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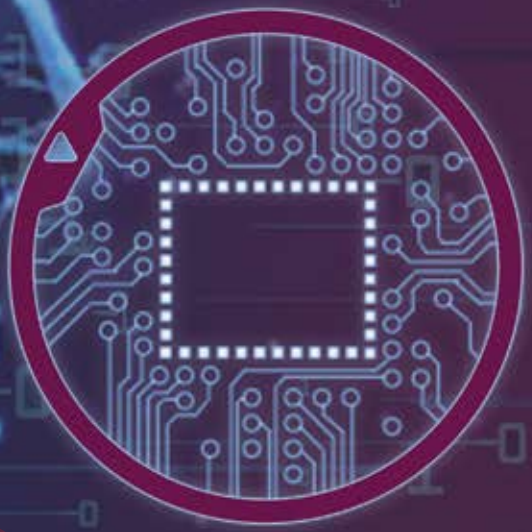

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Artificial Intelligence and Data Science
Research and Application Center

JAIDA

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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.

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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 1. 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 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 1 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 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)
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A Case Study for Mobile Wallet Implementation in Self-Sovereign Identity Infrastructure

Aslı BAHCE, Semih UTKU *

Abstract

The concept of Self-Sovereign Identity (SSI), where we can store our personal information and documents securely, as proven by the relevant authorities, and share them with the people we want, has become widespread as the personal secure data storage method that we need most in recent years. We have to physically carry our evidence-based identities obtained from events or institutions. Keeping our identity, age, health status, educational status, and many other personal data inaccessible to others and without questioning the accuracy when we share them also restricts their use in different areas. Sharing the data depending on the consent of the people and presenting the data accurately and reliably has become one of our most important needs today. With the concept of SSI, it has become possible for us to save our data as distributed, inaccessible, unalterable, and incorruptible. In addition, with the possibility of public access to the information with the consent of the people, it is possible to instantly share the information with the people/institutions we want. This study will explain mobile application processes created on SSI infrastructure. It will be possible to add different institutions to the developed system and to identify the added institutions to the users. The identities given by the institutions will be able to be proven by different institutions. Thus, the operating structure of this system will be transferred with a verifiable and reliable infrastructure. This study, it is aimed to contribute to the general operating processes of those who will develop the SSI infrastructure. To develop such a system, it has been determined that ACA-Py is the most suitable infrastructure framework. After comparing the efficacy of Askar and Indy for the selection of the wallet to be used, it was determined that the Askar wallet would be used in the system.

Keywords: Blockchain; consistency; mobile app; reliability; self-sovereign identity.

1. Introduction

Depending on the developing and changing living conditions, we use various materials, mobile applications, and identities for many different purposes today. Although this situation causes us to carry a lot of things physically; it has made it difficult for us to govern and prove our identity to the authorities. Although this problem is seen in many areas [1], if we reduce the sample, it is encountered in city life and different areas. We have to have a different card or mobile application in many areas such as transportation, event entrances, museum visits, and gyms [2]. In addition, we may need to show documents to prove our identity. The concept of SSI, where we can store our personal information and documents only in a non-public way, as proven by the relevant authorities, and share them with anyone we want, has become widespread as the secure data storage method we need most in recent years [3]. Keeping our identity, age, health status, educational status, and many other personal data inaccessible and unquestionable when we share it has become one of our most important needs in today's world where data storage and presentation become difficult. Today, when city governments make serious investments and breakthroughs in technology [4], smart cities have begun to form [5]. Many manually managed processes have now become automated. These processes required people to be included in different identities (transport cards, museum entrance cards, etc.) with this automation. With the SSI concept, it has been possible to transform these different identities from many physical instruments into a structure where we store data in the wallet (mobile application). Thus, individuals will be able to present their data, which they have stored as proven by the relevant authorities, to any person/institution at any time. People will be hosting their data in a way that cannot be shared without their permission. If we explain the operation of the system with an example; at an event entrance in smart cities using the proposed system; An event is planned for those over the age of 18 and where “Exclusive Card Owner” users can log in. Smart city residents, who have this data under their control in the mobile application, will be able to enter the event by proving both their membership type and age at once, with a simple application

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at the event entrance. Whereas, in the classical system, he had to show the event entrance card, prove that this card belongs to him, and present the document showing that he is over 18.

So how can this system be made more secure and unbreakable? The basis of these questions has been resolved with the blockchain infrastructure. With the concept of blockchain, it has become possible for us to save our data as distributed, inaccessible, unalterable, and incorruptible. In the proposed system that we developed with SSI on the blockchain, we can solve this problem much more securely and effectively. In this case, our data cannot be accessed publicly, stored as evidenced by the authorized authorities, cannot be changed, or corrupted, and can be shared instantly with the people/institutions we want. With this system, which will greatly facilitate the lives of both smart city residents and institutions managed by smart cities in different areas, many problems that make our lives easier, such as saving time, preventing erroneous discharges, transporting/managing a large number of physical materials, will be solved. This study will explain end-to-end mobile application processes created on SSI infrastructure. Users can carry their identities, which they hold for different purposes, on their mobile devices as safe, provable, and incorruptible instead of physically carrying them in their wallets, and institutions can see and accept these identities as proof. Within the scope of the study, ACA-Py - Indy and ACA-Py - Aries Go frameworks were compared, and a contribution was made to the literature on their use and features in a real system. In addition, Indy and Askar wallet performance comparisons are made and the advantages that come with Askar are stated.

The details of the proposed solution and definitions are given in Sections 3 and 4. The next Section presents the identification of the problem and the related work. Section 4 also presents an integration example. Section 5 presents the results and discussion and finally, the last section depicts the conclusion and future work.

2. Related Works

Even though SSI is a very old notion, there have been substantial studies on the topic since 2016 according to the literature [6]. It has been determined through research that the majority of published works are concerned with blockchain technology. Particularly, anonymous and personal encryption technologies as well as the anonymity capabilities provided by blockchain technology are advantageous for the practical application of this notion [7]. When the studies on the subject in the field of blockchain are examined, it is seen that since 2016, extensive studies have been put forward by the Sovrin community on this subject. In these studies, different technical solutions have been presented under the Hyperledger community to meet the SSI and Zero-Knowledge-Proof (ZKP) techniques [8]. Hyperledger-Fabric and Hyperledger-Indy are the most up-to-date technologies used in blockchain, mainly in the areas of SSI and ZKP.

In addition, the Verus blockchain solution also produces solutions on SSI, but it is at a very beginner level compared to the Hyperledger infrastructure in terms of supporting community and development level. When the solution technologies related to SSI used in the study are examined, there are commercial Evernym products and non-commercial open-source Aries solutions. While Evernym commercially develops products on the Hyperledger-Indy library, the Aries community develops open-source solutions using Hyperledger-Indy libraries on different infrastructures. The Canadian British Columbia government is actively offering SSI using these solutions developed by the Aries community. When the studies in this field are examined; first of all whether blockchain infrastructure is required for SSI is investigated. In their study, [9] examined the evolving landscape of SSI solutions and evaluated their implementations using various criteria to assess the necessity of blockchain technology in this domain. While they concluded that blockchain technology is not an absolute prerequisite for an SSI solution, their research revealed that blockchain-based solutions outperformed other solutions in terms of meeting multiple criteria. Therefore, the study suggests that blockchain-based solutions may be better equipped to meet the requirements of an SSI solution on average, compared to other alternatives.

Due to the sensitive nature of the data, the majority of SSI use cases target healthcare systems. Numerous studies examine whether or not SSI applies to the actual world. Here are some studies demonstrating that blockchain-based SSI is the most appropriate and trustworthy solution for identity management and user control of data. The research of [10] found that blockchain technology, with its distributed and decentralized structure, can offer significant benefits in healthcare. By empowering patients with control over their data and an SSI, blockchain has the potential to revolutionize the field. However, the researchers acknowledge that the development of purely decentralized Healthcare Information Systems (HIS) presents significant technical and architectural challenges. To address these challenges, the study examines the design tradeoffs and evaluates the current state of the art in HIS design. The results indicate that BC-powered Electronic Health Record (EHR) and Patient Health Record (PHR) systems are crucial in realizing a decentralized and self-governing healthcare ecosystem. While prior research, as noted by [11], has primarily focused on exploring the technological capabilities of such solutions, there remains a gap in understanding their broader impact on the healthcare ecosystem and the entire value chain. The push for distributed trust through the elimination of intermediaries and

decentralization is the core principle driving the development of pure blockchain solutions. However, the most reliable existing solutions, which are hybrid blockchain architectures, have not fully met the requirement for patient privacy protection and the right to be forgotten. Although this issue has been addressed by current solutions, none have offered a conclusive solution or proof of concept.

[12] argue that blockchain adoption over the traditional client-server paradigm is motivated by the desire to achieve greater reliability, stability, timeliness, and productivity within legal systems. This study suggests that SSI can enhance compliance with regulations and revolutionize data processing practices in healthcare by empowering patients to manage their identity information. By providing patients with control over their data, healthcare providers can become more service-oriented and develop new products and applications. The cost-effectiveness of SSIs can be seen in their ability to eliminate inefficient onboarding processes and provide fast data access and authentication. Moreover, the reliability and accuracy of data in food supply chains are critical. In the study conducted by [13], they present a practical use case that demonstrates the need for a system that ensures full visibility of process and food certifications. The researchers propose an SSI-based model that aims to address the storage and accessibility of these certifications, as well as appropriate eligibility verification. The system assumes that the certifying body issues a certificate by storing it in the InterPlanetary File System (IPFS) and only stores key information on the blockchain when a user (holder) seeks a quality certification for their product or process. The blockchain is used to store certification verification details, and certificate returns and validation are automated, providing a more efficient and reliable system for managing food supply chains. [14] suggest a second use case for the SSI application: public transportation. The research investigates the application of SSI management in the public transportation sector, which encompasses multiple operators and countries. In particular, the study investigates the application of a blockchain-based decentralized identity management system leveraging the SSI framework to provide high-level security. The authors created a low-fidelity prototype utilizing the Hyperledger Indy blockchain to demonstrate how individuals can manage their identity credentials more effectively. The prototype presents the EMC, a verifiable credential designed according to W3C global technical standards, which can be used as an identity card on European public transportation. Another example study was carried out in the field of architecture [15], They compiled 12 design models for blockchain-based self-driving identity systems, aimed at helping architects understand and apply concepts in system design. The authors divided these patterns into three groups: key management patterns, decentralized identifier management patterns, and credential design patterns. On the other hand, there are studies concerning claim-based models. [16] distinguish two main approaches regarding this topic: the Identifier Registry Model and its extension, the Claim Registry Model. They claim they will provide a more unified view of verifiable claims regarding blockchain-based SSI and elucidate terminology distinctions. On the other hand, Baars (2016) has investigated the possibility of SSI, which allows users to control their digital identity. In their case study, they explored a solution for attribute exchange, that allows Know Your Customer (KYC) attribute exchange after completing Customer Due Diligence, such as when opening a bank account. This simplifies client onboarding by eliminating duplicate documentation and can be used by insurance companies and mortgage lenders. The key research issue was: How to design decentralized identity management architecture so entities can exchange attributes and verify claims without a central authority?

In another study on claim-based models, [18] proposes a solution that obtains legally valid identity at the passport level, which requires third-party truth attestations. The proposed solution is the world's first decentralized digital passport and authentic peer-to-peer identity commons that operates on a permissionless basis. [19] provide an overview of the Sovrin SSI platform, which runs on the public permissioned Hyperledger Indy blockchain, as well as uPort and Jolocom, which operate on the public permissionless Ethereum blockchain. The authors also examine the compliance of blockchain-based identity systems with the European Union's General Data Protection Regulation (GDPR). The authors suggest that SSI can meet GDPR requirements by safeguarding data subjects' privacy while ensuring compliance with the regulation. [20] made a comparison of two SSI solutions: uPort and Sovrin. Using the proposed specifications, they evaluated uPort and Sovrin SSI and highlighted their strengths and weaknesses. A comprehensive SSI platform architecture supporting the design-as-a-service (DPaaS) was proposed in the [21] study. The authors determined the lifecycles of the three main SSI objects (keys, identifiers, and credentials) and provided a range of SSI services, including key management and credential authentication, supported by two transaction classifications.

In Table 1, examinations were made based on the most recent and current studies. At this point, it is seen that our work is more valuable than other studies, with the examinations and measurements made in different frameworks and wallets. After that, a resource has been created to guide those who will work in this field.

Table 1. *Other studies comparison.*

	[12]	[13]	[14]	[18]	[20]	Proposed System
Application Area	Healthcare	Food supply chain	Public transportation	Citizen	N/A	Citizen
SSI	Yes	Yes	Yes	Yes	Yes	Yes
Blockchain	Yes	Yes	Yes	Yes	Yes	Yes
Network	N/A	Ethereum	Sovrin	N/A	Ethereum & Sovrin	Sovrin
Storage Provider	N/A	IPFS	Indy Wallet	N/A	Digital Wallet & Edge Wallet	Askar Wallet
Comparison	No	No	No	No	Yes	Yes
Performance Measurement	No	No	No	Yes	No	Yes

3. Methodology

SSI is a word used to define the digital movement that acknowledges a person's right to own and govern their identity without administrative interference. SSI enables people to interact with the same level of freedom and trust in the digital world as they do in the offline one. SSIs are a type of digital identity that is administered in a decentralized way. Users can self-manage their digital identities by utilizing this technology, which eliminates the need for them to rely on third-party suppliers to store and centrally manage their data. Blockchain technology has emerged as a key underlying infrastructure for SSI solutions, with Ethereum blockchain being one of the popular choices. A crucial component of SSI is the use of Decentralized Identifiers (DID), which allow individuals to create and manage their unique digital identity in a censorship-resistant environment. The DID contains an encrypted link to a signed document by an authority, which includes information related to service endpoints and authorized public keys. The followings are the elements of SSI:

- A *decentralized identifier* (DID) is equivalent to a unique personal identity. Document issuer will create DIDs in a censorship-resistant blockchain environment. There will be an encrypted link of the DID to a signed document by an authority.
- *Verifiable credentials* attest information to a specific DID. These are the important standards of any SSI ecosystem. For example, a digital driving license that allows you to drive cars is one example of a verifiable credential.
- *Hyperledger Indy* is a cutting-edge distributed ledger software. It offers a flexible, modular ecosystem for creating secure, private, and powerful identities that can be used on their own or in conjunction with other blockchain networks.
- *Sovrin* is an open-source identity network built on distributed ledger technology.
- *Hyperledger Indy SDK*, which provides a distributed-ledger-based foundation for SSI.
- *Hyperledger Aries Cloud Agent Python* (ACA-Py) is a foundation for building decentralized identity applications and services running in non-mobile environments.

3.1. Scenario

The system is based on storing different types of identities in the user's wallet. For this approach, first of all, the user will get a type of identity from an institution. Let's say the user will get an exclusive card from the municipal theater center. With this card, users can watch all theaters for free. Here is the end-to-end flow for this sample:

1. The user will go to the municipal theater center to get an exclusive card.
2. The municipal theater center client opens the "Institution Web Application", selects the identity type "exclusive card owner" from the predefined identity types, and enters the information for the user.
    a. Exclusive card owner credential definition is predefined over the "Back Office Web Application" when the institution is onboarded to the system.
3. "Institution Web Application" generates a QR code that contains the institution wallet information and the "exclusive card owner" credential attributes.
4. The user scans the QR code using the "User Mobile Application".
    a. In this step, a connection is created between the institution wallet and the user wallet.
    b. Credential is issued by the institution to the user.
5. The user's identity screen is refreshed and the user can see a new identity ("exclusive card owner") in his/her wallet.

Until this step, the user gets the identity to the wallet and now the user can share this information with any business, the business knows the identity is reliable. When the user goes to the theater:

1. The user opens the “User Mobile Application”. The identities of the user are listed on the page. The user selects the “exclusive card owner” identity and the application generates a QR code and shows it on the screen.
    a. The QR code contains the user’s wallet information and credential information.
2. The theater employee opens the “Business Mobile Application”, selects from options “is the user exclusive” and scans the QR code.
    a. Verification request options are created over the “Back Office Web Application” when the business is onboarded to the system.
    b. When the business application scans the QR code, first a connection between the user and the business is created.
    c. Business requests a proof and the user generates a proof according to the credential information (is the user exclusive).
3. Because the user is exclusive, on the “Business Mobile Application”, “user is exclusive” information is displayed.

As defined end to end, a user is issued a verifiable credential by an institution, and a business can verify the user has this credential. The high-level system flow is defined in Figure 1.

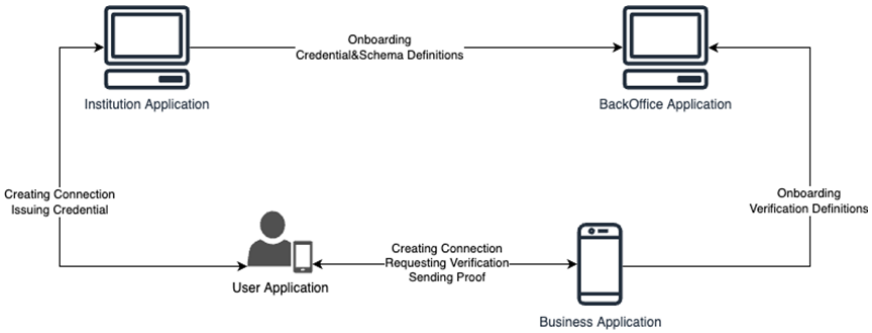

Figure 1. *System high-level flow.*

3.2. System architecture

SSI, self-managing identity is the person's possession and control of his identity without administrative authorities. SSI allows people to interact with the same confidence and freedom capacity in the digital world as in the offline world. Hyperledger-Indy was used to provide the SSI solution. Hyperledger is an open-source blockchain project that provides bridge services for developing open industrial or corporate blockchain projects. Hyperledger-Indy is a distributed ledger for identity management. To perform SSI operations on Hyperledger-Indy, we need a network that verifies our identity provider and software solutions with which we can perform identification. Sovrin was used as the network solution. Sovrin is a non-profit closed Hyperledger-Indy network to provide a controlled consensus where identity checks can be carried out. Sovrin network access is open to all, and the network nodes that provide the consensus of the transactions on the ledger are managed by the non-profit Sovrin Foundation in this case. Each identity information written on the network is realized as a result of the approval and control of the Sovrin Foundation. For this reason, it can be verified which authority each digital identity information on the network belongs to. Aries Agent and Indy-SDK were used as software solutions during the interaction with the network and the creation of user applications. Aries Agent is a library that provides RFC (Request for Comment) related to Indy. RFCs identify key topics that help standardize the Aries ecosystem. Indy SDK is an open-source library provided by Indy and provides us with infrastructure on different platforms for us to perform identity transactions.

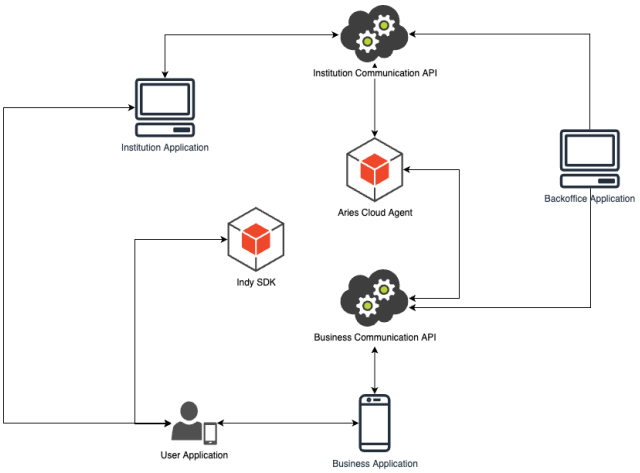

Figure 2. *System high-level architecture.*

Within the scope of this study, an architecture (Figure 2) was created using these technologies. Within this architecture;

- A mobile application has been developed for users to keep their own identities.
- A service infrastructure has been developed for users who will use the mobile application to provide their identity information according to these principles. This infrastructure is built on the Aries Cloud Agent library.
- A business layer has been created that will create the identities that will be given to individuals according to certain rules and provide the processes to communicate this according to the Indy infrastructure.
- Streams are created by creating an intermediate layer that will provide a communication layer between the SSI infrastructure and the communication of other units and that can translate different message structures.
- A mobile application has been developed for businesses to verify users' identities.
- A web application has been developed for institutions to issue users' identities.

3.2.1. Sovrin components

A public register for Credential Definitions, Schema definitions, and Issuer public keys is provided by the Sovrin network. Issuer public keys are utilized in the process of verifying proofs derived from credentials that have been issued. In this study, businesses are verifiers. Businesses verify proofs that have been offered by users.

We can summarize the functions of the components in the system, which are shown in Figure 3, as follows:

- An issuer's public identification is recorded in a Verifiable Data Registry, where it can be accessed by anybody.
- The Credential, which is signed by the Holder's public identity, is issued to the Holder by the Issuer.
- A digital wallet is something that the Holder has possession of and may use to maintain their credentials.
- The Credential Holder will present their document to the Verifier.

By accessing and resolving the public identifier on the Verifiable Data Registry, the Verifier can establish that this data is reliable.

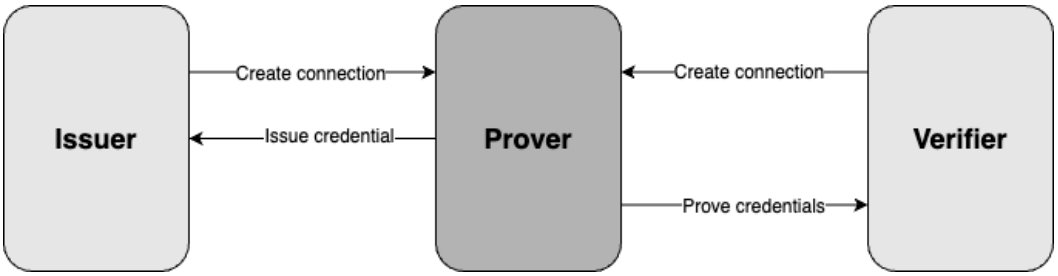

Figure 3. *Sovrin components.*

Holder: Holder is the role that owns one or more verifiable credentials and generates verifiable presentations from them. In this example, the holder is an individual, but it might also be an organization/company. The entity that the information attests to is the holder. In this study, users issue their credentials to the related institution.

Issuer: Issuer is the role that asserts claims about one or more subjects, generates a verifiable credential based on these claims, and sends the verifiable credential to a holder. Corporations, non-profit organizations, trade associations, governments, and people are examples of issuers. In this study, institutions are issuers. User credentials are issued by the institution to which the identity is related.

Verifier: A role that processes one or more verified credentials, optionally contained within a verifiable presentation. The verifier is the people, organization, company, or government to whom the holder must demonstrate the authenticity and reliability of the information.

3.2.2. Workflow description based on Indy

The ledger is designed to store Identity Records describing Ledger Entities. Public Keys, Service Endpoints, Credential Schemas, and Credential Definitions are examples of Identity Records. Each Identity Record is connected with a single DID. Multiple DIDs can be owned by each Identity Owner to safeguard their privacy. In this work, we shall make use of two distinct kinds of DIDs. The first one is Verinym. The Legal Identity of the Person Using the Verinym is Linked to the Verinym's Ownership. All parties should be able to verify, for instance, that a particular DID is used by a government to publish schemas for a particular document type. The second one is Pseudonym. In the context of ongoing digital interaction, a Pseudonym is a Blinded Identifier used to protect privacy. If a Pseudonym is utilized to maintain a single digital relationship, it is referred to as a Pairwise-Unique Identifier. Pairwise-Unique Identifiers will be used to maintain secure connections between participants in this work.

The generation of a DID that is known to the Ledger itself constitutes an Identity Record (NYM transaction). The NYM transaction can be used for the generation of new DIDs known to the ledger, the establishment and rotation of a verification key, and the setting and modification of roles. Publishing with a DID verification key verifies that someone owns this DID because only that person knows the signature key and any DID-related procedures that require it. Because the ledger is accessible to the public, anyone who wishes to publish DIDs must first get the role of Trust Anchor on the ledger. A Trust Anchor is a person or organization that is already known to the ledger and can help others bootstrap themselves into the system.

Adding the Trust Anchor role to the ledger is the first step in being able to record transactions on the ledger. Institutions will require the Trust Anchor role on the distributed ledger to generate Verinyms and Pairwise-Unique Identifiers for Users. To become a Trust Anchor, you must contact a person or organization with the Trust Anchor role on the blockchain. In the empty test ledger, only NYMs with the Steward role will be utilized, but all Stewards are automatically Trust Anchors. A connection to the Indy nodes pool is required to write and view the ledger's transactions after getting the required permissions. The ledger stores the list of nodes in the pool as NODE transactions. Libindy can restore NODE transactions from Genesis transactions. Each Pool Configuration is specified by its respective pool configuration name and JSON representation. The path to the file containing the list of Genesis transactions is the most significant field in pool configuration json.

3.2.3. Initialize backoffice wallet

The Backoffice Agent should acquire ownership of the DIDs that correspond to NYM transactions on the ledger with the Steward role. The wallet is a concept possessed by Libindy. The wallet is a secure repository for cryptographic information such as DIDs, keys, etc. To store the Steward's DID and signkey, the agent must first construct a named wallet by invoking "wallet.create_wallet." The designated wallet can then be opened using "wallet.open_wallet." This call returns the wallet handle that can be used in further libindy calls to refer to the opened wallet. After opening the wallet, a DID record can be created in this wallet by executing "did.create_and_store_my_did", which returns the generated DID and the verkey portion of the generated key. The signkey component for this DID will also be saved in the wallet, but it cannot be read directly. Initialize Backoffice flow is shown in Figure 4.

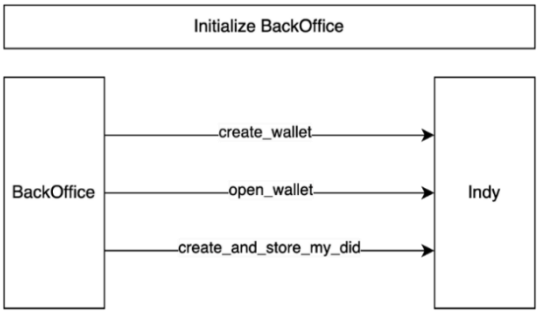

Figure 4. *Initialize backoffice flow.*

3.2.4 Onboarding of institutions and businesses

Each connection consists of two Pairwise-Unique Identifiers (DIDs). The first DID is owned by one party while the second is owned by another. Both parties are aware of both DIDs and comprehend the connection between them. The relationship that exists between them cannot be shared with other people; it is unique to those two parties due to the fact that different DIDs are used for every paired interaction.

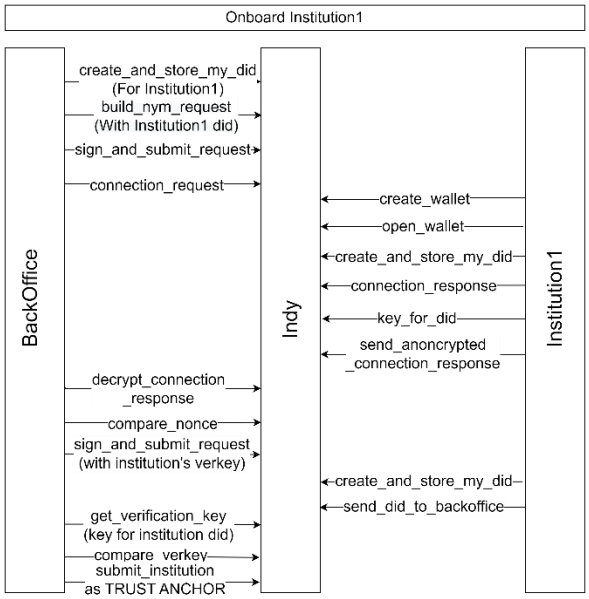

Figure 5. *Institution onboarding flow.*

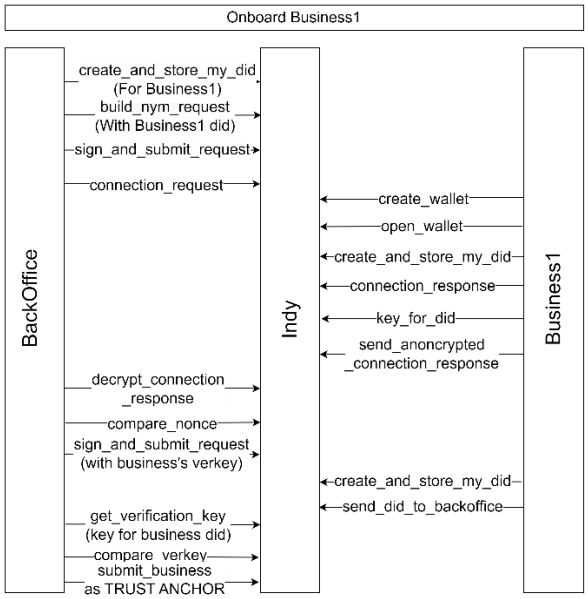

Figure 6. *Business onboarding flow.*

Each connection consists of two Pairwise-Unique Identifiers (DIDs). The first DID is owned by one party while the second is owned by another. Both parties are aware of both DIDs and comprehend the connection between them. The relationship that exists between them cannot be shared with other people; it is unique to those two parties due to the fact that different DIDs are used for every paired interaction. Onboarding processes for institutions and businesses are the same. The flow for onboarding that are shown in Figure 5 and Figure 6; same for the both institutions and businesses:

3.2.5. Creating schema and credential definitions

Credential Schema is the foundational semantic framework that describes the set of possible attributes for a Credential. There is no way to update an existing Schema. If the Schema is to be modified, a new Schema with a different version or name must be generated. Any Trust Anchor can generate and save a Credential Schema in the Ledger. Backoffice, for example, generates and publishes the Theater Card Credential Schema to the Ledger. Credential Definition is similar to Credential Schema in that the keys used by the Issuer to sign Credentials also conform to a certain Credential Schema. Again, updating data in an existing Credential Definition is not possible. Consequently, if a Credential Definition must be modified, a new Credential Definition must be generated by a new Issuer DID. Any Trust Anchor is able to create and save Credential Definitions in the Ledger. Institution1, for example, generates and publishes to the Ledger a Credential Definition for the known Theater Card Credential

Schema. The Trust Anchor retrieves the particular Credential Schema from the Ledger and generates the Credential Definition that corresponds to the received Credential Schema. The secret Credential Definition section of this Credential Schema is similarly stored in the wallet, however, it cannot be accessed directly. The Trust Anchor transmits to the Ledger the relevant Credential Definition transaction. This is how the Credential Definition for the Theater Card Credential Schema is developed. Creating a schema and creating a credential definition using the defined schema flow is shown in Figure 7.

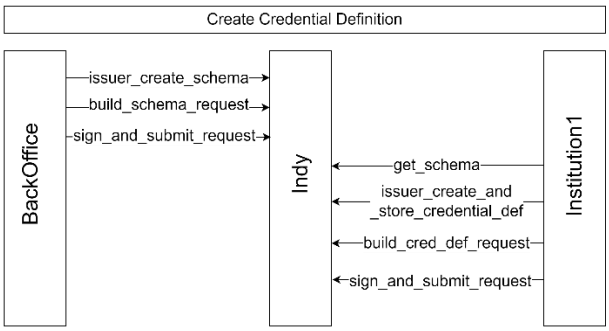

Figure 7. *Create credential definition flow.*

3.2.6. Issuing credential

A credential is an identity-related piece of information. This is assertedly accurate information. A credential is issued by a credential issuer. An issuer may be any identity owner identified by the Ledger, and any issuer may issue a credential for any identity owner it can identify. The utility and dependability of a credential are dependent on the issuer's standing with regard to that credential. First, all communications between actors are encrypted. The credential's value is issued by Institution1. A user desires to view the attributes included within the "Theater Card" Credential. These attributes are known since a Theater Card Credential Schema has been recorded in the Ledger. Nonetheless, the Theater Card Credential has not yet been sent to the user in a usable format. The User wishes to utilize this Credential. The user must first submit a request for it, but first, a Master Secret must be generated. A Master Secret is a piece of secret information used by a Prover to ensure that a credential applies exclusively to them. The Master Secret is an input that integrates information from numerous Credentials to demonstrate that they all pertain to the same subject (the Prover). Only the Prover should know the Master Secret. The user generates a Master Secret within their wallet. Additionally, the user must obtain the Credential Definition that corresponds to the credential definition id in the Theater Card Credential Offer. At this point, the user possesses everything necessary to submit a Credential Request for the Institution1 Theater Card Credential. Institution1 generates both unencoded and encoded values for every attribute in the Theater Card Credential Schema. Institution1 generates the user's Theater Card Credential. The Theater Card Credential has been issued at this time. It is stored in the user's wallet. The user is in possession of it, much in the same way that he or she would be holding a physical theater card that had been provided to them. Issuing a credential to a user by an institution flow is shown in Figure 8.

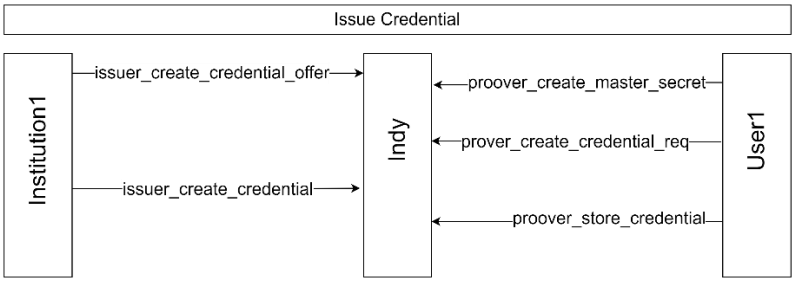

Figure 8. *Issue credential flow.*

3.2.7. Proof

When a business wants to make a proof, it should send a connection invitation to the user. The process is different than backoffice-business/institution connections because the user wallet is using Indy-SDK, but the flow is the same. After the user accepts the connection invitation, the business sends a proof request that contains the schemas' and attributes' predicates to be verified. According to the proof request, the required credential attributes

should be satisfied by the user. To accomplish this using Indy-SDK, the user must obtain the Credential Schema and Credential Definition for each credential used in the same manner as when creating a Credential Request.

At that point, the user creates the Proof for the business and when the business examines the received Proof, they will observe the following format:

- The business obtained all requested attributes.
- The business desires to examine the Validity Proof.
- To accomplish this, the business must obtain each Credential Schema and Credential Definition for each identifier given in the Proof in the same manner as the user.
- Now the business has everything necessary to verify the user's Proof.

The proof flow is shown in Figure 9.

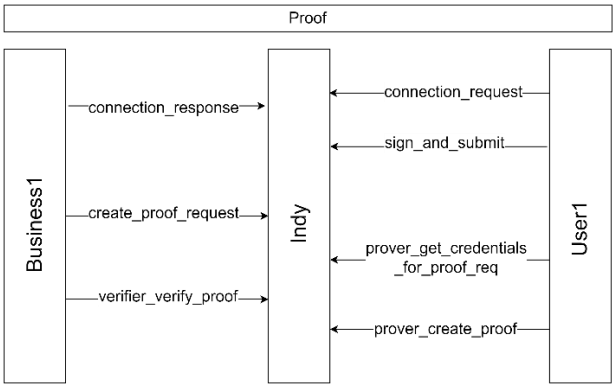

Figure 9. *Proof flow.*

3.3 Application of ACA-Py

A single instance of an Aries agent consists of two components: the agent itself and a controller. Aries agent structure is depicted in Figure 10.

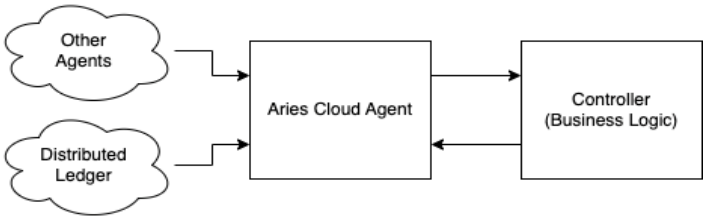

Figure 10. *Aries agent structure.*

Aries Cloud Agent is responsible for all of the core Aries functionality, including interacting with other agents, handling secure storage, sending event notifications to the controller, and getting instructions from the controller. The controller defines the behavior of a particular agent instance, including how to respond to agent events and when to trigger the agent to initiate events. The agent communicates events to the controller, and the controller responds with instructions for the agent's administrator. The agent provides a REST API to the controller for all of the administrative messages it is set to handle, and the controller registers a webhook with the agent to receive HTTP callbacks for event notifications. Aries Agents interact with one another through a messaging system known as DIDComm (DID Communication). DIDComm allows secure, asynchronous, end-to-end encrypted messaging between agents, with messages routed through an intermediary agent configuration.

ACA-Py utilizes the Ursa library and the indy sdk for cryptographic requirements and interaction with the indy blockchain, respectively.

3.3.1. Infrastructure

Initially, a Postgresql database is started up as the wallet storage. Then an Indy network was established. A Von network, which is a development-level, portable Indy Node network with a Ledger Browser, is utilized to establish an Indy network. The Ledger Browser enables a user to view the status of a network's nodes and to filter Ledger Transactions. Also, public DIDs are published via the Von network. After the Von network has been activated, a DID is created as the TRUST_ANCHOR role with a seed and made public. This seed is stored in the configuration file and utilized by the Backoffice instance.

3.3.2. Initialize backoffice wallet

To be able to create sub-wallets for institutions and businesses, multi-tenancy is enabled in ACA-Py. In multi-tenancy, a single agent is run and resources are shared between the tenants of the agent. Institutions and businesses as different tenants have their wallets and DIDs. In ACA-Py, multi-tenancy distinguishes between a base wallet and sub-wallets that are different tenants. When multi-tenancy is turned off, a sub-wallet is able to perform all operations with a single-tenant ACA-Py instance. But the base wallet has a different role and functionalities. Base wallet manages the sub-wallets and uses different endpoints on multi-tenant Admin API. In that way, the base wallet stores all configurations and information of sub-wallets and routes the messages between sub-wallets. The base wallet can not do the actions like issuing credentials, presenting proof, etc. In the design of this work, the back office is the base wallet and manages the institutions and businesses as sub-wallets. The base wallet creates the sub-wallets in managed mode. This makes the ACA-Py fully control the wallet. Thus, the messages that come from other agents can be unlocked and processed. To determine which tenant to route the message to, the mediator routing type is used. The default mediator set is stored in the base wallet, and this set is used by sub-wallets. When a connection or key is generated by a sub-wallet, it will be registered at the mediator through the base wallet relationship. Even now, the base wallet continues to perform the function of a relay by directing messages to the appropriate sub-wallets.

3.3.3. Onboarding of institutions and businesses

For both onboarding process, a tenant registration operation is started to create wallets. Using the [post] /multitenancy/wallet endpoint, the backoffice wallet sends the tenant information which includes wallet name, wallet key, webhook urls for the wallet, and other configuration parameters. Webhook urls are for calling back to the controller. ACA-Py uses webhook events to establish the connection. It is possible to designate multiple webhook targets but unique webhook targets for each wallet are created in this work. Wallet id is included in the events in "x-wallet-id" header to recognize the separation of the wallet. When a wallet is created for an institution or a business, a wallet id is created and this wallet id is stored as a record related to the institution or the business. When an operation will be called on behalf of the business or the institution, a token is created with [post] /multitenancy/wallet/{wallet_id}/token endpoint. To create a token, the admin API key, wallet key, and wallet id of the tenant are needed. Additionally, once a token is created, the previous one becomes invalid.

JSON Web Tokens (JWTs) are being utilized in an additional authentication technique for sub-wallets. Every single admin API request for the wallet that uses the Bearer authorization scheme requires the provision of a JWT token as a parameter.

3.3.4. Creating schema and credential definitions

As defined before, institutions are issuers of the system. Through the backoffice, on behalf of institutions, schema definitions are created according to the identity type of institutions. Schema definitions cover the fields of the data. Then credential definitions, that include these schema definitions, are created. Using credential definitions, institutions issue credentials to the users. These credentials are the identities of users and will be proofed by businesses.

Schema Definition:

Endpoint: [post] /schemas

Request: Schema name, version, and attributes of the schema.

Credential Definition:

Endpoint: [post] /credential-definitions

Request: Credential tag and created schema definition id.

3.3.5 Issuing credential

In issuing a credential process, there are two stakeholders: institutions as issuers that send offers to issue a credential, and users as holders that send credential requests. The first step is creating a connection between the institution and the user. If the connection exists, the existing one is used. Using the connection and the credential definition id, the institution sends an offer that includes the identity attributes to the user with [post] /issue-credential/send-offer. The user gets that offer and accepts with [post] /issue-credential/records/{cred_ex_id}/send-request. A credential exchange id is generated when the institution sends the offer.

3.3.6. Proof

In the proof process, there are two stakeholders: businesses as verifiers that request proofs, and users as holders that present proofs. As with the beginning of all transactions, a connection is needed between the verifier and the holder. If the connection exists, the existing connection is used; if not, a new connection is created. As defined in the application part, the content of the proof requests is created as a record for businesses through the back office application. When a business requests proof, the requested attributes, and restrictions come from this record. When the business scans a QR code, the connection is found or created between this business and the user, and this connection id is dynamically changed for each proof request. Business sends this combination of the request with [post] /present-proof/send-request to the user. When the request comes to the user, the user creates a proof according to the restrictions of the proof request with owned credentials. When this proof is presented with [post] /present-proof/records/{pres_ex_id}/send-presentation from the user to the business, business verifies the identity of the user and uses that identity according to the need.

4. Results

As a result of this study, the real-life use of Blockchain-based SSI technology has been implemented. Although there are many options to develop this structure, the advantages and disadvantages of each option were examined and the most suitable one for the study was decided. Considering the concept of a smart city, since one of the stakeholders of the developed system is directly human, it is considered that the system should be safe and consistent. In this direction, it was decided that it would be appropriate for the infrastructure to be blockchain-based. It is the most important rationale that a blockchain-based system is secure, consistent, and immutable. During the process of the study, the changing and developing technology was followed and put into practice. The SSI technology, which has existed for a long time, but whose applications on the blockchain are increasing, forms the infrastructure of the study for the same reason. Since SSI is a structure that provides identity management under the dominance of the person as a concept, the SSI structure overlapped and was used in this study by implementing it without making any adverse changes to the structure. At this stage, it was decided that building a system on Hyperledger Indy would give the most appropriate result.
It was decided to use the ACA-Py framework, which uses the Hyperledger Indy infrastructure and provides a more advanced infrastructure developed on indy protocols. The reason for choosing this framework is detailed in the following sections. Table 2 defines the ACA-Py properties and in Table 3 comparisons are given between ACA-Py and Indy.

Table 2. *ACA-Py properties.*

Property	Definition
Supported Signatures	CL signature, ED signature, BBSBLS signature
Supported Credential Types	Hyperledger Indy AnonCreds, W3C Standard Verifiable Credentials using JSON-LD
Supported Protocols	Aries Interoperability Protocol 1.0 (AIP 1.0), Aries Interoperability Protocol 2.0 (AIP 2.0)
Multi-Tenancy Support	Multi-tenancy in ACA-Py enables numerous tenants to use the same instance of ACA-Py with a distinct context. Each tenant receives a private, encrypted wallet containing only their info.
Mediator Support	A mediator is simply a specialized agent. Over a DIDComm connection, this agent transmits information to a client.
Multi Indy ledger support	ACA-Py supports multi Indy ledger with automatic detection.
Scaled Deployment Support	Allows deployments in scaled environments, such as Kubernetes systems, in which ACA-Py and its storage components can be horizontally scaled to accommodate the load.
Transaction Endorser Support	ACA-Py has a protocol called "Endorser Protocol" that lets a non-privileged agent called an "Author" ask another agent called an "Endorser" to sign their transactions so that they can be written to the ledger. This is needed for Indy ledgers, where new agents usually only get "Author" rights.
Supported Secure Storage Types	Aries Askar, Indy SDK "indy-wallet"
Number of Contributors	100

Table 3. *ACA-Py and Indy comparison.*

	ACA-Py	Indy
Multi-Tenancy	Supported	Not supported
Authentication	Supported	Not supported, Needs custom implementation
W3C Credentials	Supported	Not supported
Performance	With ACA-Py Askar, the DB connection implementation has been completely changed, so the performance and consistency problems have been resolved.	In the previous versions, sqlite db was used as a wallet and could be run as a single instance. Postgresql support came as a plugin to solve the single instance problem. However, performance and inconsistency problems remain.

4.1. ACA-Py Askar vs Indy performance

Table 4 shows the results of Askar and Indy performance of interacting agents. It is created from the load test results made and announced by the community.

Table 4. *Askar and Indy performance results.*

	Askar	Indy
Number of iterations	Started: 68251 In Progress: 24 Finished: 68227	Started: 18369 In Progress: 2534 Finished: 15835
Number of Connection Invitations	Total: 68251 Failed: 1	Total: 18361 Failed: 119
Number of Credential Offers	Total: 68250 Failed: 8	Total: 18083 Failed: 1957
Number of Proof Requests	Total: 68242 Failed: 2 Incorrect: 13	Total: 16123 Failed: 116 Incorrect: 0
Number of Revocation Verifications	Total: 136 Failed: 0	Total: 0 Failed: 0

Table 5 shows the performance comparison of Askar and Indy wallets. In Indy's previous versions, sqlite db was used as a wallet and could be run as a single instance. Postgresql support came as a plugin to solve the single instance problem. However, performance and inconsistency problems remain in the Indy wallet. With Askar, the DB connection implementation has been completely changed, so the performance and consistency problems have been resolved. These results are created by up-and-running two agents locally. Locally, a local Postgresql database and local instance of von-network are initiated. A did for the trust anchor is registered on the von-network.

Table 5. *Askar and Indy performance comparison.*

	Askar	Indy
Start-up Duration	34.62s	67.58s
Connection Duration	1.32s	2.03s
Credential Definition Publish Duration	6.19s	9.88s
Average Time Per Credential	2.46s	2.54s

4.2. ACA-Py vs Aries Go

Hyperledger Aries Framework Go allows communication and data exchange based on interoperable distributed ledger technologies and peer-to-peer interactions. Although Aries Go has support for many important issues such as W3C credentials, universal wallet, mediator, and BBSBLS Signature, the ACA-Py was preferred because Aries Go's development is still ongoing and it is not product ready. A comparison of ACA-Py and Aries Go frameworks is presented in Table 6.

Table 6. *ACA-Py and Aries Go comparison.*

	ACA-Py	Aries Go
Multi-Tenancy	Supported	Not supported, Needs custom implementation
Authentication	Supported	Under development
W3C Credentials	Supported	Supported
Supported Signatures	CL signature, ED signature, BBSBLS signature	ED signature, BBSBLS signature
Universal Wallet	Not supported	Supported
Mediator Service	Supported	Supported
Supported Protocols	Aries Interoperability Protocol 1.0 (AIP 1.0), Aries Interoperability Protocol 2.0 (AIP 2.0)	Aries Interoperability Protocol 2.0 (AIP 2.0)

5. Conclusions

As a result of this study, the real-life use of Blockchain-based SSI technology has been realized. The concept of SSI has started to be applied in many fields today. The studies carried out in this field, combined with the advantages of blockchain technology, have enabled the creation of safe and reliable data. With this technology, it is ensured that personal data is stored in accordance with the laws of protection of personal data all over the world. Considering the concept of a smart city, it is thought that the system should be safe and consistent since one of the stakeholders of the developed system is directly human. In this direction, the fact that the infrastructure is blockchain-based has been evaluated as the best option for this system in the most up-to-date technology. The most important reason is that a blockchain-based system is secure, consistent, and immutable. With the application developed on the infrastructure established with the concept of identity under personal dominance and blockchain security, users are able to manage their information and decide with whom to share and hide it. Since the information of the users is stored as signed by the authorities, it is ensured that all information is presented as proven correct. With the established system, the obligation to use different documents, identity cards, and/or applications for different institutions has been eliminated. It is possible to store all identities by combining them in a single application. Institutions and organizations have become able to approve the reliability of the shared document without the need for an institution-specific proof flow. The guarantee that the stored documents are unalterable and incorruptible demonstrates the reliability of the system and the necessity of its use. In order to create such a system, it has been decided that the most appropriate framework for the infrastructure to be used is ACA-Py. The most important reasons for selecting ACA-Py is; multi-tenancy support that allows the creation of multiple agent instances, mediator support that allows secure messaging between agent and client over DIDComm connection, multi-Indy ledger support that allows the ability to use multiple Indy ledgers for resolving a DID by the ACA-Py agent, scaled deployment support that allows to establish and change the running ACA-Py and storage components capacity, and authentication support which is required to guarantee security. Afterward, performance measurement was made between Askar and Indy for the selection of the wallet to be used. According to these measurements, performance and inconsistency problems exist for the Indy wallet. With Askar, the DB connection implementation has been completely changed, so the performance and consistency problems have been resolved. Askar wallet is more consistent and faster. Compared to Askar, start-up time for an agent, duration of creating a connection between two agents, publication of a schema definition and a credential definition utilizing the published schema duration over an agent, and average credential exchange times between two agents when issuing credentials are all less than an Indy wallet. Because of these results, Askar wallet is used in the system. When ACA-Py and Aries Go are compared to select a framework; ACA-Py is chosen over Aries Go because Aries Go's development is still ongoing and it is not yet product-ready. Aries Go supports a number of critical issues, such as W3C credentials, universal wallet, mediator, and BBSBLS Signature, but its development is not yet complete and it is not yet product-ready.

Since the infrastructure utilized in this study is a new technology, it is quite open to development and change. In the blockchain infrastructure, the SSI system is currently being improved.

- First of all, in this study, we used the standard Indy credentials (AnonCreds). As a consequence of the enhancements, ACA-Py now supports W3C standard verifiable jsonld credentials. Unlike Indy credentials, JSON-LD credentials can be issued without a schema or credential definition. Using Linked Data Contexts, everything required to issue the credential is embedded within the credential

itself. As a development of the current system, the W3C standard verifiable credentials will be used to assign schema-recognizable identities to users.

- While ACA-Py is selected as the framework, the primary reason is that the Aries Go framework is not yet product-ready. Although the development is not completed, multitenancy and authentication properties can be implemented and the infrastructure can be changed with the Aries Go framework. The most important reasons for replacing the infrastructure with Aries Go are that it supports a universal wallet, different did methods can be used and it is ledger agnostic. It is possible to use the "ion" method that operates on the Bitcoin network by making use of sidetree protocols. Despite being the technique with the most legitimacy, ion transactions are painfully slow because they take place on the Bitcoin network. Because of this, a more efficient method is able to be developed across the various blockchain networks (such as Avalanche, Near, Solana).
- Lastly, the implementation of support for the bounded BBSBLS signature that enables verifying the prover is currently under development for the ACA-Py framework. After the development of this feature has been finished, it will be incorporated into the system, and a feature will be introduced that will allow verifying the users within the proof process.

Declaration of Interest

The authors declare that there is no conflict of interest.

Author Contributions

Aslı Bahce: Conceptualization, Methodology, Software, Formal analysis, Writing - original draft, Results and discussions.
Semih Utku: Methodology, Validation, Writing - review & editing, Supervision.

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Data Driven Modelling of Microstrip Patch Antenna

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Abstract

The design and analysis of microstrip patch antennas are crucial for microwave applications, such as communication systems, radar, and imaging devices. However, the complex interactions between the antenna's geometrical parameters, material properties, and performance characteristics make the design process computationally expensive and time-consuming. This paper presents a comprehensive study on data-driven surrogate modeling techniques for efficient design and optimization of microstrip patch antennas. We discuss various surrogate modeling techniques, such as support vector regression machine, Gaussian process models, artificial neural networks, and deep learning-based approaches, and evaluate their performance in predicting the antenna's performance metrics. Additionally, we demonstrate the application of surrogate modeling in the optimization of microstrip patch antennas and address the challenges and future research directions in this field.

Keywords: Antenna; artificial intelligence; optimization; surrogate models.

1. Introduction

The utilization of Radio Frequency (RF) communication has become an essential component of contemporary society, with its implementation extending across diverse fields, including telecommunications, sensing, and wireless power transmission. The Industrial, Scientific, and Medical (ISM) band is a significant segment in the RF spectrum that presents a distinctive prospect for a broad spectrum of applications owing to its unlicensed nature. The International Telecommunication Union (ITU) has allocated the ISM bands, which are usually centered around 2.4 GHz, 5.8 GHz, and 24 GHz, to cater to a diverse range of applications without requiring explicit licensing or regulatory approval. The adaptability of these frequency bands has facilitated the swift advancement and dissemination of wireless technologies and apparatuses, thereby engendering new and inventive implementations.

Microstrip patch antennas have gained widespread popularity in microwave applications due to their low-profile, lightweight nature, and ease of fabrication [1-4]. The design of microstrip patch antennas involves the optimization of various geometrical parameters, such as patch dimensions, substrate thickness, and feed position, to achieve the desired performance characteristics, such as radiation pattern, bandwidth, and gain [5]. However, the complex relationships between these parameters and the antenna's performance characteristics make the design process computationally expensive and time-consuming, particularly when employing traditional electromagnetic simulation tools [6].

In recent years, there have been notable advancements in the design of microwave antennas, which can be attributed to the increasing need for communication, sensing, and radar systems with superior performance. The growing complexity and evolving requirements of these systems have resulted in a heightened demand for modelling techniques that are both efficient and accurate. These techniques are necessary to enable swift design iterations and performance optimization. The accuracy of traditional full-wave electromagnetic (EM) simulations is well-established, however, their computational demands are substantial and time-consuming, which can present obstacles for tasks that require timely decision-making and optimization. The utilization of data-driven surrogate modelling has surfaced as a potent and adaptable approach that connects the disparity between computationally costly simulations and prompt, dependable predictions. Surrogate models, also referred to as metamodels, utilize data derived from a restricted set of simulations or experiments to furnish an estimation of the fundamental systems. This approach offers valuable insights into the behavior of the systems while considerably mitigating the computational load. Data-driven surrogate modeling offers an attractive solution to overcome these challenges by

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providing rapid and accurate predictions of the antenna's performance characteristics based on a limited set of input-output data [7]. Surrogate models, also known as metamodels are approximations of the underlying complex system, which can be trained using available data to provide predictions at a significantly reduced computational cost [8]. In this paper, we present a comprehensive study on data-driven surrogate modeling techniques for efficient design and optimization of microstrip patch antennas for microwave applications [9].

2. Antenna Design and Its Surrogate Modelling

Herein, the present study investigates a Microstrip patch antenna design (depicted in Figure 1) featuring a square-shaped radiator and a tapered transmission line. Table 1 provides the lower and upper bounds of the variable space for the given problem. The Latin-Hyper cube Sampling (LHS) technique has been selected as the sampling approach for producing training and testing samples, utilizing the input domain specified in Table 1. A set of 800 data samples was utilized to assess the efficacy of the data-driven models, with 800 samples allocated for training and 200 for hold-out purposes. Each data sample generated in this study includes the scattering parameter response within the frequency range of 1-4 GHz, with a step size of 0.1 GHz. This study employs prevalent artificial intelligence algorithms for data-driven surrogate modelling, and their outcomes are exhibited in Table 2. The results presented in this study were obtained through a k-fold validation approach, where k was set to 5. Additionally, a hold-out dataset consisting of 200 samples was used, and the Relative Mean Error (RME) metric (as defined in Equation 1) was employed. The M2LP model has been determined to be optimal for this problem based on its lowest error value in both k-fold validation and hold out data sets.

$$RME = \frac{1}{N}\sum_{i=1}^{N}\frac{|Target_i - Predicted_i|}{|Target_i|} \quad (1)$$

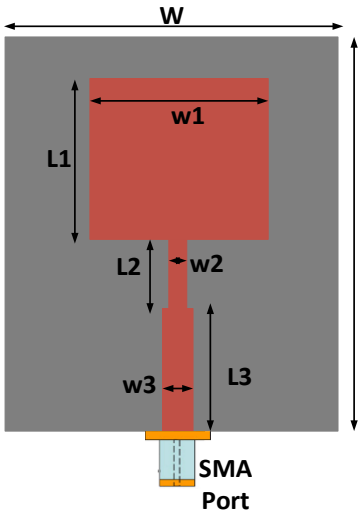


Figure 1. *Schematic of the studied antenna.*

Table 1. *Design variables and their variation limits*

Parameter	Lower	Upper	Parameter	Lower	Upper
L1	20	30	W1	30	40
L2	5	15	W2	0.5	1.5
L3	5	15	W3	2	4

Table 2. *Performance results of algorithms.*

Model	Hyper-Parameters	K-fold/Holdout
SVRM [10]	Epsilon=0.2, Kernel of Radial basis	9.9% / 10.7 %
Gaussian Process Regression [11]	Kernel 'ardmatern52', predication Block coordinate descent block size of 1500	6.4% / 7.6%
MLP [12]	Two hidden layers with 25-30 hidden neurons with trained with Levenberg-Marquardt back propagation	7.3% / 8.2%
M2LP [13]	depth of 3 with initial neurons size of 128	4.2% % 5.1 %

3. Study Case

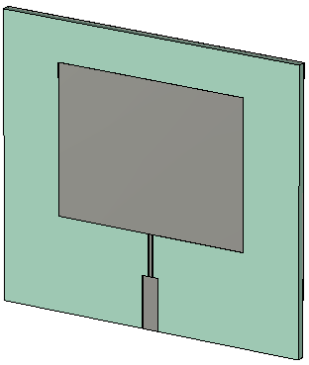
Optimization plays a crucial role in various scientific and engineering applications. The search for efficient optimization techniques has led to the development of several nature-inspired algorithms, including Genetic Algorithms, Ant Colony Optimization, and Particle Swarm Optimization (PSO). It was proposed by Kennedy and Eberhart in 1995, and since then PSO has attracted considerable attention due to its simple nature and working principle [14]. In PSO each individual, called a particle, represents a potential solution in the search space. The particles move iteratively through the search space, updating their positions and velocities according to their own experiences and those of their neighbors. The best position found by any particle in the swarm is named as "global-best", while the best position found by a particle individually is called "personal-best". The present study has opted for PSO as a proficient meta-heuristic optimization method to optimize antenna geometries [15-17]. The cost function, as represented by Eq. (2), has been employed to steer the search process.

$$\text{Cost} = \sum_{f_{\min_1}}^{f_{\max_1}} \frac{C_1}{\left|S_{11_i}(f)\right|} \tag{2}$$

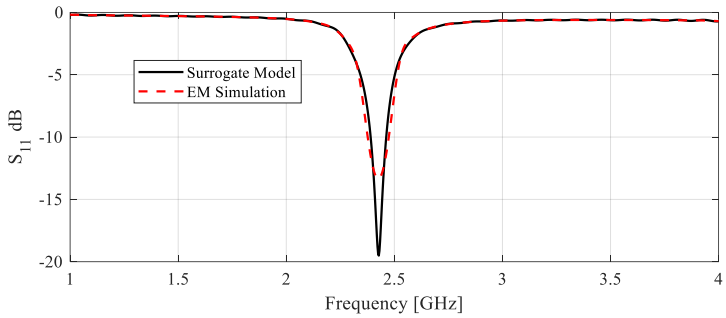
The value of weighing C1 is set to unity, and the frequency range is specified as 2.3 to 2.5, centered at 2.4 GHz, for applications in the ISM band. Table III displays the geometric design variables that were optimally selected through the implementation of PSO. Figure 2 displays the simulated performance of the antenna that has been optimally designed. To validate the efficacy of the proposed data-driven surrogate model, a comparison is made between the simulated performance of the optimal antenna obtained through M2LP and the results obtained through a full-wave simulation model. As depicted in Figure 2, the simulated S11 characteristics are in close agreement with the expected results presented in Table II.

Table 3. *Optimal determined design parameters of the Antenna in [mm]*

L1	28.8	**W1**	37.3
L2	8	**W2**	0.8
L3	10	**W3**	3.2
L	59.5	**W**	54.8



(a)



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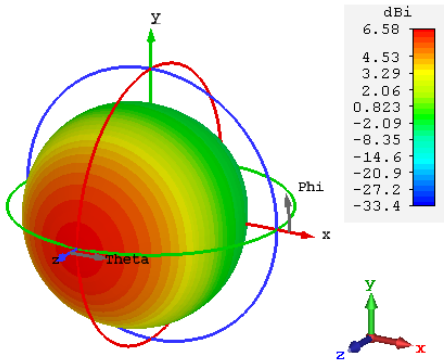

(c)

Figure 2. *(a) full wave simulation model of optimally designed antenna, (b) simulated S_{11} results of M2LP and full wave simulation model, (c) simulated radiation pattern of the antenna @ 2.4 GHz.*

4. Conclusion

This study presents a methodology for optimizing the design of a Microstrip Antenna using a computationally efficient approach that relies on data-driven surrogate modelling techniques. The surrogate representation of the antenna problem was created using data samples obtained from 3D electromagnetic simulators. The optimal solution for this problem was determined to be M2LP based on a performance comparison of a series of regression algorithms. Subsequently, in order to validate the proposed methodology, three distinct case studies were selected and treated as optimization problems to be solved using the aforementioned approach. The outcomes derived from this approach were then juxtaposed with those obtained from 3D EM full wave simulator results. The results demonstrate that the proposed surrogate modelling approach effectively identifies the desired geometrical design variables to elicit the desired design response. Furthermore, the results obtained exhibit a high degree of agreement with the outcomes of 3D EM simulations.

Declaration of Interest

The authors declare that there is no conflict of interest.

Author Contributions

Conceptualization, Mehmet BEREKET, Mehmet A. BELEN and Aysu BELEN; methodology, Mehmet BEREKET; data generation, Mehmet A. BELEN; investigation, Aysu BELEN; benchmarking models, Aysu BELEN; writing—original draft preparation, Aysu BELEN, Mehmet A. BELEN; writing—review and editing, Mehmet BEREKET and Mehmet A. BELEN; visualization, Mehmet A. BELEN; supervision, Mehmet A. BELEN; project administration, Mehmet A. BELEN. All authors reviewed the manuscript.

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Data Driven Modelling of Microstrip Frequency Selective Surface for X Band Applications

Aysu BELEN

Abstract

Efficient and accurate modelling approaches have become necessary in computational science and engineering due to the rising complexity and high dimensionality of physical and engineered systems. The utilisation of data-driven surrogate modelling has surfaced as a potent methodology to overcome the disparity between computationally expensive simulations and prompt, dependable predictions. The current study offers a thorough examination of data-driven surrogate modelling methods as they pertain to the optimisation and design of microstrip frequency selective surfaces (FSSs) within microwave systems. In this discourse, we delve into the rudiments of surrogate modelling, diverse categories of surrogate models, and their respective merits and demerits in the realm of FSS modelling. The utilisation of widely used Artificial Intelligence algorithms is implemented for the purpose of data-driven surrogate modelling, and their efficacy is evaluated through the Relative Mean Error metric. The research findings indicate that the M2LP surrogate model exhibits optimal performance in the specific scenario under investigation. Furthermore, the Honey Bee Mating Optimisation algorithm is utilised to optimise the design of FSS. The results of our study demonstrate that data-driven surrogate modelling is an efficient and effective method for designing and optimising microstrip frequency selective surfaces (FSSs). Specifically, our approach yielded a gain improvement of nearly 3 dB within the chosen frequency band. The forthcoming research endeavours to investigate the optimisation of more intricate FSS designs for analogous applications that encompass broader operation bands.

Keywords: Antenna; data driven; gain enhancement; optimization; surrogate model.

1. Introduction

In the realm of computational science and engineering, the increasing complexity and high dimensionality of physical and engineered systems have intensified the demand for efficient and accurate modeling approaches. Traditional simulation-based models often require immense computational resources and time, posing significant challenges for time-sensitive decision-making and optimization tasks [1]. To address this issue, data-driven surrogate modeling has emerged as a powerful and versatile methodology that bridges the gap between computationally expensive simulations and rapid, reliable predictions. Surrogate models, also known as metamodels are approximate representations of the underlying systems, providing valuable insights into their behavior while significantly reducing the computational burden. By leveraging data obtained from a limited number of simulations or experiments, these models facilitate the exploration of vast design spaces and enable efficient optimization, uncertainty quantification, and sensitivity analysis. Moreover, they have found widespread applicability in various disciplines, such as fluid dynamics, materials science, structural engineering, and microwave engineering modelling [2].

Frequency Selective Surfaces (FSSs) have emerged as a crucial element in the design and optimization of modern microwave and millimeter-wave systems, driven by the rapidly increasing demand for high-performance communication, sensing, and radar technologies [3]. As periodic structures that selectively transmit, reflect, or absorb electromagnetic waves based on their frequency, FSSs enable the tailoring of electromagnetic responses and offer a versatile means for controlling the interaction between waves and structures. Among the various FSS design approaches, microstrip-based FSSs have garnered significant interest due to their compactness, low profile, ease of fabrication, and integration with planar technologies [4].

While traditional FSS design methodologies have demonstrated considerable success, the growing complexity of microwave systems and the increasing demand for high-performance solutions have spurred the need for more efficient and accurate design approaches. Data-driven surrogate modeling has emerged as a powerful tool for addressing this need, providing a means to rapidly and accurately predict the performance of microstrip FSSs while significantly reducing the computational burden typically associated with full-wave electromagnetic simulations [5]. By leveraging a limited set of simulation or experimental data, surrogate models enable the efficient exploration of vast design spaces, facilitating the optimization of FSS performance and the identification of novel design configurations.

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This paper presents a comprehensive investigation of data-driven surrogate modeling techniques applied to the design and optimization of microstrip frequency selective surfaces in microwave systems. We begin by discussing the fundamentals of surrogate modeling, including key concepts such as regression, interpolation, and dimensionality reduction, and their relevance to microstrip FSS design. Subsequently, we delve into various types of surrogate models, such as polynomial regression, Gaussian process models, artificial neural networks, and deep learning-based approaches, highlighting their strengths and limitations in the context of FSS modeling.

2. FSS Design and Its Surrogate Model Representation

The researched unit element for the FFS design is depicted schematically in figure 1. Table 1 contains the design variables for the cell and their respective ranges. Figure 2 shows a parametric analysis of the variables. It should be noticed that every variable has a sizable impact on the element's resonance frequency. The parameters must be simultaneously optimised in a global sense in order to get the best design variables for a given scattering parameter response. However, direct EM-driven is quite costly in terms of computing. Regression models based on artificial intelligence (AI) are used in this work to lower CPU expenses. Both the training and test (holdout) data sets need to be somewhat modest in size in order to retain minimal costs. Here, the model is built using 500 training samples produced via Latin-Hypercube Sampling (LHS) and 100 hold-out samples. Each sample is an evaluation of a scattering parameter vector over the frequency range of 2 to 10 GHz with a 0.1 GHz increment. Some design variables are assumed to be constants or functions of other variables in order to reduce the overall number of design variables/problem dimensions.

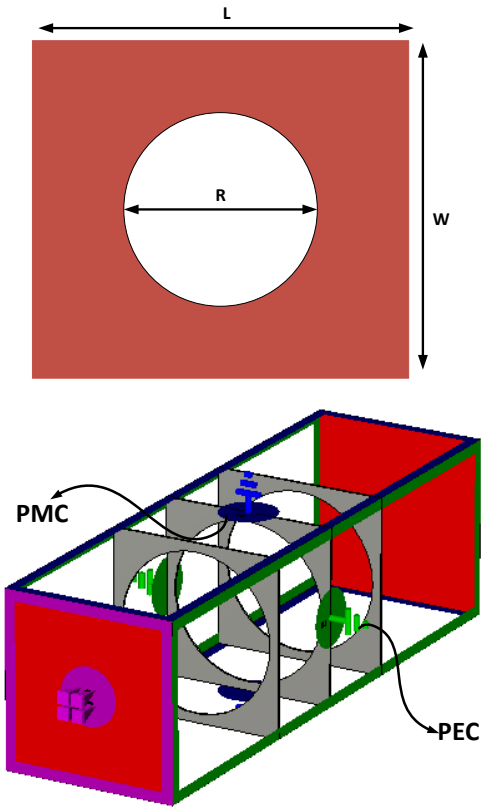


Figure 1. *Schematic of the proposed FSS element.*

TABLE 1. *Design variables and their variation limits*

Parameter	Lower	Upper	Parameter	Lower	Upper
L	10	30	R	5	20
W	10	30	G	5	20

This study employs prevalent Artificial Intelligence algorithms for data-driven surrogate modelling, and their outcomes are exhibited in Table 2. The results presented in this study were derived through a k-fold validation technique with k=5, in conjunction with an extra hold-out dataset comprising of 200 samples. Also Bayesian Optimization algorithm is used for determination of hyper-parameters. The Relative Mean Error (RME) metric (Eq. 1) was utilised to evaluate the performance of the model. The Modified Multi-layer Perceptron (M2LP) is an enhanced version of the traditional multi-layer perceptron (MLP), an artificial neural network model that maps sets of input data onto a set of appropriate outputs. The MLP, while effective, has certain limitations when it comes to computational speed and the ability to handle complex problems. The M2LP aims to overcome these limitations by implementing adjustments in the design of the MLP architecture.M2LP will be employed as the ideal model for this study case, because it has the lowest error value in both the hold-out and k-fold validation data sets.

$$RME = \frac{1}{N}\sum_{i=1}^{N}\frac{|Target_i - Predicted_i|}{|Target_i|} \quad (1)$$

TABLE 2. *Performance results of algorithms.*

Model	Hyper-Parameters	K-fold/Holdout
SVRM [6]	hyperpar.epsilon=0.2, hyperpar.kernelfunction= Radial basis	9.3% / 10.1 %
Gradient Boosted Tree [7]	hyperpar.learningrate=0.035 hyperpar.Numestimators=4700 hyperpar.depth=4	8.6% / 9.2%
M2LP [8]	hyperpar.depth=3 hyperpar.Numneuron= 64	4.6% % 5.5 %

3. Study Case

The present section employs the M2LP surrogate model to perform design optimisation of the FSS. The Honey Bee Mating Optimisation (HBMO) is a meta-heuristic algorithm that draws inspiration from the mating strategy of Honey Bees, and serves as the search engine. This algorithm has been documented in literature [9]. The HBMO technique is a method that utilises the principles of evolutionary algorithms and is based on population dynamics. In this specific procedure, the most physically capable person (potential solution) is designated as the dominant individual, or Queen Bee. The fertility rate of Queen Bees or queen candidates is determined by the quality of design that corresponds to a specific individual, represented by a parameter vector. In each successive generation, the calibre of the newly generated individuals is evaluated in relation to that of the Queen. The individual possessing superior traits assumes the role of the queen, thereby influencing the production of new individuals in the succeeding generation. This outline pertains to the overarching aspect of the optimisation procedure. The literature contains information regarding the operational intricacies of the algorithm [10]. One of the parameters that has a significant impact on the fitness of the Queen Bee is the consumption of royal jelly. The provision of certain nutrients has been shown to increase the lifespan of a typical bee from a mere thirty days to up to two years. This phenomenon is crucial in the development of a bee into a Queen. This phenomenon is also utilised in the HBMO protocol to facilitate local optimisation.

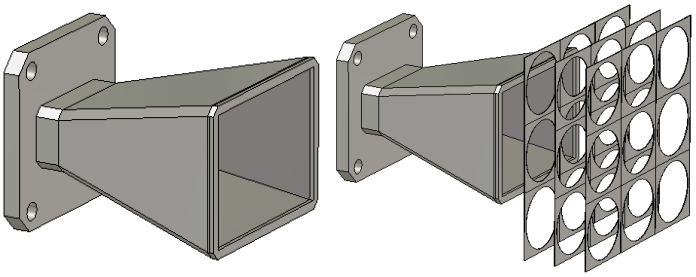
$$\text{Cost} = \sum_{f_{\min_1}}^{f_{\max_1}} \frac{C_1}{\left|S_{11_i}(f)\right|} \quad (2)$$

Here, weighing coefficients C_1= is taken equal to unity. The utilized cost in Eq. (2) is aim to maximize the magnitude of S_{11} values in the given frequency ranges of 10.4 and 10.6 GHz. The values shown in Table III were derived by the HBMO method employing the cost function in Eq. 2 and the M2LP surrogate model as an ideal model for the chosen operation band.

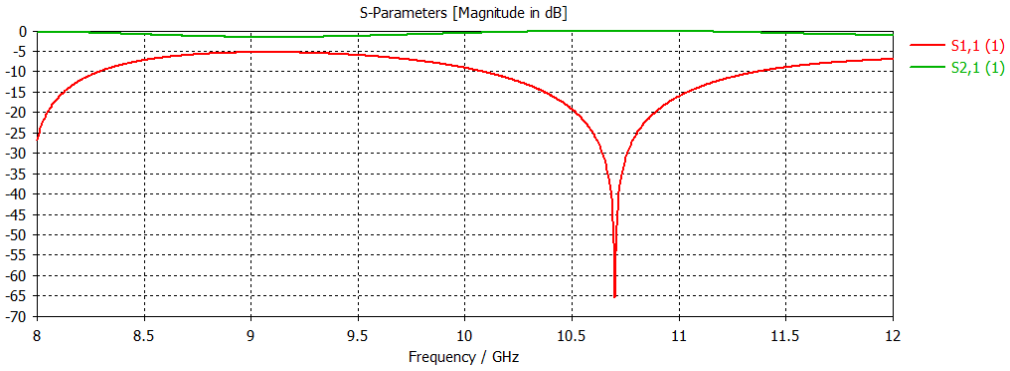
TABLE 3. *Optimal design parameters of FSS design [mm]*

L	20	**R**	18
W	20	**G**	11

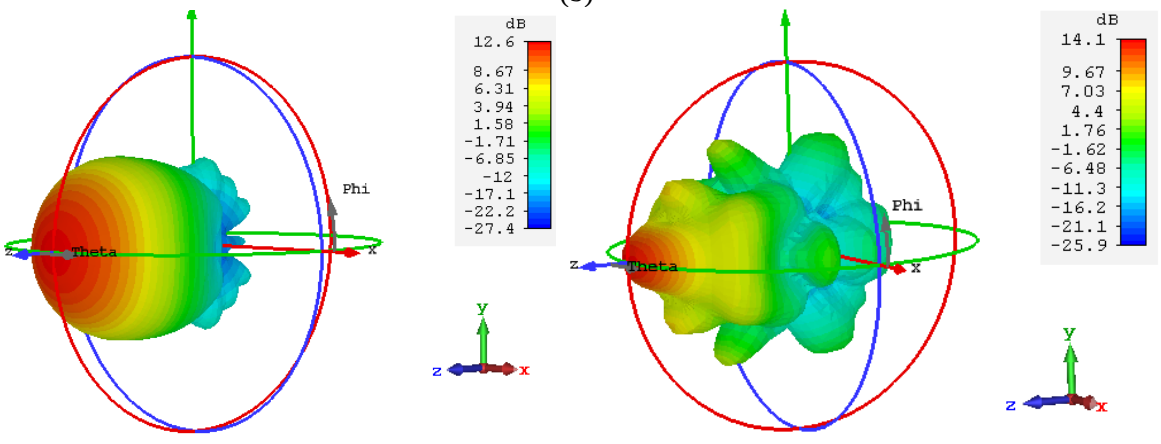
To validate the results obtained from the optimally selected parameter using M2LP, a full-wave simulation model of proposed FSS loaded antenna is modelled in CST environment (Fig. 2). The performance of the optimally designs FSS loaded horn antenna and the antenna without FSS structures are compared and as a results the overall performance of the antenna is clearly seen that being enhanced for the aimed operation band.



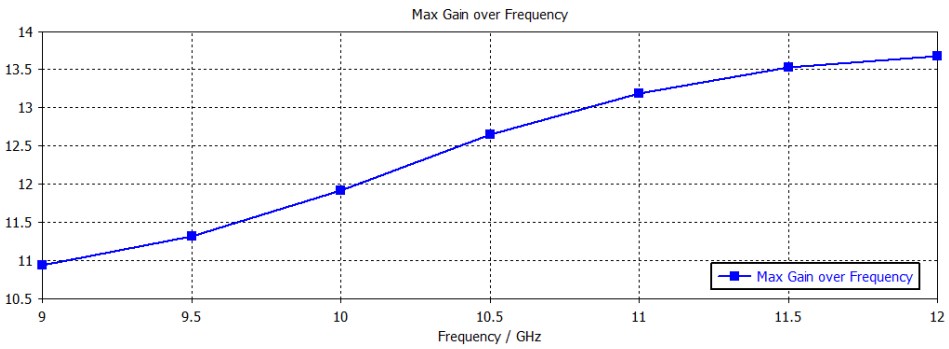
(a)



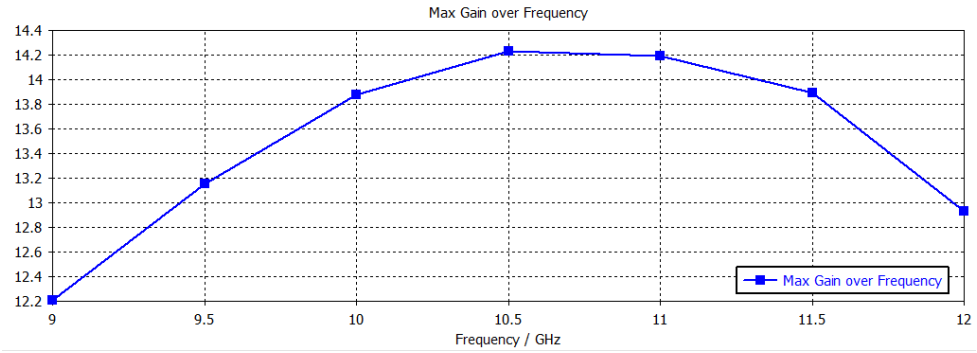
(b)



(c) (d)



(e)



(f)

Figure 2. *3D view of horn and FSS loaded horn antennas, (b) simulated S_{11} of optimal FSS array, simulated gain of (c) Horn antenna, (d) FSS loaded antenna, @ 10.5 GHZ, simulated maximum gain characteristic of (e) Horn antenna, (f) FSS loaded antenna.*

4. Conclusion

Here as it can be observed form the obtained results, by using data driven surrogate modelling design and optimization of a frequency selective surfaces array for performance enhancement of a horn antenna can be achieved in a computational efficient manner. Here gain improvement of almost 3 dB is achieved at the selected frequency band (10.5 GHz) which can be furthered increased with increased number of array element and layer sizes. In future works it is aimed to use more complex frequency selective surfaces designs optimization for similar application with wider range of operation band.

Declaration of Interest

The authors declare that there is no conflict of interest.

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Performance Evaluation of a Pretrained BERT Model for Automatic Text Classification

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Abstract

This study presents a pre-trained BERT model application on texts that are extracted from website URLs automatically to classify texts according to the industry. With the aim of doing so, the related dataset is first obtained from different kinds of websites by web scraping. Then, the dataset is cleaned and labeled with the relevant industries among 42 different categories. The pre-trained BERT model which was trained on 101.000 advertisement texts in one of our previous ad text classification studies is used to classify texts. Classification performance metrics are then used to evaluate the pre-trained BERT model on the test set and 0.98 overall average accuracy and 0.67 average F1 score for 12 among 42 categories are obtained. The method can be used to test the compatibility of texts to be used in online advertising networks with the advertiser's industry. In this way, the suitability of the texts, which is an important component in determining the quality of online advertising, within the industry will be tested automatically.

Keywords: Ad text; bidirectional encoder representations from transformers; digital marketing; natural language processing; text classification.

1. Introduction

Digital marketing is the marketing of products or services using digital technologies, mainly on the Internet, but also including mobile phones, display advertising, and any other digital medium [1]. The term digital marketing has evolved over time from a specific term that describes the marketing of products and services using digital channels to a term that describes the process of using digital technologies to acquire customers and create customer preferences, promote brands, retain customers and increase sales. Accordingly, many types of research have begun to be conducted on effective advertising studies examining the relationship between investment and conversion in online advertising. Within the scope of these researches, machine learning algorithms and natural language processing (NLP) techniques are used to draw meaningful results from advertisement data such as written and even visual or audio content of advertisements, user movements, device information, location information, or demographic data [2]. Search network ads, which have been used for a long time, especially in search engines such as Google, are mostly displayed to users as text-based. The most important feature of a quality search ad work is that the content presented to the consumer is relevant and effective. Ad quality on online advertising platforms depends on many different factors, including how relevant the texts are to searches, the likelihood of consumers clicking the ad, and the experience on the landing page after the ad is clicked. Higher ad quality leads to better ad position and lower cost [3]. At this point, the preparation of advertising texts that respond to consumer needs and calls plays an important role in effectively transferring the product/service offered by the advertiser to potential customers. In this study, a text classification method BERT architecture [4] is proposed to evaluate which text context may be more relevant to a relevant industry. In the studies [4]-[5] studies were examined and it was observed that BERT architecture gave better results than models such as Word2vec and LSTM in similar text classification problems. For this reason, it was decided to use the BERT model in the study. It was also observed that the average accuracy rate of the classification process we performed with the BERT model which was trained on advertisement texts in our previous study for 42 categories [6], can successfully classify a large number of texts automatically generated from the URLs of the websites according to the sectors.

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In the following sections of this article, the details of the studies we have carried out and the results obtained as a result of these studies are presented.

2. Related Work

Deep learning is a type of artificial neural network that uses sequential processing unit layers for feature extraction and each layer output feeds the next layer's input [7]. The theoretical foundations of deep learning, which has created an exciting new trend in machine learning in recent years, are well rooted in the classical neural network (NN) literature [8]. Thanks to the high capacity of neural networks to learn attributes from data, deep learning has been the subject of research in many fields besides NLP. One of the subjects of natural language processing, which has been studied for a long time and has important application areas, is text classification. Deep learning methods are also used for text classification and there are various current studies on this subject.

The use of deep learning representations for document classification has become increasingly popular in natural language processing (NLP) tasks. Statistical methods have been quickly replaced by deep learning as the state-of-the-art for many text classification tasks. Over the years, the focus has shifted from word representation generation (e.g. Word2Vec [9] or GloVe [10]) to generating embeddings of sentences or texts. Many architectures have been explored for this task, but the most commonly used are those based on the Transformers architecture [11]. This architecture provides self-supervised training and variable-length input.

BERT (Bidirectional Encoder Representations from Transformers) is a sentence encoder model based on the Transformers architecture introduced in 2018 [12]. It can be considered a state-of-the-art embedding model [13]. BERT models typically consist of interconnected encoder and decoder layers, and include a self-attention layer, a feed-forward pass-through layer, and a redundant hopping link. Many variants of BERT have been introduced since 2018, such as ALBERT [14], a lightweight version of BERT for smaller memory consumption and faster training, and DistilBERT [15], also smaller and faster, but pre-trained with information distillation.

An interesting extension is SBERT (SentenceBERT) [16], where a BERT model is fine-tuned with a Siamese or triplet architecture. This model is computationally efficient and produces embeddings that can be compared using cosine similarity, which reflects semantic meaning. An important extension is RoBERTa [17], which is also available because it is a multilingual model that can perform well in low-resource languages.

A sample study proposes a new approach for sequential short-text classification that combines recurrent neural networks (RNNs) and convolutional neural networks (CNNs) [18]. The proposed model in the study first uses an RNN to learn long-range dependencies between words in a short text. The output of the RNN is then fed into a CNN, which learns local patterns in the text. The CNN's output is then used to classify the short text. Another study proposes a new approach for sentence classification with CNNs by learning local patterns in the text [19]. They achieved state-of-the-art results on all four different datasets. In this study, they aimed to classify customer reviews as negative or positive. In another study, they used the BERT model for conflict event annotation [20]. The authors collected a dataset of news articles from the Global Terrorism Database (GTD) and extracted features from the text of the news articles. The features included the presence of certain keywords, the sentiment of the text, and the topic of the text. These texts then classified into different categories, such as conflict event, non-conflict event, and non-event. They achieved an accuracy of 88.7%. In another study, comparative analyzes of BERT model and traditional natural language processing approaches were carried out on data sets such as messages shared on social media, movie-series reviews, news content, and the results were presented. It has been proven by empirical values that BERT gives better results in different areas than traditional NLP approaches [21].

Many papers have been published and models exist for English texts, but the topic of NLP in other languages is limited but has been gaining momentum in recent years [22]. There were such studies that compared the BERT model with other models and in one such, the authors evaluated the BERT and DistilBERT model performances on collected two datasets of text from social media in the Filipino language [23]. According to the study, authors evaluated the two models on a held-out test set. The evaluation results showed that the BERT model achieved an accuracy of 80.2%, and the DistilBERT model achieved an accuracy of 79.5%.

In the study that this study was inspired from, the authors collected a dataset of ad text from Google Ads. The dataset consists of over 1 million ad texts [24]. The ad texts then preprocessed by removing stop words and punctuation marks. They also converted the ad text to lower case. They used the fine-tuned BERT model to classify ad text into different categories, such as product, service, and event. Then they fine-tuned the BERT model on the preprocessed ad text. The fine-tuning process was done using the Adam optimizer and the cross-entropy loss function and the fine-tuned BERT model achieved an accuracy of 94.5%. In other similar study, the authors was develop a new approach for ad text classification using the BERT model and achieved achieve an accuracy of 90.2% on a relatively small dataset [25].

Thanks to existing studies in the literature, it is proven that the BERT model achieves a significant accuracy for both text and ad text classification. This study aims to contribute to the state-of-the-art by developing an automated text classification system for the digital marketing field.

Table 1. *Data of Randomly Selected Categories Examples*

ID	Categories	URL
0	Art Education	https://www.opus-muzik.net/ https://www.akademipendik.com/
1	Cosmetics	https://www.espadekozmetik.com/ https://cosming.com/
2	Flower Order	https://yasmincicek.com/ https://antalyacicekcilik.com.tr/
3	Foreign Language Education	https://www.akademikdilkursu.com/ https://globaldilakademisi.com.tr/
4	Machine	https://adilmakina.com.tr/ https://mstendustriyelmakina.com/
5	Occupational Retraining	https://www.onlinedersmerkezi.com/ https://akademizeka.com/
6	Office Furnitures	https://theoffice.com.tr/ https://bahcesehirmobilyacarsisi.com/
7	Packaging	https://oggetti.com.tr/ https://patpat.com.tr/
8	Promotional Items	https://kcpromosyon.com/ https://www.mercanpromosyon.com/
9	Psychological Counseling	https://www.cocukpsikiyatrisi.com/ https://izmirpsikolojikdanismanlik.com/
10	Rent a Car	https://www.dervishotokiralama.com/ https://www.modernotokiralama.com/
11	Software Services	https://www.surrealyazilim.com/ https://www.akinsoftistanbul.org/
12	Technical Service	https://kombitamirci.net/ https://elektrotamir.com/
. .	. .	. .
42	Investment	https://www.dijitalpara.com.tr/ https://mbsyatirim.com/

3. Materials and Method

3.1 Dataset

For the study, the dataset is obtained from various websites by web scraping and contains approximately 101.000 data that belong to 42 different types of industries. In order to perform web scraping, AdresGezgini's database is used to select various URLs and manually labeled them according to the addressed industry itself to

create ground truth labels and some of the URLs with corresponding industries are given in Table 1 in order to understand the dataset better. After gathering different URLs from the database, texts are obtained by web scraping. Since we have the obtained texts and their ground truth labels in the dataset, the next step would be data preprocessing texts for the pre-trained BERT model. To do so, several data preprocessing methods are performed (Figure 1). In the data preprocessing stage, the dataset is first cleared of repetitive data. Punctuation and symbols are omitted, both the leading and the trailing characters are removed and all texts are lowercased. Because the texts are obtained from random URLs, there is of course an imbalance of data for each category namely industry. Since each category has different numbers of texts and those texts have different numbers of words, the outputs of the categorical probabilistic classification method taken from the BERT model trained with this imbalanced dataset were analyzed and it was observed that it showed a superior success.

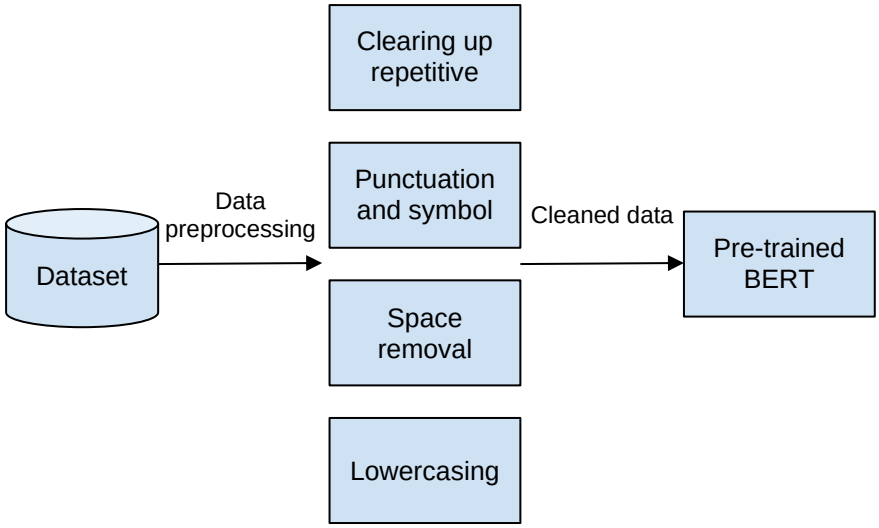

Figure 1. Data Preprocessing Steps

3.2 Method

3.2.1 Classification with BERT Model

The BERT model [26] is a transformer model introduced by Google in 2018, designed to pre-train bidirectional representations from unlabeled text and then fine-tune it using labeled text for different NLP tasks. With BERT, the translation success of the Google Translate application has also increased significantly, and now this application can translate even very long sentences between different languages with great accuracy without loss of meaning. Transducers have a structure that works with the self-attention mechanism formed by the tail structure (Figure 2).

The BERT model maps a query and a set of key-value pairs to an output. Here, vectors are formed that can express the correlation between the query, keys, values and the output itself. The output is calculated by the weighted sum of the values and the weight assigned to a value, with the rate of agreement with the key corresponding to the query [28]. The BERT model processes a text both from right to left and from left to right, so it can learn the relationships between elements in the text. In the training phase, MLM (Masked Language Modeling) and NSP (Next Sentence Prediction) techniques are used. In MLM technique, masked words are tried to be predicted using open (unmasked) words. With this technique, analysis and estimation are made on the words in the sentence. In the NSP technique, the relationship of the sentences with each other is examined. The relationship of a sentence with the sentence that follows it is examined. Structures built with the BERT model require a pre-trained model. For this reason, in our study, the BERT-BASE-TURKISH-UNCASED [29] model, which is a pre-trained BERT model for Turkish language by the Loodos team, using the 200GB dataset obtained from sources such as e-books, news articles, online blog posts and wikipedia has been preferred. In this study, the pretrained BERT model is fine-tuned and is used as a language model that can be used to classify text into different categories. In this study, the BERT model was used to classify text that was extracted from website URLs. The

text was first extracted from the URLs using a web scraping tool. The text was then cleaned and labeled with the relevant industry among 42 different categories. During the fine-tuning, early stopping criteria is employed to mitigate overfitting and promote generalization. Therefore, during fine-tuning, no over-fitting situation is observed. The BERT model was then used to classify the text. The classification performance of the BERT model was evaluated on a test set.

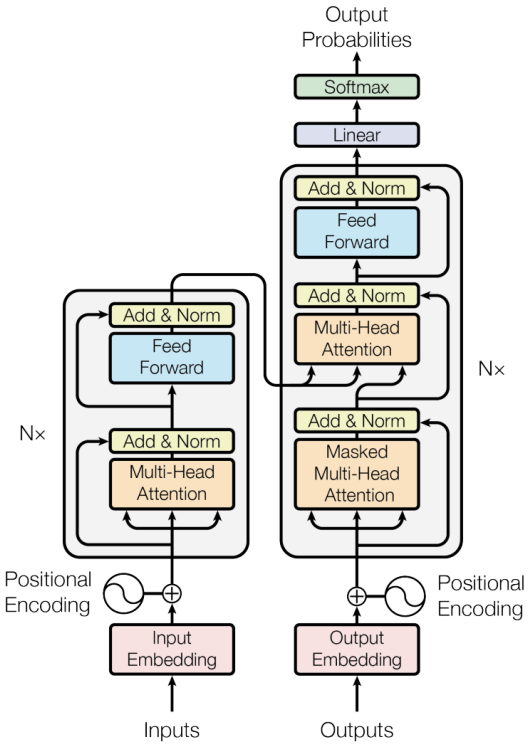

Figure 2. BERT Model Architecture [27]

The BERT model is applied to the problem of industry classification in the following steps:

- The text is extracted from website URLs using a web scraping tool.
- The text is cleaned and labeled with the relevant industry among 42 different categories.
- The BERT model is used to classify the text.
- The classification performance of the BERT model is evaluated on a test set.

The BERT model is able to achieve high accuracy for industry classification because it is pre-trained on a large dataset of text and code. The BERT model is also able to understand the context of a text, which is important for industry classification.

The method presented in this study can be used to test the compatibility of texts to be used in online advertising networks with the advertiser's industry. In this way, the suitability of the texts, which is an important component in determining the quality of online advertising, within the industry will be tested automatically.

3.2.2 Model Performance Evaluation

In order to accurately evaluate the performance of the model, the F1 score was followed along with the accuracy value. True Positive (TP), False Positive (FP), True Negative (TN) and False Negative (FN) values are used to calculate the F1 score. TP is the positive result of both the model's estimated and the true value, TN the negative results of both the model's prediction and the true value, FP the negative result when the model prediction is positive, and the FN the positive result when the model's prediction is negative, and the true value. In this case, TP and TN are considered correct results, FP and FN are incorrect results.

While calculating the accuracy value, it is calculated by the ratio of the TP and TN values that the model predicts correctly to all the predicted TP, TN, FP, FN values (1). The precision value is the ratio of the number of TP values predicted by the model to the number of TP and FP values, which are all positive results produced by

the model (2). The recall value can be found by the ratio of the number of TP values predicted by the number of TP and FN, which are all positive results that the model should produce (3). F1 score can be defined as the harmonic mean of precision and recall values (4).

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

$$Recall = \frac{TP}{TP + FN} \quad (3)$$

$$F1\ Score = 2\ x\ (\frac{Precision\ x\ Recall}{Precision + Recall}) \quad (4)$$

4. Results

The aim of this study was to evaluate the performance of a pretrained BERT model for the task of classifying texts extracted from various types of URLs. A total of 101.000 samples were used to train and evaluate the model, with 840 samples of the data set aside for testing.

The pre-training parameters of the model used are given in Table 2. This model has been fine-tuned and made ready for use. The pretrained BERT model was trained for 20 iterations (epochs) using a batch size of 128.For the training of the pre-trained BERT model in Turkish language we used in our study, the dataset consisting of advertisement texts was divided into predetermined categories, 70% of the dataset was used as the training dataset and 30% was used as the test dataset to test the model. Since the training-test separation was made categorically, training and testing were carried out with equal amounts of data from each category.

Table 2. *Parameters of the Pretrained BERT Model*

Model	Hidden Size	Max Sequence Length	Attention Heads	# of Hidden Layers	Architecture	Vocabulary Size
(Loodos 2020)	768	512	12	12	BERT For Masked LM	32000

Then, after the model was trained in 10 iterations with 14,349 training data and 3,588 test data, the analyzes were performed on the results of the 3rd iteration, since there was no increase in accuracy, precision, sensitivity and F-1 values after the 3rd iteration of the model. Here, different training-test set partitions were compared and it was aimed to produce results in accordance with the 70%-30% ratio used in similar studies in the literature.

It was seen that the lowest value among the precision values of the categories in the test data set belonged to the 5th category, which contains 25 test data. In the sensitivity analysis, the lowest value was found in the class containing 97 test data belonging to the 1st category. For the F-1 score, the 5th category and the minimum value were compared. It is seen that the lowest successful categories of the model consist of the data with the lowest rate in the training and test data set. Based on this situation, it is seen that an accuracy of over 90% can be obtained in cases where the training and test data, which is ideal for similar studies, are more than 1000 on a category basis. Table 3 shows the classification report of the 3rd iteration. As can be seen here, the model reaches a high training accuracy from the first iteration, but can reach a high test accuracy after the third iteration.

The results showed that the pretrained BERT model achieved a high average accuracy of 0.98, indicating that it was effective in accurately classifying the majority of the samples. The accuracy was computed as the ratio of correctly classified samples to the total number of samples. The high accuracy achieved by the model suggests that it can be useful for identifying texts from different types of URLs.

However, the overall mean precision and recall values were relatively low at 0.33 and 0.28, respectively. On the other hand, it is observed that F1-score is calculated relatively higher for 12 categories among 42 categories and these categories are given in Table 4. The average F1-score is calculated as 0.67 for these 12 categories. The average F1-score is calculated as 0.67 for those categories. The reason behind this situation is in the previous study, the BERT model is trained with advertisement texts rather than randomly scraped texts from websites.

Precision measures the proportion of correctly classified positive samples out of all samples classified as positive, while recall measures the proportion of correctly classified positive samples out of all actual positive samples. The low precision and recall metrics suggest that the model had limitations in correctly identifying all positive samples. Specifically, the model had a tendency to incorrectly classify negative samples as positive, resulting in a low precision value. Additionally, the model was not able to correctly identify all actual positive samples, resulting in a low recall value.

Table 3. *Iteration Test Report for Pretrained BERT Model*

ID	Precision	Sensitivity	F1 Score	Ad Texts
0	0.90	0.95	0.92	353
1	0.99	0.77	0.87	97
2	0.92	0.92	0.92	414
3	0.93	0.87	0.90	378
4	0.88	0.87	0.87	187
5	0.78	0.84	0.81	25
6	0.95	0.94	0.90	474
7	0.87	0.93	0.91	560
8	0.92	0.90	0.94	444
9	0.91	0.98	0.94	168
10	0.94	0.93	0.94	363
11	0.87	0.82	0.84	125
Accuracy			**0.91**	**3588**
Average	**0.91**	**0.91**	**0.91**	**3588**

Table 4. *Test Results Higher Than %45 F1 Score*

Category Names	F1 Score
Art Education	0.77
Energy	0.48
Flower Order	0.90
Foreign Language Education	0.81
Occupational Retraining	0.51
Office Furnitures	0.59
Packaging	0.82
Promotional Items	0.71
Psychological Counseling	0.65
Rent a Car	0.78
Technical Service	0.50
Investment	0.47
Average	**0.67**

The average F1-score, which is the weighted harmonic mean of precision and recall, was also relatively low at 0.28. This further highlights the limitations of the model's performance in terms of correctly identifying positive

samples. However, the average F1-score for certain 12 categories that are mentioned in Table 1 is 0.67 which indicates that the pre-trained BERT model is still successful to classify texts.

In summary, the pretrained BERT model demonstrated a high accuracy in classifying texts extracted from different types of URLs. However, the model's overall performance in terms of precision and recall was limited except for specific categories, indicating the potential for further improvement. Future work could focus on fine-tuning the model on specific data or incorporating additional features to enhance its performance. Future work also might be focused on using a transfer learning method rather than fine-tuning an existing model. The results demonstrate the potential of using pretrained BERT models for classification tasks while highlighting the importance of evaluating the model's precision and recall metrics in addition to its accuracy.

5. Conclusions

The aim of this study was to evaluate the BERT model performance that was trained on advertisement texts. Based on the results obtained from the pre-trained BERT model, the model shows a high average accuracy of 0.98, which suggests that it is effective in classifying texts extracted from different types of URLs. However, the relatively low average precision and recall values of 0.33 and 0.28, respectively, indicate that the model has limitations in correctly identifying all positive samples. However, for the 12 categories given in Table 1, the pre-trained BERT model gives an average 0.67 F1-score. The reason why the pre-trained BERT model was not able to classify texts with higher F1-score is the insufficiency of the dataset. With a higher number of data, the model's performance would be better. And, the model was also trained on advertisement texts but tested on scraped texts from different websites. These limitations suggest that further improvements could be made to enhance the model's precision and recall metrics, potentially by incorporating additional features or fine-tuning the model on specific data. Overall, these findings demonstrate the potential of using pre-trained BERT models for classification tasks, while highlighting the importance of evaluating the model's precision and recall in addition to its accuracy. Future work will be focused on to trained the BERT model with data that are obtained from websites and evaluating its performance with more samples.

Declaration of Interest

The authors declare that there is no conflict of interest.

Author Contributions

Aslı Yatkınoğlu: Writing - review & editing, Collecting the data, Results and discussions. Amine Gonca Toprak: Writing - review & editing, Validation, Training, Results and discussions. Sercan Çepni: Software, Methodology, Formal analysis, Collecting the data. Öykü Berfin Mercan: Methodology, Validation, Training, Results and discussions. Şükrü Ozan: Supervision, Conceptualization, Methodology.

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Predicting Stock Price from Historical Data using LSTM Technique

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Abstract

The accurate prediction of stock prices in the financial domain has always been a challenging task. While the Efficient Market Hypothesis declared that it is impossible to predict stock prices accurately, research has shown that stock price changes may be predicted with some degree of certainty with predictive models if appropriate and suitable variables are chosen. This work presents a robust and accurate model using statistical and Long Short-Term Memory (LSTM) techniques. Daily stock price data of a particular company was collected from the Yahoo Finance database which served as the primary source for the analysis. The Long Short-Term Memory (LSTM) technique was mainly used to forecast the stock market closing price on a particular day. The accuracy of this model was evaluated through multiple matrices which included Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), R-squared, and Directional Accuracy. This provided a clear and comprehensive assessment of the accuracy and performance. This study not only predicted the stock price using the proposed LSMA model but also analysed its accuracy by comparing it with popular conventional methods such as Simple Moving Average (SMA) and Exponential Moving Average (EMA) providing insights into the effectiveness of the LSMA model.

Keywords: Directional accuracy; long short-term memory; recurrent neural network; simple moving average; stock price prediction.

1. Introduction

Much research work has been done to predict the stock prices and it is a popular and anticipated subject matter in the financial domain. Several researchers have attempted to utilise time-series data to predict future values, but the accuracy of these predictions has been relatively low [1], [2], [3] and [4]. Two sides argue debating the possibility of predicting the stock price. In fairness to the opposite side, it is difficult to predict stock values because they depend on a variety of variables, such as the political climate, world economy, corporate the decision making of a company and performance, etc. Therefore, utilising methods to anticipate stock values by examining patterns over the previous several years could prove to be highly beneficial in making informed stock market moves. Such methods could help maximise profits and minimise losses.

Research has demonstrated that predictive models, when utilising appropriate and relevant variables, can achieve reasonably accurate stock price predictions. Recent research has focused on variable selection, functional form specification, and forecasting methods to improve prediction accuracy. In their study, Sen and Datta Chaudhuri propose a novel time series decomposition approach to stock price forecasting [5] and [6]. The proposed approach involves decomposing the stock prices time series into seasonal, trend, and random components, allowing for a more comprehensive analysis of the underlying patterns and trends in the data. The results of the study show that the proposed method outperforms traditional forecasting methods such as ARIMA and Neural Networks in terms of prediction accuracy, indicating its potential usefulness in stock market prediction.

Kim and Han [7] developed a model for predicting the stock price index that combined artificial neural networks (ANN) and genetic algorithms (GAs) with the discretisation of features. Analysing technical indicators to identify the direction of price movements in the daily Korean stock price index was among the data used in their study (KOSPI). They gave their chosen features and formulas using data encompassing samples of 2928 trade days, spanning from January 1989 to December 1998. In addition, they used optimisation of feature discretisation, a method related to dimensionality reduction. Their use of GA to enhance the ANN is one of their work's strengths. First, they used 12 fixed observational inputs and processing components in the hidden layer. Another drawback is that the authors only paid attention to two aspects of optimisation during the learning phase of the ANN. Even yet, they continued to think that feature discretisation optimisation in GA has a lot of potentials.

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A technique to forecast the movement of the Japanese stock market using an enhanced artificial neural network model was also reported by Qiu and Song [8]. In this study, scientists create a hybrid GA-ANN model by combining genetic algorithms with artificial neural network-based models.

Many other research work has been done to predict the future movement of stock prices and it is a popular and anticipated subject matter in the financial domain [9]. Those literature argues for or against the efficient market hypothesis [10]. The main flaw in the stock price prediction theories currently proposed in the literature is their inability to forecast stock price trends over a brief period [11]. The current work tries to remedy this weakness by utilising deep neural networks LSTM modelling and prediction capabilities for stock price movement.

Örsel and Yamada [12] adopt a naive view and suggest that they tend to go up over a long period, but follow a random walk model in the short term. They tried to find out the effectiveness of machine learning algorithms, such as Kalman filtering and long-short term memory architectures. The authors found that the LSTM model was more effective than the Kalman filter in predicting future stock prices.

Predicting stock price using RNN or LSDM is much more effective because the neural network that learns sequence patterns through internal loops and their gate structure like RNN, and LSDM are robust and can store information for a long time, and unnecessary information was forgotten/discarded [13] and [14].

Wimmer and Rekabsaz [15] propose a new approach to predicting stock market movements using Vision-Language models, specifically CLIP, to extract features from stock data. Authors conduct experiments on the German share index and assess various models for stock price prediction using historical data. They find that their approach outperforms existing deep learning-based models and examine the potential for faster decision making.

In the global economy, the amount of money that can be invested in the stock market is limited. However, considering the interest of various participants in the financial market, such as individuals, domestic institutions, and foreign financial institutions, this limit is constantly being tested. According to our world economic, if a stock price is growing, some other stock prices should be declining in the very near future. The objective of this paper is to predict the closing price using Long short-term memory. Using LSTM, given the previous movement pattern of the stock, an investor will be able to anticipate the price of a stock in the upcoming time frame. The strategy incorporates metrics like acceleration, pivot points, and range, all of which are dependent on daily data close stock price.

The goal of statical analysis of stock prices, which is used to find patterns in stock movement and capitalise on them. In this work, two conventional moving average methods like Simple moving average (SMA), and Exponential Moving Average (EMA) are devised towards this end to compare between conventional and machine learning techniques. There are mainly four components used in this work. (1) A time-series data set of daily stock prices of a particular company, (2) a comprehensive feature selection or engineering, (3) a long short-term memory (LSTM) based deep learning model and (4) Evaluation. In this paper, Long Short-Term Memory to indicate stock price analysis and prediction was used. It is believed by us that this strategy will offer a variety of important information to stock market investors, particularly short-term investors.

2. Methodology

2.1. Selecting the data

The data used in this approach was collected from Yahoo Finance by choosing the name of a certain firm or company that is desired to be predicted. A list of daily stock data was seen by accessing the "Historical Data" portion of the website. After that, the CSV file can be downloaded and the time period that will be used for analysis can be filtered out using this method. Historical data for six different companies were collected using this method.

2.2. Description of the data

An example of the data and variables can be seen in Figure 1.

Date	Open	High	Low	Close*	Adj Close**	Volume
Dec 13, 2022	98.07	99.80	97.42	98.14	98.14	12,494,569
Dec 12, 2022	93.09	93.88	91.90	93.56	93.56	27,363,900
Dec 09, 2022	93.90	94.49	93.02	93.07	93.07	21,873,700

Figure 1: *Data sample columns*

The dataset comprises various details of the stock, including Date, High, Low, Open, Close, Adjacent close, and Volume. However, the sole focus of our prediction is to determine the closing price of the stock.

1. **Date:** The date column indicates the date following other additional information. Various dates are tracked by dates, so it is important not to shuffle the data because our model is mainly time series.
2. **Open:** Open refers to the initial price at which a stock commenced trading on the stock exchange at the start of the trading day.
3. **High and Low:** The 'high' and 'low' values of a stock are frequently included in financial magazines and websites. High represents the price at which a stock has traded at any given time. The low represents the time's most affordable pricing. The intraday high and low of a stock are frequently referred to as its daily high and low.
4. **Adj. Close:** It is the closing price after taking into account all applicable splits and dividend payouts is known as the 'adjusted close.'
5. **Close:** Close refers to the price at which a stock end trading for that day. Sometimes, overnight price changes in stocks might be caused by things like firm earnings reporting in after-hours trading.
6. **Volume:** Volume represents the total number of shares traded for a particular stock on a given day. The volume is a measure of market activity. Higher volume means there is more interest in the stock, while lower volume can indicate less interest or lower liquidity.

Importance of closing price: The closing price is the last trending price of the day. Any time frame's reference point is often thought of as the close price. It is the price that traders agreed upon following the day's activity. When analysing historical stock price data, financial institutions, regulators, and individual investors use the closing price as a benchmark indicator of the stock's value on a particular day. It is a fundamental measure of an asset performance over time as depicted in Figure 2.

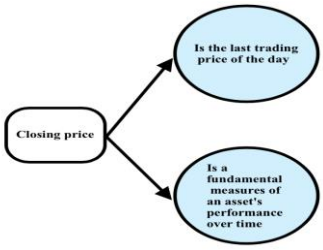

Figure 2: *Importance of closing price*

2.3. Used technique (Long Short-Term Memory)

In this work, LSTM (long short-term memory) is used. LSTM is commonly used in deep learning and artificial intelligence. Unlike conventional feed-forward neural networks, LSTM has feedback connections and can processe complete data sequences, in addition to individuale data points, making it a recurrente neural network.

The three gates, input, forget, and output, are represented by the letters I, f, and o in the formula Eqs. (1), (2), and (3). The learned data is preserved in the cell state C, as shown in the formula Eq. (5), which is then sent as the output h, as represented by the formula Eq. (6). Considering the information gathered from each timestamp, all these calculations are performed for every timestamp t (t-1).

In Eqs. (1)-(6), x_t represents the input at timestamp t, and *U* and *W* are weight matrices. The sigmoid function is denoted by *σ,* and the hyperbolic tangent function is denoted by *tanh*. Eq. (1) calculates the input gate, Eq. (2) calculates the forget gate, Eq. (3) calculates the output gate, Eq. (4) computes the temporary cell state, Eq. (5) updates the cell state, and Eq. (6) calculates the final output.

$$i_t = \sigma(x_t U^i + h_{t-1} W^i) \quad (1)$$

$$f_t = \sigma(x_t U^f + h_{t-1} W^f) \quad (2)$$

$$o_t = \sigma(x_t U^o + h_{t-1} W^o) \quad (3)$$

$$C'_t = tanh\,(x_t U^g + h_{t-1} W^g) \tag{4}$$

$$C_t = \sigma(f_t * C_{t-1} + i_t * C'_t) \tag{5}$$

$$h_t = hanh(C_t) * o_t \tag{6}$$

The function of the input gate is to decide what to include in the existing cell state, while the forget gate determines what information should be discarded from the current cell state and the amount of information to be discarded. The output gate, which is employed in the final equation, regulates how much output the first two gates compute. Such a recurrent neural network may process complete data sequences in addition to single data points. The architecture of long- and short-term memory is depicted in Figure 3.

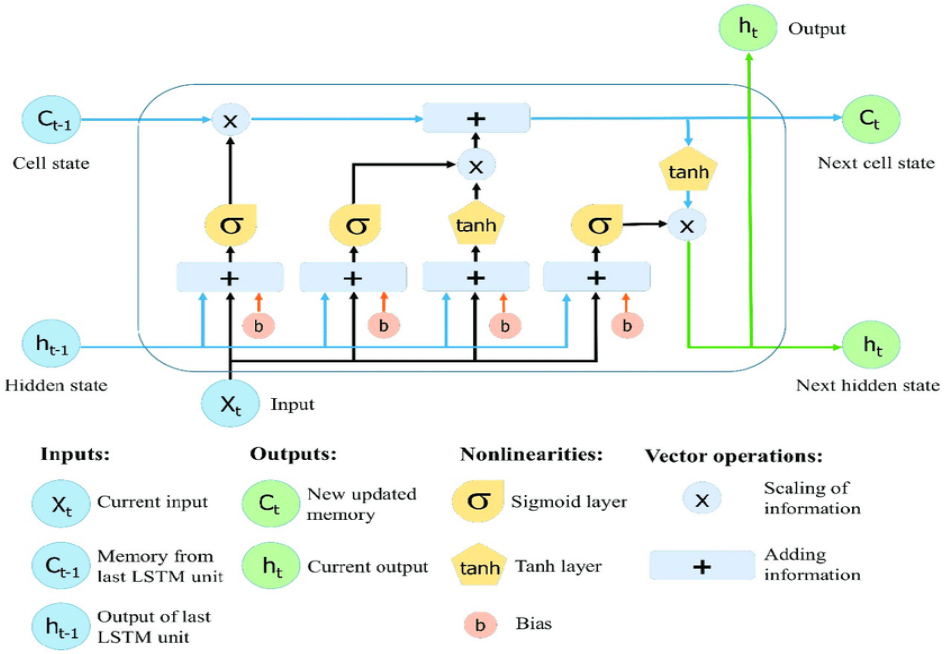

Figure 3: *Architecture of Long Short-term memory. Reproduced from Yan [16].*

LSTM has a wide range of applications including stock market prediction, rainfall-runoff modelling [17], fMRI data analysis, and anomaly detection [18]. While standard RNN is good at preserving information, it is not effective in learning long-term dependencies due to the vanishing gradient problem. LSTM overcomes this issue by using memory cells that run through the chain and allow information flow to remain unchanged. The gate mechanism of LSTM selectively passes information by using a sigmoid layer, hyperbolic tangent layer, and point-wise multiplication operation. The key component of LSTM is the cell state which interacts linearly with the gate mechanism.

2.4. Advantages and disadvantages of LSTM

The objective of this paper is to predict stock market movement/price using historical data. Based on that objective here are some advantages and disadvantages of using Long Short-Term Memory (LSTM) technique over other available techniques:

Advantages:

1. LSTM can handle long term dependences and it has the ability to remember past information for a very long time, which will benefit us because this paper is dealing with financial time series data.
2. LSTM can handle non-linear relationships between variables which is important for capturing the complex dynamics of the stock market.
3. LSTM can learn from data and can adapt new data, which is important for financial forecasting in an ever changing market.

Disadvantages:

4. LSTM can be a resource hungry especially when dealing with large amounts of data.

5. LSTM can overfit the training data, which may lead to poor results when it applied to real or new data.
6. LSTM requires a large amount of training data to achieve good accuracy or performance.

2.5. General block diagram of the system

The block diagram depicted in Figure 4 breaks down the major components of the selected modes and displays flow control. Moreover, it represents the complete architecture of the proposed technique.

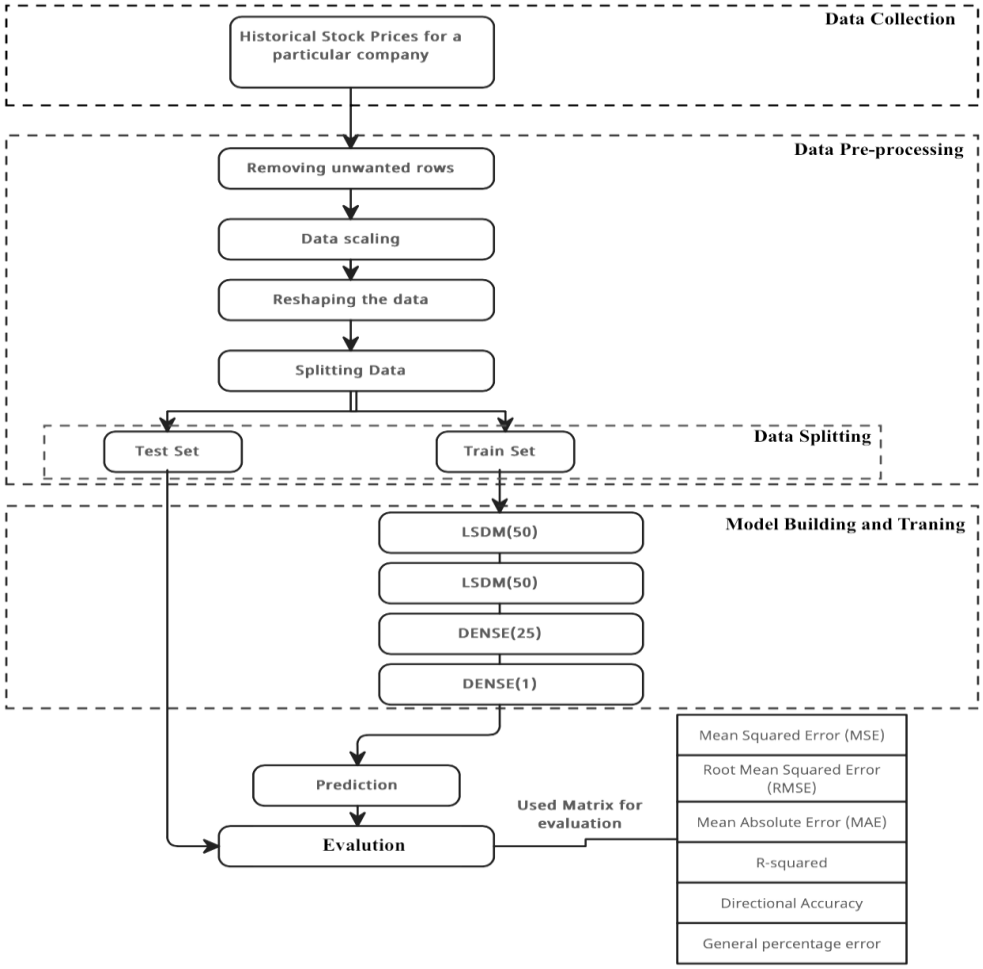

Figure 4: *General block diagram [Dotted border indicates major component/stage of the system. The top right corner of dotted border contains the name of the component/stage.]*

The selected system is detailed in Figure 4, which consists of four general stages which are Data collection, Data preprocessing, Model building and prediction and Evaluation. In data collection, historical data of a company is taken from Yahoo Finance. In the data preprocessing step, the collected data is subjected to several operations such as removing unwanted rows, scaling, reshaping, and splitting the data into train and test datasets. The reasoning behind this processes was elaborated in subsequent sections. In the model building and training step desired LSTM model was build and trained from train set data. Finally, in the evolution step the accuracy of the model is evaluated by various matrices which are detailed in the evolution section.

2.6. Data preprocessing

When working with real data, it is usually advisable to normalise or rescale the data within a set range, just like with any other machine learning model. This will help the model to rapid convergence by preventing characteristics with higher numeric values from unfairly interfering with and biasing the model. Selected model used the following techniques to preprocess selected data:

2.6.1. Removing wanted rows

Unwanted rows were removed from the dataset because those rows can negatively affect our model.

2.6.2. Data visualisation

Data visualisation helps us to understand how our data is moving. Understanding the kind of data being dealt with is important.

Figure 5: *Plotting data focusing on closing price history. For (AAPL) or Apple*

Figure 6: *Plotting data focusing on closing price history. For (AAPL) or Apple*

Figure 5 represents a graph where the closing price (in dollar) is represented on the y-axis and the x-axis represents the dates. This graph indicates a steady increase in closing prices. Figure 6 represents a graph where the closing price (in dollar) is represented on the y-axis and the y-axis represents the dates. Blue curve price indicates high, and orange indicates the low price of a stock in a day. This data shows High and Low price of a day is stable and is not vary much from one another.

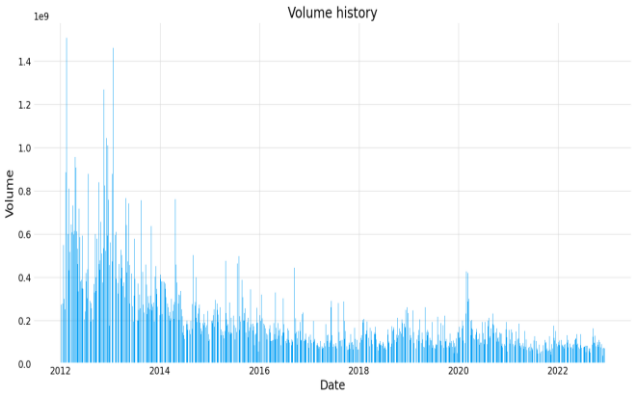

Figure 7: *Plotting data focusing on Volume history. For (AAPL) or Apple*

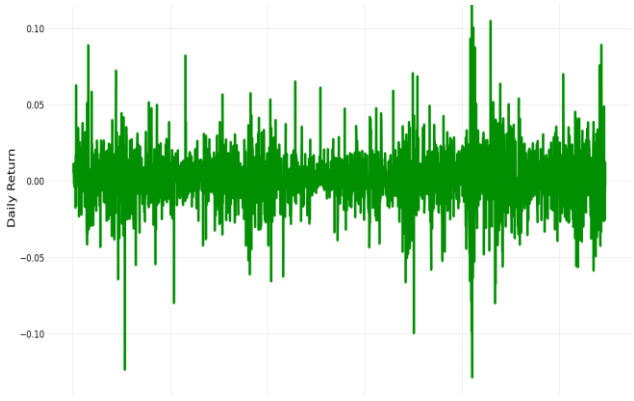

Figure 8: *Plotting data on daily return. For (AAPL) or Apple*

In Figure 7, the daily trading volume (in millions) is represented on the y-axis and the x-axis represents the dates. On the other hand, Figure 8 shows the daily return percentage of the stock, with the y-axis representing the daily return percentage and the x-axis representing the dates.

2.6.3. Creating data frame

In total, 12 years of historical data were collected. However, it was found that not all companies had data available for 12 years. The primary approach was to train the model using as much available data as possible.

2.6.4 Splitting data

Table 1 presents the data split into train and test datasets, comprising a total of 4380 rows. The split ratio used was 80-20, where 80% of the data was used to train the model and 20% was used to test the model.

Table 1. Splitting dataset

	Data set	***Training Dataset***	***Testing Dataset***
Time interval	01/01/2011 – 08/12/2022	01/06/2011 – 08/12/2019	01/06 / 2019 – 08/12/2022

2.6.5. Scaling the data

The data was scaled between 0 to 1 because scaling the data between 0 and 1 is advantageous before feeding it into a neural network.

2.6.6. Building LSTM model

In total 2 LSTM were added with 50 neural each. Two Dense layers were added with 25 and 1 neural, respectively, as illustrated in Figure 9.

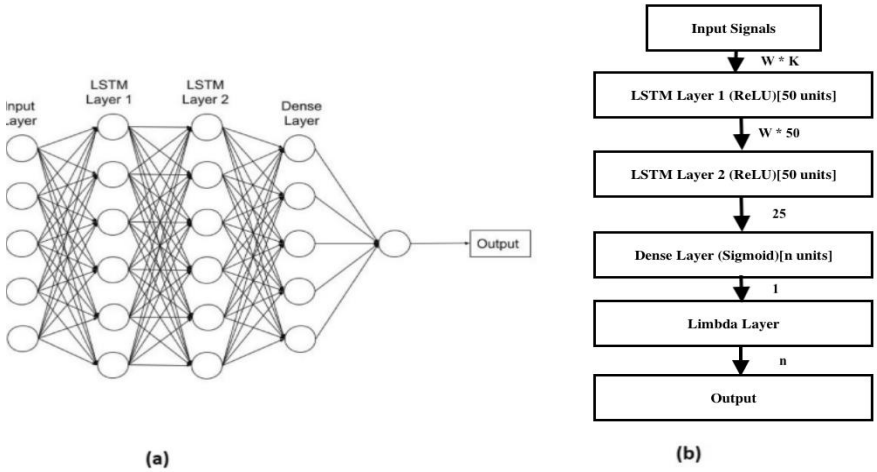

Figure 9: LSDM model with 2 LSTM layers and 2 dense layers. Figure (a), represent process through input to output. And, Figure (b), represent block diagram of LSTM with detailed information about each layer.

3. Result And Analysis

3.1. Plotting our findings

The closing stock price is obtained, and the comparison between the predicted and original closing price can be observed simultaneously in Figure 10 and Figure 11.

By analysing Figure 10, one can infer that the predicted and original closing prices of the stock are close, providing a comprehensive understanding. It also reveals that the prediction of stock prices for the next day, week,

or month results in highly accurate outcomes. However, when forecasting beyond four months, the predictions tend to become less precise. A detailed discussion of the accuracy and evaluation is presented in a later section.

	Close	predictions
Date		
2021-01-05	87.045998	87.078453
2021-01-06	86.764503	86.988075
2021-01-07	89.362503	86.870628
2021-01-08	90.360497	87.168510
2021-01-11	88.335999	87.754349
...	...	...
2022-12-05	99.870003	98.471504
2022-12-06	97.309998	98.913086
2022-12-07	95.150002	98.754662
2022-12-08	93.949997	98.011292
2022-12-09	93.070000	96.930969

Figure 10: Close (actual price) and predicted values

Figure 11 represents a graph where the closing price (in dollars) is plotted on the y-axis, and the x-axis represents the dates. The blue curve indicates train data value and orange indicates predicted data values and red indicates the original price of a stock in a day. The overlapping curves in this graph indicate that the predicted price was quite accurate.

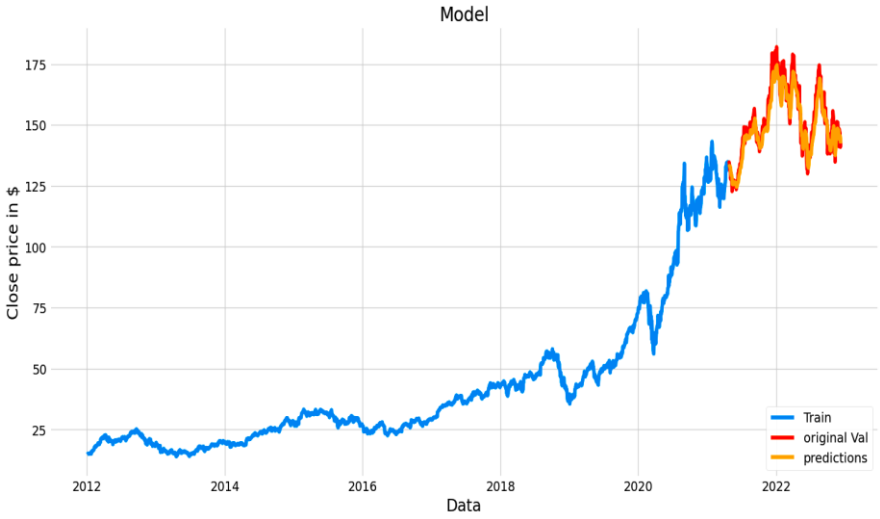

Figure 11: *Train, original values and predicted values (For AAPL or Apple)*

3.2. Accuracy

3.2.1. Finding

Our dataset ranges from 01/01/2011 – 08/12/2022. To determine the accuracy of the model, the team made a prediction for the closing price of AAPL for November 9th, 2022, which was previously unknown to the model. The predicted value was 142.81 dollars, while the actual closing price on that day was 144.49 dollars. By calculating the percentage of error, a 98% accuracy rate was achieved for AAPL.

3.2.2. Finding average accuracy for our selected six companies

Six of our selected companies are Google, Netflix, Goldman Sachs, Apple, Nasdaq and JPMorgan Chase & Co.

Table 2. Finding average accuracy.

	Predicted price($)	***Real Price ($)***	***Accuracy(%)***
Google (GOOG)	95.72	93.559	97.74
Netflix (NFLX)	321.862	315.179	97.923
Goldman Sachs (GS)	353.48	363.179	97.33
Apple (AAPL)	142.81	144.49	98.84
Nasdaq (GILD)	80.58	88.54	91
JPMorgan (JPM)	131.34	134.21	97.86
		In Average	96.78

Table 2 presents the average accuracy of our selected six companies, which is 96.47%. But merely relying on the accuracy metric is insufficient to assess the performance of a model. Therefore, the subsequent section elaborates on and evaluates the model using various other evaluation metrics.

3.2.3. Evaluating our model based on different metrics

Following evolution metrics are used to determine the true accuracy of the model. Several metrics were used to evaluate our model. These metrics are listed below:

1. Mean Squared Error (MSE)
2. Root Mean Squared Error (RMSE)
3. Mean Absolute Error (MAE)
4. Directional Accuracy
5. R-squared

Mean Squared Error (MSE): MSE is used as evaluation metric in machine learning for regression problems. It measures the average squared difference between the estimated values and the actual values. In Eq. (7), N is the number of data points, y is the actual value, and ŷ is the predicted value.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - y_i)^2 \quad (7)$$

The MSE value typically ranges from 0 to infinity. A lower MSE indicates better accuracy, as it means the predicted values are closer to the real or actual values. An MSE of 0 indicates a perfect match between the predicted and actual values, which is rarely achievable in real-world scenarios. As the MSE value increases, it indicates a larger average difference between predicted and actual values, signifying a less accurate model.

Table 3. Mean Squared Error (MSE) for different companies

	MSE Value
Google (GOOG)	24
Netflix (NFLX)	160
Goldman Sachs (GS)	136.72
Apple (AAPL)	16
Nasdaq (GILD)	1.30
JPMorgan (JPM)	14.71
In Average	58.78

Table 3 represents the Mean Squared Error (MSE) values, which indicate the accuracy of the model's predictions. The majority of the companies exhibit low MSE error values, while NTFX and GS displayed moderate accuracy, resulting in a relatively high average MSE value.

Root Mean Squared Error (RMSE): This metric is used to evaluate stock prices and their corresponding actual values. Careful examination of the RMSE formula Eq. (8) reveals that it allows us to obtain an absolute measure of error by taking into account the discrepancy (or error) between the real or actual (At) and predicted or anticipated (Ft) price values for all N timestamps.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - y_i)^2} \tag{8}$$

The RMSE value typically ranges from 0 to infinity. A lower RMSE indicates better accuracy, as it means the predicted values are closer to the real or actual values. An RMSE of 0 indicates a perfect match between the predicted and actual values, which is rarely achievable in real-world scenarios. As the RMSE value increases, it indicates a larger average difference between predicted and actual values, signifying a less accurate model.

Table 4. Mean Squared Error (RMSE) for different companies

	RMSE Value
Google (GOOG)	4.91
Netflix (NFLX)	12
Goldman Sachs (GS)	11
Apple (AAPL)	4.40
Nasdaq (GILD)	1.14
JPMorgan (JPM)	3.83
In Average	6.21

Table 4 indicates, predicted prices are very accurate. Less than 10 RMSE value indicates that the model is predicting very close to the real price.

Mean Absolute Error (MAE): Measures the average absolute difference between the predicted and actual values. Eq. (9) is calculated as the average of the absolute differences between the predicted and actual values.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|y_i - y_i\right| \quad (9)$$

MAE value range between 0 to infinity. Lower MAE indicates more accurate results.

Table 5: Mean Absolute Error (MAE) for different companies

	MAE Value
Google (GOOG)	4.18
Netflix (NFLX)	9
Goldman Sachs (GS)	10
Apple (AAPL)	3.46
Nasdaq (GILD)	0.81
JPMorgan (JPM)	3.18
In Average	5.1

Table 5 indicates, predicted prices are very accurate. Less than 10 MAE value indicates that the model is predicting very close to the real price.

Directional Accuracy: This is a metric used to measure the percentage of predictions made by a model that correctly predicts the direction of the true value. Following Eq. (10):

$$DA = \frac{\sum_{i=1}^{n} sign(y_i - y_i) = sign(y_{i-1} - y_{i-1})}{n-1} \quad (10)$$

A correct directional prediction occurs when the predicted value has the same sign (positive or negative) as the actual value. A value above 0.5 would indicate that the model is performing well.

Table 6: Directional accuracy (DA)for different companies

	DA Value
Google (GOOG)	0.52
Netflix (NFLX)	0.51
Goldman Sachs (GS)	0.89
Apple (AAPL)	0.45
Nasdaq (GILD)	0.51
JPMorgan (JPM)	0.52
In Average	0.57

Table 6 indicates, predicted prices direction are moderately accurate. The model's predicted direction of the stock price movement (whether it will go up or down) has been accurate about 57% of the time.

R Squared: It is a statistical measure that represents the proportion of the variance for a dependent variable. Eq. (11) measures the goodness of fit of a linear regression model.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - yi)^2}{\sum i=1^{n}(y_i - \overline{y})^2} \quad (11)$$

R Squared value ranges from 0 to 1, with a higher value indicating a better fit of the regression model to the data.

Table 7: R Squred error for different companies

	R2 Value
Google (GOOG)	0.91
Netflix (NFLX)	0.98
Goldman Sachs (GS)	0.55
Apple (AAPL)	0.90
Nasdaq (GILD)	0.96
JPMorgan (JPM)	0.96
In Average	0.877

Table 7 indicates, a value of 0.877 means that 87.7% of the variability in the dependent variable (y) can be explained by the independent variable(s) (x) in the regression model. A higher R-squared value indicates a better fit of the model to the data.

3.2.4. Comparing with other methods:

Comparing LSTM accuracy with 30-day Simple Moving Average and Exponential Moving Average. This comparison will help us to understand the finding. SMA can calculated by following equation Eq. (12).

$$SMA = \frac{\sum_{i=n-k+1}^{n} p_i}{k} \tag{12}$$

A simple moving average can be used to find the unweighted mean of the past K data points. The smoother the curve is, the higher the value of K, however increasing K reduces accuracy. The simple moving average is calculated if the data points are p1, p2,..., pn.

The weighted average of the preceding K data points is revealed by the Exponential Moving Average (EMA). The most recent data points are given more weight and significance by EMA. The equation Eq. (13) provides the formula to compute the EMA during the time period t.

$$EMA_t = \{_{alphapricet + (1-\alpha)EMAt - 1 \quad t > 1}^{price_1 \quad t = 1} \tag{13}$$

Using Simple and exponential Moving Average method, stock price was predicted for a single day. The accuracy is compared with Long Short-Term Memory and shown in Table 8.

Table 8: Comparison between LSTM vs SMA vs EMA

	LSTM	***SMA***	***EMA***
Accuracy	96.646%	91.17%	94.85%

Table 8 clearly indicates that LSTM is more accurate than SMA and EMA. While SMA and EMA exhibit comparable performance, they are significantly outperformed by LSTMs

4. Conclusion And Future Work

This study has demonstrated the effectiveness of using LSTM for stock price prediction. For the benefit of shareholders and short-term investors, this paper offers a system for predicting stock price value utilising long short-term memory. The main objective in employing such a prediction method is to maximise profit from the

stock. By employing comprehensive feature engineering and selecting appropriate input features, this model was able to achieve a high accuracy rate of 96%. By increasing the size of the training data, the system can achieve higher accuracy and a lower error rate.

Predicting some of the stock prices like Tesla (TSLA) and GameStop (GME) gives us a less accurate result. Because these kinds of companies are more volatile than other companies and subject to sudden changes in response to various factors such as economic news, political events, or even social media trends. Additionally, some stocks may be influenced by factors that are difficult to quantify or predict, such as changes in consumer preferences, shifts in market sentiment, or unexpected disruptions to supply chain.

In future work, deep learning models that incorporate financial news stories as well as traditional financial metrics, such as closing price, traded volume, and profit and loss statements, could be developed in order to achieve even better results. This approach would provide a more comprehensive understanding of the factors that influence stock prices and would enable the model to capture and learn from complex relationships between financial and non-financial events. Incorporating natural language processing techniques to extract relevant features from news articles and combining them with numerical data could potentially improve the accuracy and robustness of the predictive model.

Declaration of Interest

The authors declare that there is no conflict of interest.

Author Contributions

Foysal Ahamed Nirob contributed to the conceptualization, methodology, data collection, analysis, interpretation, and writing of the manuscript. He was primarily responsible for conducting the research, implementing the machine learning techniques, analyzing the results, and interpreting the findings.

Dr. Mohammad Mahmudul Hasan provided guidance and reviewed the research approach throughout the project. He played a crucial role in building the initial structure of the research paper. His expertise and insights were valuable in shaping the overall direction of the study.

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Edge Detection for 3 Dimensional Video Quality Assessment

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Abstract

The impact of 3 Dimensional (3D) video technologies on user perception of 3D videos can only be highlighted by considering the impact of these technologies on user perception of 3D videos. It is true that enabling this can be accomplished by taking into account the crucial criteria of defining the nature of a 3D video. Under the light of this fact, an edge detection algorithm relying on the Canny edge detector, is used to derive preliminary results to develop a No Reference (NR) model for the VQA of a 3D video. The performance evaluation results obtained by using the proposed algorithm prove that proposed study is quite effective in the VQA of a 3D video.

Keywords: 3D video, edge detection, video quality assessment.

1. Introduction

Improving the performance of three-dimensional (3D) multimedia services is heavily dependent on meeting two goals. One of these goals is to achieve maximum efficiency during the transmission of 3D video contents, while the other is to improve the viewing experience at the user end. These two goals can only be addressed by developing costeffective and Human Visual System (HVS)-friendly 3D Video Quality Assessment (VQA) metrics [1][2][3][4].

The VQA is essentially accomplished in two ways in the literature. One of these ways is subjective testing, in which real viewers are used for VQA. Another approach is to use computer algorithms to perform objective evaluation. Because real viewers are employed during the VQA processes, the data provided by subjective tests is assumed to be correct. However, subjective tests are both costly and time consuming. As a result, objective measures are preferred by researchers attempting to accomplish the goal of optimum transmission efficiency due to their low cost and speedy processes [5][6].

In the literature, the objective metrics are classified into three groups based on the use of the original video at the receiver side during the VQA process. One of these categories is the Full Reference (FR) metric, which requires the original video to be present at the receiver in order to compare the quality of the compressed (distorted) video to that of the original. Another category makes use of basic data derived from the original video rather than entire information about the original video. This metric type is known as Reduced Reference (RR). The No-Reference (NR) metric type is the third VQA category in which the original video sequence is not used at all during the VQA process. Because the original video must be transferred to the receiver side for the VQA process, the FR and RR kinds cause problems in multimedia applications. Although there are FR metrics such as PSNR (Peak-Signal-to-Noise-Ratio), VQM (Video Quality Metric) [7] and SSIM (Structural Similarity Index) [8] that are widely used to estimate video quality, it is difficult to provide an equally recognized example of an NR metric. As a result, for the VQA, the NR metric type is more practicable and efficient [5][6]. In light of this fact, an NR metric is considered in this study.

Due to the nature of HVS, it is quite significant to determine effective factors for developing 3D NR VQA metrics.

Given these facts, the Canny, edge detection operator, which is an excellent approach for gathering edge information of objects in an image, is used in this work to provide preliminary findings utilizing color videos for establishing a NR VQA metric.

The rest of the paper is organized as follows. The edge information measurement algorithm is introduced in Section 2. In Section 3, the performance assessment results and discussions are presented. Finally, Section 4 concludes this study and points to the future work.

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2. Edge Information Measurement Algorithm

In this study, the methodology of edge detection for video sequences is based on the Canny edge detection algorithm, which is a mature and efficient method for calculating structural information. The edge detection optimization operator Canny is determined by the variation of pixel sizes in an image [9] [10]. The Canny algorithm has five phases that can be implemented. The first stage involves smoothing image noise with a Gaussian filter. The second step is to determine the slope force and direction of each pixel using Gradient, the first order partial derivative. A base Gradient operator can be described mathematically as in (1.1).

$$\nabla f \equiv grad(f) \equiv \begin{bmatrix} g_x \\ g_y \end{bmatrix} \equiv \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \tag{1.1}$$

Using the numerical optimization of the one-way edge step gives the conclusion that Gauss is the first derivative, which is represented with the following mathematical equation (1.2).

$$\frac{d}{dx} e^{-\frac{x^2}{2\sigma^2}} = \frac{-x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}} \tag{1.2}$$

A two-dimensional circular Gaussian function softens the image so that it can determine all possible distances in all conceivable directions. Gradient is then calculated. The edges associated to the available coordinates in the image are then calculated using the maximum non-suppression to refine the smoothing image Gradient in the third stage.

Gradient amplitude and direction are then used to estimate the edge size and direction at each point.

If f(x,y) is the input image and G(x,y) is given as a Gaussian function, equation 1.3 can be written.

$$G(x, y) = e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{1.3}$$

As a result of the convolution of G and f, a smooth image is obtained as formulated in 1.4.

$$f_s(x, y) = G(x, y) * f(x, y) \tag{1.4}$$

This process is continued by calculating the gradient amplitude (M) and direction (α) as shown in equations 1.5 and 1.6.

$$M(x, y) = \sqrt{g_x^2 + g_y^2} \tag{1.5}$$

$$\alpha(x, y) = \tan^{-1} = \left[\frac{g_x}{g_y} \right] \tag{1.6}$$

In the equations, gx and gy are partial derivatives.

Since it is obtained using gradient, it typically contains large peaks around the local maximum. Using non-maximum suppression to refine the smoothed image Gradient, the edges in the image in possible x and y coordinates are determined.

In the fourth phase, a threshold is employed to eliminate erroneous points and to detect and connect the discrete points of the image's edges. This process can be executed with a single threshold level by making the values below the threshold level zero. Incorrect threshold level selection may result in erroneous or partial findings [9-12].

In recent years, some scholars have suggested and applied various methods based on the Canny algorithm to practical engineering. The researchers experimented with several threshold selection strategies in order to improve the Canny algorithm's successrate. Er-Sen Li et al. gain some improvement in edge detection outcomes by employing the Otsu approach in threshold selection [11][12].

This study's threshold level runs from 0 to 1. The Otsu operator and adaptive threshold determination approach presented in [12] are employed in this investigation to select the threshold level. As a consequence of the graphic work completed, it is considered that the threshold level compatible with the HVS should be 0.08.

Finally, the Canny algorithm and threshold level combination method suppress the pixels that are not regarded edges. In other words, these pixels have a pixel value of 0. The pixels judged to be edges are given the value 1. The total number of ones is then normalized with the spatial resolution in this study, which is known as Normalized Numbers of Ones (NNO).

3. Results and Discussions

In order to derive results, the color sequences of 10 different color+depth map based 3D video test sequences (i.e, Windmill, Interview, Breakdance, Chess, Advertisement, Ballet, Butterfly, Farm, Football and Newspaper) are coded using the Joint Scalable Video Model (JSVM) codec version 9.13.1 with 5 different Quantization Parameters (QPs) (i.e., 25, 30, 35, 40, 45) at 25 frame rate.

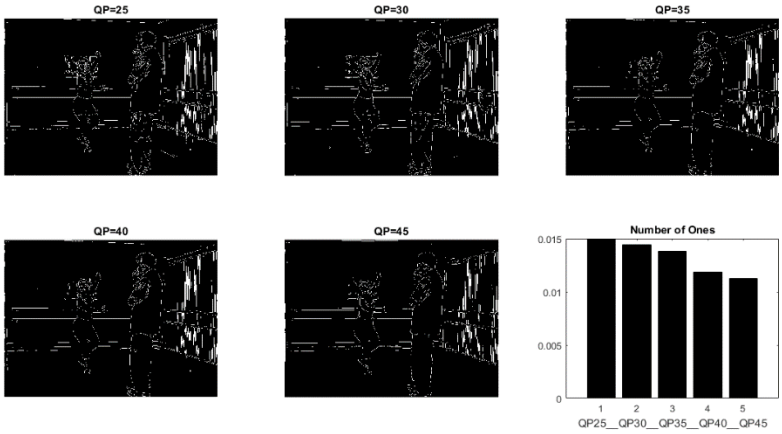

Fig. 1. The edge information of a snapshot of the "Ballet" video sequence and its associated NNOs for the 5 QPs

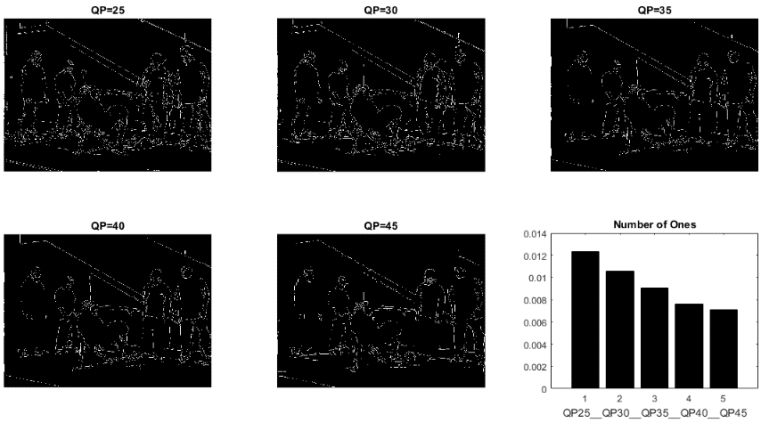

Fig. 2. The edge information of a snapshot of the "Breakdance" video sequence and its associated NNOs for the 5 QPs

Then, the edge information is obtained using the Canny algorithm and the NNOs are also calculated for the same encoded 7 video sequences and 5 different QPs. Figs. 1 and 2 show how the edge information and the NNOs differ for the Ballet and Breakdance video sequences encoded with 5 different QPs, respectively. These results are used as representative results for presenting how the edge information and the NNOs differ for the video sequences. As observed from the figures, the NNOs decrease as the video quality decreases. Similar results are obtained for the remaining 5 color video sequences.

4. Conclusions

In this study, the edge detection features envisaged as significant for the HVS, have been utilized to derive results. These results can be considered as preliminary results for developing a NR 3D VQA metric. These preliminary results present that the edge information is quite promising to be used in the development of a 3D VQA metric. By this study, it will be easier and more practical to measure 3D video quality on the receiving side, which is a critical demand for multimedia technologies. In future studies, it is aimed to evaluate other edge detection methods and develop an efficient NR VQA metric using these preliminary results.

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Author Contributions

Author 1: Methodology, Results and Discussions, Software. Author 2: Review and Editing, Conclusions.

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