, "Hourly Forecasting of Solar Irradiance based on CEEMDAN and Multi-strategy CNN-LSTM neural networks," *Renewable Energy, pp.* 1665-1683, 2020.

[13] O. T. Bişkin and A. Çifci, "Forecasting of Turkey's Electrical Energy Consumption using LSTM and GRU Networks," *BSEU Journal of Science,* vol. 8, no. 2, pp. 656-667, 2021.

[14] K. D. Ünlü, "A Data-Driven Model to Forecast Multi-Step Ahead Time Series of Turkish Daily Electricity Load," *Electronics* , vol. 11, no. 1524, 2022.

[15] "Colaboratory," Google, [Online]. Available: https://colab.research.google.com/.

[16] "TensorFlow v2.14.0," [Online]. Available: https://www.tensorflow.org/.

[17] "Pandas 2.1.1," [Online]. Available: https://pandas.pydata.org/.

[18] "Keras," [Online]. Available: https://keras.io/.

[19] "Mathplotlib," [Online]. Available: https://matplotlib.org/.

[20] S. Hochreiter and J. Schmidhuber, "Long short-term memory," *Neural Comput. 9 (8)* , p. 1735–1780, 1997.

[21] M. Ajith and . M. Martínez-Ramón, "Deep learning algorithms for very short term solar irradiance forecasting: A survey," *Renewable and Sustainable Energy Reviews,* vol. 182, p. 113362, 2023.

[22] S. Cantillo-Luna, R. Moreno-Chuquen, D. Celeita and G. Anders, "Deep and Machine Learning Models to Forecast Photovoltaic Power Generation," *Energies,* vol. 16, no. 4097, 2023.

[23] A. Gensler, . J. Henze, . B. Sick and N. Raabe, "Deep Learning for Solar Power Forecasting – An Approach Using Autoencoder and LSTM Neural Networks," in *IEEE International Conference on Systems, Man, and Cybernetics • SMC 2016* , Budapest, Hungary, 2016.

[24] M. Neshat, M. M. Nezhad, S. Mirjalili, D. A. Garcia, E. Dahlquist and A. H. Gandomi, "Short-term solar radiation forecasting using hybrid deep residual learning and gated LSTM recurrent network with differential covariance matrix adaptation evolution strategy," *Energy,* vol. 278, no. 127701, 2023.

Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida

Vol. 3, No. 2, pp. 124-137, 2023
Research Article
Received: 05/11/2023 Accepted: 14/12/2023

Navigating in Complex Indoor Environments: A Comparative Study

Alper Hüseyin DOĞAN[1,*], Tarık Veli MUMCU[2]

Abstract

Autonomous robots face significant challenges in path planning and continuous motion planning in indoors due to their ability to navigate within these complex spaces. These complex problems arise in a wide range of application environments, including indoor areas such as corridors, rooms, and similar spaces. This study presents a comparative simulation analysis of path-finding techniques employed for indoor autonomous robot navigation. Conventional path-finding techniques, including Voronoi diagram and potential field, have been selected to illustrate these established methods. However, they were found to be unreliable and insufficient in coping with the intricacies of real-world situations characterised by non-linearity. Various artificial intelligence techniques were evaluated to showcase the superiority of artificial intelligence over conventional methods. The methods included genetics algorithm and neural networks. The use of these artificial intelligence methods proved their ability to handle complex navigation tasks with greater ease and strength, highlighting their vital contribution in overcoming obstacles. Additionally, we utilize the well-known A* algorithm as a benchmark to evaluate and compare the performance of filtering techniques, particularly Kalman and particle filters in the context of path tracking under diverse conditions, including scenarios with gaussian and exponential noise. Through these analyses, we shed light on the performance of Kalman and particle filters when applied in conjunction with the A* algorithm for path tracking, offering valuable insights into their effectiveness in real-world, noisy environments.

Keywords: Adaptive Path Planning; autonomous robot navigation; path tracking.

1. Introduction

Today, autonomous robots are capable of executing various tasks with exceptional accuracy and speed while maintaining safety. An entirely autonomous robot has the capacity to perceive and analyse its surroundings, identify objects, and execute an action or manipulation within that setting. Autonomous robots have shown great potential and efficiency, particularly when compared to automated guided vehicles, due to their capability to navigate without reliance on guidance devices or centralized control [1]. Obstacle avoidance requires directing a robot's movement to navigate predictable or unpredictable obstacles. The application of a diverse range of algorithms including soft computing, image processing, control systems, statistical techniques, and conventional techniques allow for effective autonomous navigation, even in dynamic environments [2]. The robot's current location and sensor data affect its motion. When given a map and an intended goal point, path planning is necessary to determine a path from the starting position to the goal position [3]. However, there might be several potential paths available, considering the unrestricted area in which the robot can operate. Path planning algorithms aim to obtain the optimal path or an acceptable approximation to it. The optimal path generally is defined as the one with the lowest computational cost [4].

Conventional methods include Voronoi diagram, potential field and the like. Voronoi diagram propose a mathematical approach to define obstacles and optimize robot path [5]. Potential field use potential field calculations to determine robot paths and avoid obstacles [6]. Soft computing refers to the use of inexact calculations to solve computationally complex tasks. This approach allows for solutions to problems that may be too difficult or time-consuming to solve using current hardware. Soft computing is different from hard computing as it tolerates imprecision, partial truth, uncertainty, and approximation. The human mind serves as a role model for soft computing [7]. Much research has been conducted on applying soft computing techniques such as neural networks, genetics algorithm, and more to path planning and navigation problems. Genetics algorithm use natural selection principles to solve optimization problems and improve paths [8]. Artificial neural networks (ANNs) enhance the learning capabilities of robots and help them better understand their surroundings [9]. The A* algorithm has proven to be a reliable approach for solving pathfinding problems [10].

This paper discusses navigation techniques in indoors, path planning methods. The techniques analysed are divided into two categories: conventional methods and artificial intelligence (AI) methods. In this study, we also examine path tracking algorithms to comprehensively analyse navigation specifically the Kalman filter and particle filters. The Kalman filter has proven successful in tracking moving objects in real-time scenarios [11]. Particle filter is a robotics technique that utilises the Monte Carlo method. Its principal goal is to update the robot's position distribution by incorporating new observations [12].

The remainder of the paper is organized as follows: Section 2 addresses the complications of navigating in ever-changing surroundings that autonomous robots face and highlights the significance of simultaneous localization and mapping (SLAM). Section 3 an examination of a range of conventional techniques for path planning and navigation, encompassing Voronoi diagram, and potential field. In Section 4, analysis of AI techniques, including genetics algorithm and neural networks. Section 5 showcasing filtering techniques for path tracking, particularly Kalman and particle filters. Section 6 discusses the advantages and disadvantages of AI techniques in comparison to conventional methods and reports performance metrics for Voronoi diagram, potential field, A* algorithm, genetics algorithm and neural networks. Finally, the paper is summarized and concluded by Section 6.

2. Explanation of Autonomous Robot Navigation Problem

2.1. Mobile robots

Mobile robots are capable of locomotion and are not limited to a single physical location. They can be designed to operate in vast workspaces and explore uncharted territories, enabling them to successfully navigate their environment, whether it is in the air, on land or underwater. Additionally, the term “mobile robot” refers to robots that have the ability to move, as opposed to stationary robots. These robots can be remotely controlled via guidance systems to carry out specific tasks. Alternatively, they can operate autonomously. Mobile robots have the capability of navigating unfamiliar environments without requiring human interaction or guidance devices. The key components of a mobile robot typically include a controller, which is typically a microprocessor or personal computer, control software, sensors tailored to the specific requirements of the robot, and actuators that allow the robot to move within its environment. Mobile robots can be manufactured in any size, depending on their intended tasks and the location where they will operate [13-15].

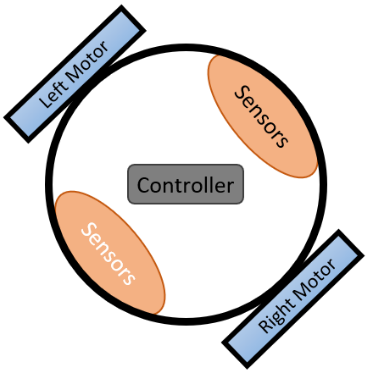


Figure 1. *A simplified model of mobile robot.*

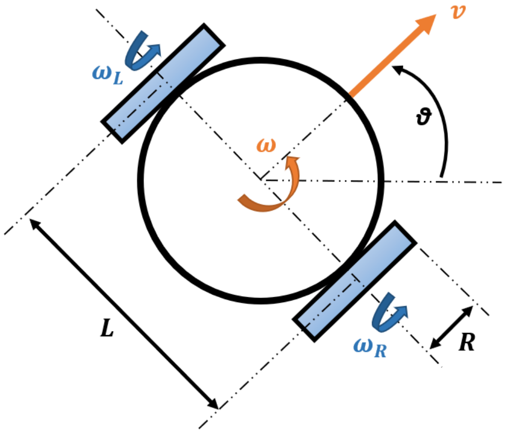


Figure 2. *DD visualization of the parameters.*

Figure 1 shows a simplified model of a mobile robot with mounted motors on its chassis, facilitating its mobility. The choice of the motors depends on the planned tasks for the robot. The robot is capable of moving in forward or reverse directions, altering its movement by adjusting the speed differential of its wheels. This

*Corresponding author

ALPER HÜSEYİN DOĞAN; Istanbul University-Cerrahpasa, Institute of Graduate Studies, Electrical and Electronics Engineering Department, Türkiye; e-mail: alperhuseyin.dogan@ogr.iuc.edu.tr; 0000-0002-1782-0465

TARIK VELİ MUMCU; Istanbul University-Cerrahpasa, Faculty of Engineering and Architecture, Computer Engineering Department, Türkiye; e-mail: tarik.mumcu@iuc.edu.tr; 0000-0002-8995-9300

approach is known as the differential drive (DD) and can be implemented using two separately wheeled robots. DD is a popular and easily controlled approach. Figure 2 visualises the parameters of DD approach.

In the DD method, the robot is capable of movement along both the x and y axes, as well as changing direction on this coordinate plane. Consequently, the robot possesses three degrees of freedom (DoF). The matrix presents the DoF in Eq. (1).

$$q = \begin{bmatrix} x \\ y \\ \Theta \end{bmatrix} \tag{1}$$

Θ, rotation of the robot about z-axis. (x, y), position of the robot on the x-y coordinate plane. For the robot to change direction, it is essential that both wheels turn at different speeds. Additionally, the radius of the wheels plays a significant role. Eqs. (2) and (3) demonstrate the correlation between the angular velocity of the wheels and their corresponding linear velocity.

$$v \cdot R = r \cdot \omega \cdot R \tag{2}$$
$$v \cdot L = r \cdot \omega \cdot L \tag{3}$$

r, wheel radius in meters. ω, left and right wheel speeds, in radians per second. Eqs. (4) and (5) illustrate the results, presenting the speed v in meters per second and the angular velocity ω in radians per second.

$$v(t) = \frac{v \cdot R(t) + v \cdot L(t)}{2} \tag{4}$$

$$\omega(t) = \frac{v \cdot R(t) - v \cdot L(t)}{r \cdot c} \tag{5}$$

rc, wheelbase in meters. All of these equations provide us with the mathematical depiction of this system Eq. (6).

$$\begin{bmatrix} \dot{x}(t) \\ \dot{y}(t) \\ \Theta(t) \end{bmatrix} = \begin{bmatrix} cos(\Theta(t)) \cdot v(t) \\ sin(\Theta(t)) \cdot v(t) \\ \omega(t) \end{bmatrix} \tag{6}$$

Eq. (7) depicts a kinematic model of the system.

$$\begin{bmatrix} \dot{x}(t) \\ \dot{y}(t) \\ \Theta(t) \end{bmatrix} = \dot{q} = \begin{bmatrix} cos(\Theta) & 0 \\ sin(\Theta) & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v(t) \\ \omega(t) \end{bmatrix} = j(\Theta) \cdot v \tag{7}$$

$\dot{q}$, derivation of the state vector is the outcome of alterations in both x-axis and y-axis speed and angular velocity [16-18].

2.2. Navigation

One of the primary areas of research in the field of robotics concerns applications of autonomous robot navigation. The intelligent robotic navigation system refers to the robot's ability to locate a path while avoiding obstacles and reach the target point from a predetermined starting point by means of sensors, control and navigation software, all without any human intervention. The robot must update its position constantly during its journey, monitor its surroundings, and develop strategies to achieve its objectives, whilst simultaneously executing these tasks. Moreover, these determinations need to be made in real-time [19].

Typically, an odometer is used to calculate position in solving an autonomous robot navigation issue. However, this creates the need for a map. Localisation through odometry information obtained from wheel velocities involves determining the position, direction and angle of the robot using an encoder with the coordinate plane as reference. The rotational speed of the wheels is used to calculate the direction of the robot, which is essential for localisation. However, relying solely on the robot's own position calculations does not suffice for navigation purposes. The robot must be aware of its starting point, current location, and destination. A map is necessary for conveying this information, and the starting point should be indicated on the map for the robot's guidance.

2.3. Simultaneous localisation and mapping

The autonomous robot must safely perform various tasks with a high degree of autonomy. The crucial aspect is that the robot follows the desired approach. However, for the robot to achieve this objective, answering two core questions is paramount: "Where am I?" and "What does the outside world look like?" The first question is connected to the issue of localisation, which demands that the robot knows its position to attain its purpose [20].

On the other hand, the second query concerns environmental data gathering. The robot seeks to identify the appearance of the external environment. This task is known as mapping in scientific literature. In this process, the robot endeavours to create a map or layout of the surrounding external world by relying on its sensory data [21].

In addition to the previously stated information [16], the localisation and mapping problem involves determining the location of a robot and acquiring environmental information. The SLAM problem was first introduced in a paper [22] and has gained popularity among researchers and mobile robotics communities over the past twenty-five years [23].

Since its inception, SLAM has been extensively applied in various field. In the past, the extended Kalman filter (EKF) was widely employed to address this issue [24]. Subsequently, particle filter solutions were introduced [25]. Currently, Kalman filters continue to be a popular method for solving the SLAM problem. However, visual SLAM techniques are gaining widespread recognition in the field [26].

3. Conventional Techniques Used in Navigation Applications

3.1. Voronoi diagram

Numerous researchers have employed the Voronoi diagram as an effective tool in their previous studies. The Voronoi diagram is defined as the division of a plane with n points into distinct areas, wherein each area contains only one generating point, and all of the points within a given area are closer to its generating point than any other. A sensor-based system capable of determining the safest path for robots within their operating environment have been introduced [27]. An alternative approach for safe navigation in the presence of obstacles is founded the generalised Voronoi diagram (GVD) [28]. The drawback of this technique is the computation of the entire GVD, which is very expensive and is often used for offline applications and global path planning [29]. Alternatively, it is feasible to estimate the GVD through specific algorithms applied to the Voronoi tessellation of the sensor measurements [30]. Another option is to discretize the known map into cells and use computer vision techniques [31] based on distance transforms [32]. However, these methods necessitate a balance between accuracy and computational load, particularly in cluttered and limited environments.

3.2. Potential field

Potential field methods are commonly utilised within the field of mobile robotics for the purposes of both path planning and motion control. Potential field method introduced, which incorporates a repulsive potential field around the obstacles and forbidden zones to enable collision avoidance, while employing an attractive potential field around the end goal to guide the robot towards its target. Path planning can be categorized into two subgroups: universal planning, where the robot has full knowledge of its environment via a pre-existing map before initiating movement, and local planning, where the robot builds a map of its surroundings as it moves towards its target. The potential field method can be applied to both universal and local planning techniques [33].

The potential field method provides effective and straightforward solutions to navigation issues. Nevertheless, a significant drawback is that robots may also encounter local minima because an obstacle usually generates a repulsive field locally, which can negate desirable target behaviours. Currently, extensive research is underway to address this challenge actively. Demonstrated the efficacy of simulated annealing in overcoming this problem, a previous study showed promising results [28]. Full or partial details of obstacles can be used to change the potential field surrounding them, in order to avoid local minima [34-36], or by modelling obstacles geometrically through envelopes [37]. Another enhancement to avoid local minima involves including multiple attractive points in the target instead of just one point [38] or virtual obstacles can be added to move away from local minima [39]. The artificial potential field can be improved by introducing a potential density alongside obstacles to aid in path planning using a quasi-geodesic curve [40]. Strategies for navigating local minima can also incorporate behavioural tactics, including wall tracking [41].

4. Artificial Intelligence Techniques Used in the Navigation Applications

4.1. Genetics algorithm

The genetic algorithm is a widely used search technique for optimising results. Its inspiration comes from the study of evolutionary biology encountered in nature. The algorithm searches for the best possible solution through natural selection in a complex multidimensional space. In the genetic algorithm, the population generated at first is random and the possible solution to the problem is referred to as a population. The fitness value of each solution is determined by the objective function of the problem. After selecting more suitable solutions to the problem, genetic operations such as mutation and crossover are applied to produce a new population comprised of better candidates. This process is repeated until the maximum number of generations have been generated or until an acceptable fitness value is obtained. This method is utilised to generate and analyse optimised outcomes in various applications.

Genetic algorithm has been proposed for motion planning in robots, specifically targeting a single point instead of the whole workspace [42]. A motion planning procedure has also been proposed for load-carrying robots, utilizing GA to find optimal solutions and fuzzy logic for plan implementation [43]. An evolutionary algorithm has been proposed to address the issue of autonomous robot navigation in an environment where there are several unknown polygonal obstacles [44]. Genetics algorithm (GA) are potent search techniques, grounded in natural selection and featuring crossover, mutation, and favourable gene selection processes. They have the potential to cover large spaces unlike standard search and optimisation methods.

The term “chromosomes” is used to describe potential solutions to a problem. The population comprises these chromosomes collectively. Each population undergoes fitness function calculation one at a time. The fitness function enables the creation of a selection process, challenging the chromosomes to survive until the end of this process. Usually, the chromosomes that suit best have higher chances of selection. Finally, genetic operations such as crossover and mutation are applied to these new solutions. After applying genetic operators to chromosomes, a new population is generated [45]. The success of the new population is then recalculated, taking into account the suitability of each new chromosome. Finally, the best chromosome is identified, resulting in an optimal or near-optimal solution. GA is currently being utilised to solve path planning problems, with examples of such studies found in the literature.

Path planning task using genetics algorithm has been successfully executed in an unfamiliar environment [46]. The simulation results indicate the efficacy of genetics algorithm in resolving navigation issues in dynamic settings.

The primary limitation of genetics algorithm is their inability to determine when an exact solution has been reached, as solutions of near-optimum quality are accepted instead. Consequently, the solution obtained is not necessarily optimal. Furthermore, executing the algorithm again on the same problem with identical input can produce substantially different outcomes. As a result, it is challenging to discern the best solution for these reasons [47].

4.2. Artificial neural networks

ANNs are able to learn through rapid data processing [48]. ANNs have greatly contributed to the development of autonomous robots in the field of robotics, particularly in kinematic and dynamic modelling and path planning. An autonomous robot is capable of moving around in its operating environment. Through the use of ANNs, robots can acquire decision-making abilities that were previously exclusive to humans. However, the robot requires physical capability to execute its decisions. In accordance with a study [49], a path planning system founded on dynamic ANNs has been proposed by a researcher. This system has the capacity to navigate a robot on a level area encircled by stationary or dynamic obstacles. The ANN employed for path planning has been taught using an extended back propagation approach, whilst an artificial potential field technique has been utilised to ensure the avoidance of collisions. Other ANNs have been employed to improve the avoidance of stationary obstacles. This approach was suggested when mobile robot navigation systems were first comprehended [50, 51]. A multi-layer feedforward ANN architecture was developed by researchers, who transformed the problem into a classification issue to simplify the output. Training samples for the ANN controller were accumulated using reinforcement Q-learning technique. The ANN controller runs in the background and trains itself once more by using its backup signal during the interaction with the environment. The result of this study indicates that a hybridised technique, converging these two methods, offers a superior solution to this type of problem than applying either technique in isolation.

ANNs comprise highly concurrent building blocks that exhibit clear design principles. This enables ANNs to be utilised in complex systems. Whilst ANN architectures cannot rival conventional methods for performing error-free numerical operations, they offer superior solutions to problems involving ambiguity, prediction, or classification.

ANNs have numerous advantages. One benefit is the ability to update weight coefficients between agents to perform specific tasks. For example, related weight coefficients are updated until the neural network model performs in the desired manner. Consequently, learning is completed by this neural network model. ANNs are commonly used in efficient learning problems and pattern recognition applications.

4.2.1. A Algorithm*

The A* algorithm is a particularly effective approach to solving the pathfinding problem. This algorithm aims to find the shortest path from a starting point to a destination. The A* algorithm combines two key components: actual cost and estimated cost. The actual cost represents the total cost of travelling from the starting point to a node. The estimated cost, on the other hand, represents the estimated cost of getting from that particular node to the destination node. These two costs allow the A* algorithm to select the most appropriate node at each step [52].

Over time, significant improvements have been made to the algorithm and numerous studies have been carried out. Iterative deepening versions have been developed that make the A* algorithm run faster and avoid excessive memory usage [53]. Epsilon optimisation refers to an improvement that allows the A* algorithm to find an optimal solution within a specified tolerance range in addition to the shortest path [54]. Research focusing on the development of heuristics that improve the performance of the A* algorithm is crucial [55]. A parallel version of the A* algorithm has been defined to run quickly on multi-processor systems [56]. The hybrid A* algorithm is used to solve larger and more complex problems by combining the A* algorithm with other search methods [57]. In this study, the A* algorithm is preferred to make the comparisons more understandable, as it's a well-known and fundamental path planning algorithm.

5. Filtering Techniques for Path Tracking

5.2. Kalman filter

In navigation applications, one of the most popular methods is the Kalman filter [58]. Due to its capability to extract advantageous information from disruptive data and its minimal computational and memory demands, it is utilised within numerous application domains like spacecraft navigation, robotics motion planning, wireless sensor networks, and signal processing [59]. Filters can be thought of as designs that reduce input data and parse it into desired output data in navigation applications. The Kalman filter assumes that the system is linear. Therefore, all system dynamics and measurements can be expressed as continuous-time linear differential equations and discrete-time difference equations. The uncertainty in state values and measurement updates follows a zero-mean Gaussian distribution. When the system is perfectly linear and all noise follows a zero-mean Gaussian distribution, the most efficient state observer is the Kalman filter [60]. In Eq. (8), the discrete time difference equation is presented:

$$x_{k+1} = Fx_k + Bu_k + w_k \tag{8}$$

x represents the state vector of estimated values. The matrix F determines changes in future states based on the current state, while matrix B determines changes based on input data. W is a random variable with a Gaussian distribution of zero mean ($w_k \sim N(0, Q_k)$), and U represents the input value. When this equation is time dependent rather than time independent, it can be expressed as follows:

$$x_k = F_k \cdot x_{k-1} + B_k \cdot u_k + w_k \tag{9}$$

As the matrices F and B take different values at varying time intervals, they are incorporated in the Eq. (9) with index k. These shifts can either depend on time or may be a result of external data. The F_k matrix is known as Φ in literature [61, 62]. The equation for updating the measurement can only be expressed in discrete time and is as follows:

$$z_k = H_k \cdot x_k + v_k \tag{10}$$

The measured values z_k correspond to the state values x_k through the matrix H_k. A random variable, vector v_k, follows a white Gaussian distribution ($v_k \sim N(0, R_k)$) and influences the measured value.

The Kalman filter uses the above equations to estimate the mean of state x_k and calculate the covariance matrix P_k for this estimation. The initial estimate for the mean is x_0, while P_0 represents the initial covariance matrix. The filter then generates new states by applying the dynamic equations.

5.3. Particle filters

Particle filters are estimation techniques that deploy the Sequential Monte Carlo (SMC) method in non-linear and non-Gaussian Markovian state spaces. They are utilised in cases where the Kalman filter would be ineffective because of non-Gaussian or non-linear parameters. The issue involves utilizing known state probabilities and predicting future states $p(x_t|x_{t-1})$ based on current state values. Additionally, measurement likelihood $p(y_t|x_t)$ is obtained through measurement prediction equations [63]. Based on these functions, the equation for state estimation can be expressed as follows [64]:

$$p(x_t|y_{1:t-1}) = \int p(x_t|x_{t-1})p(x_{t-1}|y_{1:t-1})dx_{t-1} \tag{11}$$

Using the previous measurements $(y_{1:t-1})$ Eq. (11) calculates the probability of the state at the future time interval x_t. The update equation is then applied to include the present measurement values y_t into the problem [65].

$$p(x_t|y_{1:t}) = \frac{p(y_t|x_t)p(x_t|y_{1:t-1})}{\int p(y_t|x_t)p(x_t|y_{1:t-1})dx_t} \tag{12}$$

Eq. (12) updates the probability from the previous time interval to the current time interval with the latest measurement, y_t.

Particle filters are advantageous in determining nonlinear, non-Gaussian distributed systems. One drawback of particle filters is that they necessitate a large quantity of particles when used to portray multidimensional state spaces.

6. Simulation Studies & Results

In this paper we have carried out a comparative analysis of path planning algorithms, dividing them into two main categories: conventional and AI techniques. The algorithms under consideration encompass a diverse set, including potential field, Voronoi diagram, A* algorithm, genetic algorithm, and neural networks. The motivation behind this study is to evaluate the performance of these algorithms in a discrete environment, similar to a grid world. This assumption simplifies the representation of the environment and the robot's movements. The robot under consideration is holonomic, meaning that it is free to move in any direction without constraints. This assumption allows us to explore a wide range of path planning algorithms without worrying about non-holonomic constraints. The initial position and the target point are known in advance, and the robot is equipped with complete knowledge of the map of the environment.

The map shown in the Figure 3 simulates an indoor environment with a structured layout designed to challenge path planning algorithms. The dimensions of the map are 120 metres in width and 60 metres in height, with a grid size of 1 metre per cell. A notable feature of this map is the inclusion of seven different rooms, each contributing to the complexity of the path planning task. These seven rooms are arranged in a grid-like pattern running from the top left to the bottom right of the map. Room 1, located in the top left corner, serves as the robot's starting position, culminating in Room 7, located in the bottom right corner, which serves as the target point. Each room is connected by corridors and separated by walls or obstacles, presenting a complex navigation challenge. With a robot radius of 1 metre, precision is required to traverse the map effectively while avoiding obstacles and finding an optimal path, making this map a realistic and complex testbed for evaluating path planning algorithms in indoor environments.

The performance of path planning algorithms is assessed according to factors such as path length and execution time, providing useful insights into their effectiveness and efficiency in navigating these complex environments. We will now present a detailed analysis of the algorithm's functionality in an intricate indoor setting. Our analysis employs both quantitative data and visual representations to provide a comprehensive overview of the algorithm's performance.

Figure 3. *Map representation of an indoor environment*

Table 1 provides visual representation which demonstrate the calculated paths from the starting to the goal destination for each of the algorithms of the paths produced by diverse path planning algorithms in the specified environment outlined in Figure 3.

The potential field algorithm encountered difficulties and didn't reach the goal point. It became imprisoned within the primary area located at the environment's upper left corner. This outcome is consistent with the method's susceptibility to local minima. The Voronoi diagram method achieved the objective but took longer and produced an inefficient route. The estimated path exceeds 170 metres in length. This behaviour is in line with the Voronoi approach's tendency to favour open space and may require post-processing for optimal path refinement. The A* algorithm exhibited its well-documented strength by generating the second shortest path. Specifically, it produced a path that was approximately 1.5 metres shorter than the path produced by the genetics algorithm approach. This finding aligns with A*'s ability to optimally balance exploration and exploitation while employing heuristic information, indicating the high degree of path optimisation achieved by the A* when navigating the intricate indoor environment. The approach employing genetic algorithm differentiated itself through accomplishing the third shortest path and finishing the task in under ten seconds - notably ai methods are quicker than conventional techniques. This confluence of a reduced path length and rapid computation confirms Genetics algorithm as an admirable selection in this setting. The Long Short-Term Memory (LSTM) model emerges as the dominant path planning algorithm among the assessed alternatives, also outpacing both A* and genetics algorithms. This neural network-based technique demonstrated outstanding results, excelling notably in its adaptability and efficiency in navigating complex indoor environments. This adaptability is particularly valuable where traditional algorithms may struggle due to their fixed rules and heuristics. The LSTM model, using its sequence-based data processing and memory retention, outperformed its counterparts in producing the shortest path and completing the task in a remarkably short amount of time, thereby ranking as the optimal choice for path planning in this specific setting. Notably, the model achieved a mean absolute error (MAE) of *0.0584* and a loss value of *0.0109* during training. Further exploration and refinement of the LSTM-based approach could provide even more promising results in intricate indoor environments.

Table 1. *Simulation results of the algorithms*

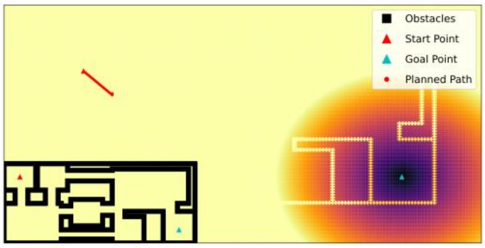
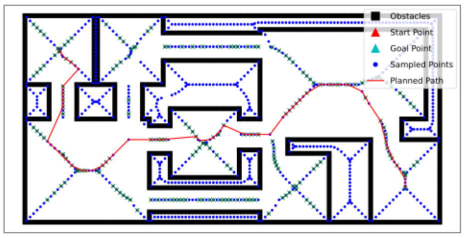
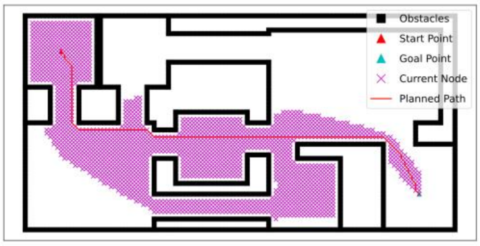
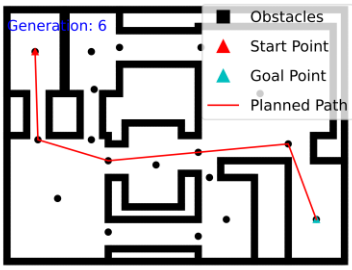
<table>
<tr><th>Algorithm</th><th>Planned Paths</th></tr>
<tr><td>Potential Field</td><td></td></tr>
<tr><td>Voronoi Diagram</td><td></td></tr>
<tr><td>A* Algorithm</td><td></td></tr>
<tr><td>Genetics Algorithm</td><td></td></tr>
<tr><td>Artificial Neural Networks</td><td></td></tr>
</table>

Table 2 displays the path lengths calculated by all algorithms on the map and their respective computation times in comparison.

Table 2. *Path length (m) and computation time (sec) comparisons of algorithms.*

	Potential Field	Voronoi Diagram	A* Algorithm	Genetic Algorithm	LSTM
Path Length	Not Found	170.10	130.04	131.24	**128.33**
Computation Time	Not Found	28.58	2.74	8.54	**0.17**

In this study we also employed a simulation analysis aimed at evaluating the effectiveness of filtering techniques under different noise conditions. Two distinct scenarios were examined: one incorporating Gaussian noise and the other integrating exponential noise. These analyses serve as a valuable preliminary investigation into the efficacy of Kalman and particle filters. In both experiments, a robot navigated through a known environment from a specified starting point to a goal point covering a total length of approximately 130.04 metres using an A* path planning algorithm while facing the challenge of noisy sensor measurements and motion commands. The results of these experiments highlight critical insights into the filtering system's behaviour.

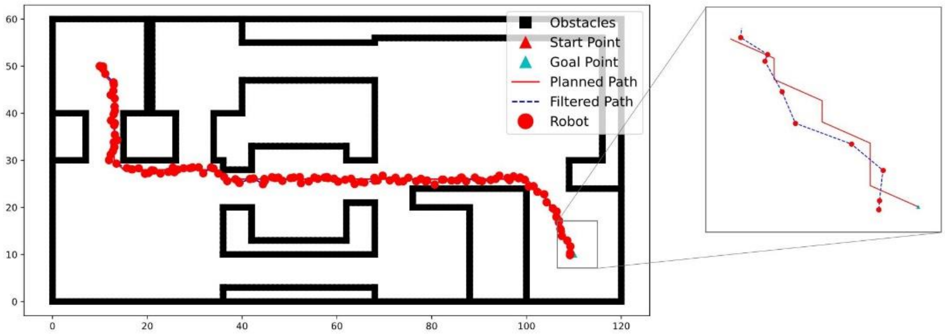


Figure 4. *Path tracking using the Kalman filter with added Gaussian noise*

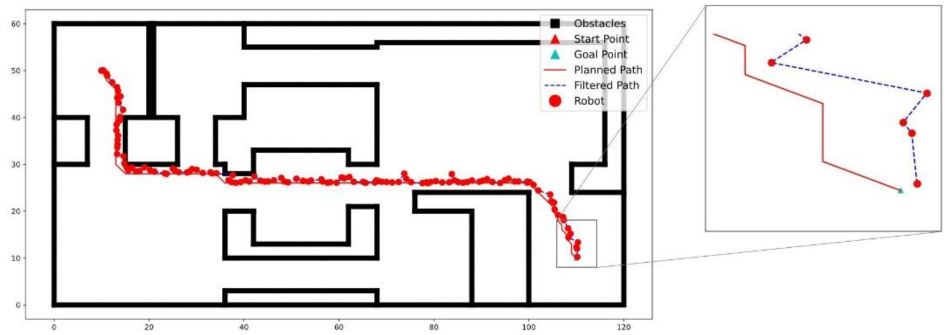


Figure 5. *Path tracking using the Kalman filter with added exponential noise*

Figure 4 illustrates the path taken by the robot using the Kalman filter with added Gaussian noise scenario. The Kalman filter efficiently reduced the tracking error to approximately 136.54 metres, successfully guiding the robot to the goal. The filter's ability to achieve this high level of accuracy in the presence of Gaussian noise emphasizes the robustness and effectiveness of the Kalman filter for state estimation. The tracking error was used as a valuable metric for evaluating the filtering system's performance under this specific noise type, with an execution time of 9.19 seconds for this scenario. Conversely, during the experiment shown in Figure 5, featuring exponential noise, the Kalman filter exhibited a tracking error of around 140.97 metres, signifying a slightly higher level of inaccuracy compared to the Gaussian noise scenario. Although the robot ultimately reached its goal successfully in both scenarios, the results clearly indicate that Gaussian noise, with its symmetric and bell-shaped distribution, yields better tracking performance when compared to non-Gaussian exponential noise. This difference is expected, as Gaussian noise is more amenable to the linear, minimum mean square error estimation framework of the Kalman filter. The execution time for the Kalman filter in this scenario was 9.13 seconds.

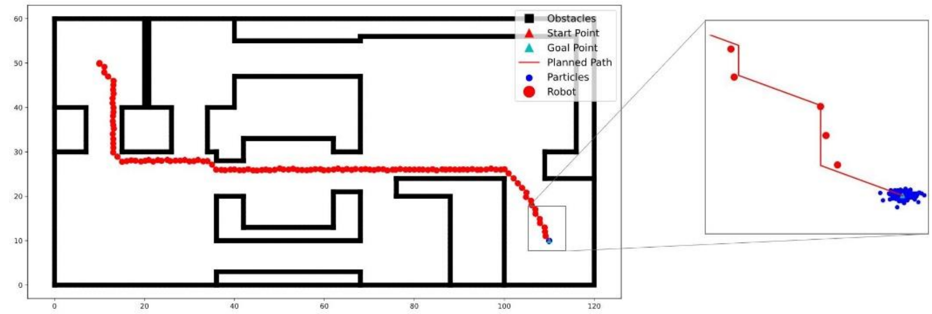


Figure 6. *Path tracking using the particle filter with added Gaussian noise*

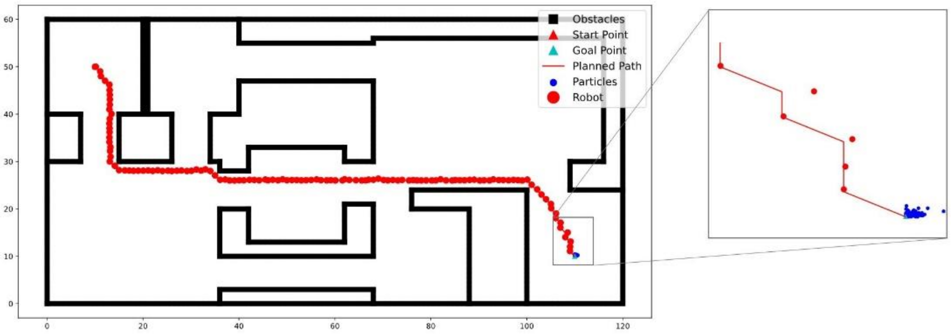


Figure 7. *Path tracking using the particle filter with added exponential noise*

Figure 6 exhibits the path taken by the robot after the application of the particle filter in a scenario with Gaussian noise. The tracking error, which measures the discrepancy between the estimated and true path taken by the robot, is found to be 132.08 metres. This indicates the average deviation between the Particle Filter's estimated path and the ground truth path. Since the filter estimates the robot's position based on noisy measurements and motion, minor deviations from the true path are expected. Additionally, the tracking error might be slightly affected by the resampling process, as particles with lower weights may not accurately represent the true path. The execution time for the particle filter with Gaussian noise was 10.44 seconds. On the other hand, in particle filter with added exponential distribution scenario as depicted in Figure 7 indicates that the robot successfully reached the goal with a tracking error of 124.82 meters. Notably, this value is lower than the tracking error in the Gaussian noise scenario. This suggests that the particle filter with an exponential distribution may perform better under these specific noise conditions, even though the execution time for this scenario was slightly longer at 13.33 seconds.

These findings offer valuable insights into the comparative performance of filtering techniques. It's interesting to note that the particle filter outperformed the Kalman filter in the presence of Gaussian noise, contrary to our initial expectations due to its adaptability and ability to handle a variety of noise distributions effectively. The particle filter's flexibility and resampling mechanism enable it to maintain accurate state estimates, even in cases where Gaussian noise is expected. This suggests that for certain scenarios or noise characteristics, the particle filter might be a more suitable choice for state estimation. The longer execution time of the particle filter compared to the Kalman filter's execution time is likely due to the particle filter's probabilistic nature and resampling process, which requires more computational resources.

7. Conclusion

In conclusion, the area of self-governing robot direction is swiftly progressing, with different conventional and artificial intelligence methods at hand to aid robots in navigating intricate environments. Conventional methods such as Voronoi diagram and potential field have limitations in handling indoor environments, whereas artificial intelligence methods such as genetics algorithm, and neural networks provide increased adaptability and strength in managing complex navigation tasks.

The A* algorithm has been demonstrated as a fundamental method for resolving pathfinding issues, and the integration of artificial intelligence approaches with conventional practices has the capability to construct navigation systems that are more durable and effective. The adeptness of robots to navigate unfamiliar surroundings without human intervention or guidance mechanisms has the potential to revolutionize numerous sectors.

Nevertheless, there remain significant obstacles to the advancement of fully autonomous robots, involving the necessity for precise and sturdy sensing, mapping, and localization, as well as the aptitude to operate instantaneously. Overcoming these issues will demand additional research and development in field like computer vision, machine learning, and sensor technology.

In addition, the simulation study emphasizes the significance of considering the noise characteristics when selecting a filtering technique. The choice between Kalman and particle filters should be based on the specific requirements of the application and the underlying noise distribution, as highlighted by the results obtained in our experiments. These findings provide valuable guidance for practitioners in the field of state estimation and robotics, enabling them to make informed decisions about filter selection based on the noise conditions they are likely to encounter in real-world applications.

The realm of autonomous robot navigation is an innovative and dynamically growing research domain with enormous capacity for transforming numerous aspects of our daily lives. With advancing technology and novel applications, a greater number of autonomous robots are projected to emerge in the future, substantially enhancing efficacy, productivity and safety in multiple industries.

Declaration of Interest

The authors declare that there is no conflict of interest.

Author Contributions

Alper Hüseyin DOĞAN: conceptualization, methodology, collecting the data, performed analysis, writing. Tarık Veli MUMCU: conceptualization, methodology, review, editing, supervision.

References

[1] G. Fragapane, R. De Koster, F. Sgarbossa, and J. O. J. E. J. o. O. R. Strandhagen, "Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda," vol. 294, no. 2, pp. 405-426, 2021.

[2] J. A. Oroko and G. Nyakoe, "Obstacle avoidance and path planning schemes for autonomous navigation of a mobile robot: a review," in *Proceedings of the Sustainable Research and Innovation Conference*, 2022, pp. 314-318.

[3] N. Adzhar, Y. Yusof, M. A. J. A. i. S. Ahmad, Technology, and E. S. Journal, "A review on autonomous mobile robot path planning algorithms," vol. 5, no. 3, pp. 236-240, 2020.

[4] J. R. Sanchez-Ibanez, C. J. Perez-del-Pulgar, and A. J. S. García-Cerezo, "Path planning for autonomous mobile robots: A review," vol. 21, no. 23, p. 7898, 2021.

[5] D. Chen, A. Xiao, M. Zou, W. Chi, J. Wang, and L. J. a. p. a. Sun, "GVD-Exploration: An Efficient Autonomous Robot Exploration Framework Based on Fast Generalized Voronoi Diagram Extraction," 2023.

[6] G. Klančar, A. Zdešar, and M. J. S. Krishnan, "Robot Navigation Based on Potential Field and Gradient Obtained by Bilinear Interpolation and a Grid-Based Search," vol. 22, no. 9, p. 3295, 2022.

[7] L. J. I. J. o. C. I. S. Magdalena, "What is soft computing? Revisiting possible answers," vol. 3, no. 2, pp. 148-159, 2010.

[8] Z. Zhang, R. Lu, M. Zhao, S. Luan, M. J. J. o. I. Bu, and F. Systems, "Robot path planning based on genetic algorithm with hybrid initialization method," vol. 42, no. 3, pp. 2041-2056, 2022.

[9] F. Cruz, R. Dazeley, P. Vamplew, I. J. N. C. Moreira, and Applications, "Explainable robotic systems: Understanding goal-driven actions in a reinforcement learning scenario," vol. 35, no. 25, pp. 18113-18130, 2023.

[10] D. Foead, A. Ghifari, M. B. Kusuma, N. Hanafiah, and E. J. P. C. S. Gunawan, "A systematic literature review of A* pathfinding," vol. 179, pp. 507-514, 2021.

[11] C. Urrea and R. J. J. o. S. Agramonte, "Kalman filter: historical overview and review of its use in robotics 60 years after its creation," vol. 2021, pp. 1-21, 2021.

[12] Y. Wang, X. J. C. i. Wang, and neuroscience, "Research on SLAM road sign observation based on particle filter," vol. 2022, 2022.

[13] R. C. J. T. I. j. o. r. r. Arkin, "Motor schema—based mobile robot navigation," vol. 8, no. 4, pp. 92-112, 1989.

[14] D. M. J. I. A. T. O. M. Auslander, "What is mechatronics?," vol. 1, no. 1, pp. 5-9, 1996.

[15] R. H. Bishop, *The mechatronics handbook-2 volume set*. CRC press, 2002.
[16] J. J. A. Mireles Jr and U. o. T. a. A. Robotics Research Institute, "Kinematic models of mobile robots," 2004.
[17] M. I. Ribeiro and P. J. I. d. S. e. R. Lima, "Kinematics models of mobile robots," vol. 1000, p. 1049, 2002.
[18] R. Siegwart, I. R. Nourbakhsh, and D. Scaramuzza, *Introduction to autonomous mobile robots*. MIT press, 2011.
[19] Z. Liang, X. Ma, and X. Dai, "Extended Monte Carlo algorithm to collaborate distributed sensors for mobile robot localization," in *2007 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, 2007, pp. 1647-1652: IEEE.
[20] M. Paskin and S. J. a. p. a. Thrun, "Robotic mapping with polygonal random fields," 2012.
[21] J. Fuentes-Pacheco, J. Ruiz-Ascencio, and J. M. J. A. i. r. Rendón-Mancha, "Visual simultaneous localization and mapping: a survey," vol. 43, pp. 55-81, 2015.
[22] T. Bailey, J. Nieto, J. Guivant, M. Stevens, and E. Nebot, "Consistency of the EKF-SLAM algorithm," in *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2006, pp. 3562-3568: IEEE.
[23] R. C. Smith and P. J. T. i. j. o. R. R. Cheeseman, "On the representation and estimation of spatial uncertainty," vol. 5, no. 4, pp. 56-68, 1986.
[24] G. Dissanayake, H. Durrant-Whyte, and T. Bailey, "A computationally efficient solution to the simultaneous localisation and map building (SLAM) problem," in *Proceedings 2000 ICRA. Millennium Conference. IEEE International Conference on Robotics and Automation. Symposia Proceedings (Cat. No. 00CH37065)*, 2000, vol. 2, pp. 1009-1014: IEEE.
[25] R. S. Pol and M. Murugan, "A review on indoor human aware autonomous mobile robot navigation through a dynamic environment survey of different path planning algorithm and methods," in *2015 International conference on industrial instrumentation and control (ICIC)*, 2015, pp. 1339-1344: IEEE.
[26] P. Cheeseman, R. Smith, and M. Self, "A stochastic map for uncertain spatial relationships," in *4th international symposium on robotic research*, 1987, pp. 467-474: MIT Press Cambridge.
[27] S. Garrido, L. Moreno, M. Abderrahim, and F. Martin, "Path planning for mobile robot navigation using voronoi diagram and fast marching," in *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2006, pp. 2376-2381: IEEE.
[28] H. Choset and J. Burdick, "Sensor based planning. I. The generalized Voronoi graph," in *Proceedings of 1995 IEEE international conference on robotics and automation*, 1995, vol. 2, pp. 1649-1655: IEEE.
[29] P. Bhattacharya, M. L. J. I. R. Gavrilova, and A. Magazine, "Roadmap-based path planning-using the voronoi diagram for a clearance-based shortest path," vol. 15, no. 2, pp. 58-66, 2008.
[30] R. Mahkovic, T. J. I. T. o. S. Slivnik, Man,, C.-P. A. Systems, and Humans, "Constructing the generalized local Voronoi diagram from laser range scanner data," vol. 30, no. 6, pp. 710-719, 2000.
[31] R. Marie, H. B. Said, J. Stéphant, O. J. J. o. I. Labbani-Igbida, and R. Systems, "Visual servoing on the generalized voronoi diagram using an omnidirectional camera," vol. 94, pp. 793-804, 2019.
[32] A. Datta, S. J. I. T. O. S. Soundaralakshmi, Man,, C.-P. A. Systems, and Humans, "Fast parallel algorithm for distance transform," vol. 33, no. 4, pp. 429-434, 2003.
[33] F. Janabi-Sharifi and D. Vinke, "Integration of the artificial potential field approach with simulated annealing for robot path planning," in *Proceedings of 8th IEEE international symposium on intelligent control*, 1993, pp. 536-541: IEEE.
[34] H. Lyu and Y. J. A. S. Yin, "Fast path planning for autonomous ships in restricted waters," vol. 8, no. 12, p. 2592, 2018.
[35] T. Weerakoon, K. Ishii, A. A. F. J. J. o. A. I. Nassiraei, and S. C. Research, "An artificial potential field based mobile robot navigation method to prevent from deadlock," vol. 5, no. 3, pp. 189-203, 2015.
[36] J. Zhang, J. Yan, and P. J. I. A. Zhang, "Fixed-wing UAV formation control design with collision avoidance based on an improved artificial potential field," vol. 6, pp. 78342-78351, 2018.
[37] Z. Wu, G. Hu, L. Feng, J. Wu, and S. J. A. A. Liu, "Collision avoidance for mobile robots based on artificial potential field and obstacle envelope modelling," vol. 36, no. 3, pp. 318-332, 2016.
[38] F. A. Cosío, M. P. J. M. Castañeda, and c. modelling, "Autonomous robot navigation using adaptive potential fields," vol. 40, no. 9-10, pp. 1141-1156, 2004.
[39] M. G. Park and M. C. J. K. i. j. Lee, "A new technique to escape local minimum in artificial potential field based path planning," vol. 17, pp. 1876-1885, 2003.
[40] J. Agirrebeitia, R. Avilés, I. F. De Bustos, G. J. M. Ajuria, and M. Theory, "A new APF strategy for path planning in environments with obstacles," vol. 40, no. 6, pp. 645-658, 2005.

[41] T. Zhang, Y. Zhu, and J. J. I. R. A. I. J. Song, "Real-time motion planning for mobile robots by means of artificial potential field method in unknown environment," vol. 37, no. 4, pp. 384-400, 2010.
[42] T. Shibata and T. J. P. o. t. I. I. S. o. I. C. Fukuda, "Intelligent motion planning by genetic algorithm with fuzzy critic," pp. 565-570, 1993.
[43] P. J. Angeline, "Genetic programming: On the programming of computers by means of natural selection: John R. Koza, A Bradford Book, MIT Press, Cambridge MA, 1992, ISBN 0-262-11170-5, xiv+ 819pp., US $55.00," ed: Elsevier, 1994.
[44] Man-Tak Shing and G. B. Parker, "Genetic Algorithms for the Development of Real-Time Multi-Heuristic Search Strategies.," *ICGA*, pp. 565-572, 1993/7/17.
[45] P. Shi and Y. Cui, "Dynamic path planning for mobile robot based on genetic algorithm in unknown environment," in *2010 Chinese control and decision conference*, 2010, pp. 4325-4329: IEEE.
[46] R. L. Haupt and S. E. Haupt, *Practical genetic algorithms*. John Wiley & Sons, 2004.
[47] P. Beeson, N. K. Jong, and B. Kuipers, "Towards autonomous topological place detection using the extended voronoi graph," in *Proceedings of the 2005 IEEE International Conference on Robotics and Automation*, 2005, pp. 4373-4379: IEEE.
[48] Bekey G. A. and G. K.Y., "Neural Networks in Robotics.," *Kluwer Academic Publishers*, 1993.
[49] I. Engedy and G. Horváth, "Artificial neural network based mobile robot navigation," in *2009 IEEE International Symposium on Intelligent Signal Processing*, 2009, pp. 241-246: IEEE.
[50] N. Leena, K. J. I. J. o. M. Saju, and C. Engineering, "A survey on path planning techniques for autonomous mobile robots," vol. 8, pp. 76-79, 2014.
[51] C. Li, J. Zhang, and Y. Li, "Application of artificial neural network based on q-learning for mobile robot path planning," in *2006 IEEE International Conference on Information Acquisition*, 2006, pp. 978-982: IEEE.
[52] P. E. Hart, N. J. Nilsson, B. J. I. t. o. S. S. Raphael, and Cybernetics, "A formal basis for the heuristic determination of minimum cost paths," vol. 4, no. 2, pp. 100-107, 1968.
[53] N. J. Nilsson, *Artificial Intelligence: A New Synthesis*. Morgan Kaufmann Publishers Inc., 1998.
[54] I. Pohl, "Bi-directional and heuristic search in path problems," 1969.
[55] P. E. Hart and N. J. Nilsson, "A Formal Basis for the Heuristic Determination of Minimum Cost Paths.," *EEE Transactions Systems Science and Cybernetics*, vol. 4, pp. 100-107, 1968.
[56] A. Felner, R. E. Korf, and S. J. J. o. A. I. R. Hanan, "Additive pattern database heuristics," vol. 22, pp. 279-318, 2004.
[57] M. Goldenberg *et al.*, "Enhanced Partial Expansion A*," *The Journal of Artificial Intelligence Research (JAIR)*, vol. 50, 05/01 2014.
[58] S. Haykin, *Kalman filtering and neural networks*. John Wiley & Sons, 2004.
[59] K. Nagarajan, N. Gans, and R. Jafari, "Modeling human gait using a kalman filter to measure walking distance," in *Proceedings of the 2nd Conference on Wireless Health*, 2011, pp. 1-2.
[60] F. Ahmed and R. Mandal, "Survey on the Kalman Filter and Related Algorithms," in *Int. Res. J. of Eng. and Technol.*, vol. 5no. 5): International Research Journal of Engineering and Technology (IRJET), 2018, pp. 4219-4223.
[61] A. Doucet, N. De Freitas, and N. J. S. M. C. m. i. p. Gordon, "An introduction to sequential Monte Carlo methods," pp. 3-14, 2001.
[62] P. S. Maybeck, "Stochastic models, estimation and control," *Navtech Book & Software Store*, vol. volume 1, 1994.
[63] B. Øksendal and B. Øksendal, *Stochastic differential equations*. Springer, 2003.
[64] G. Kallianpur, *Stochastic filtering theory*. Springer Science & Business Media, 2013.
[65] S. Brahimi, R. Tiar, O. Azouaoui, M. Lakrouf, and M. Loudini, "Car-like mobile robot navigation in unknown urban areas," in *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, 2016, pp. 1727-1732: IEEE.