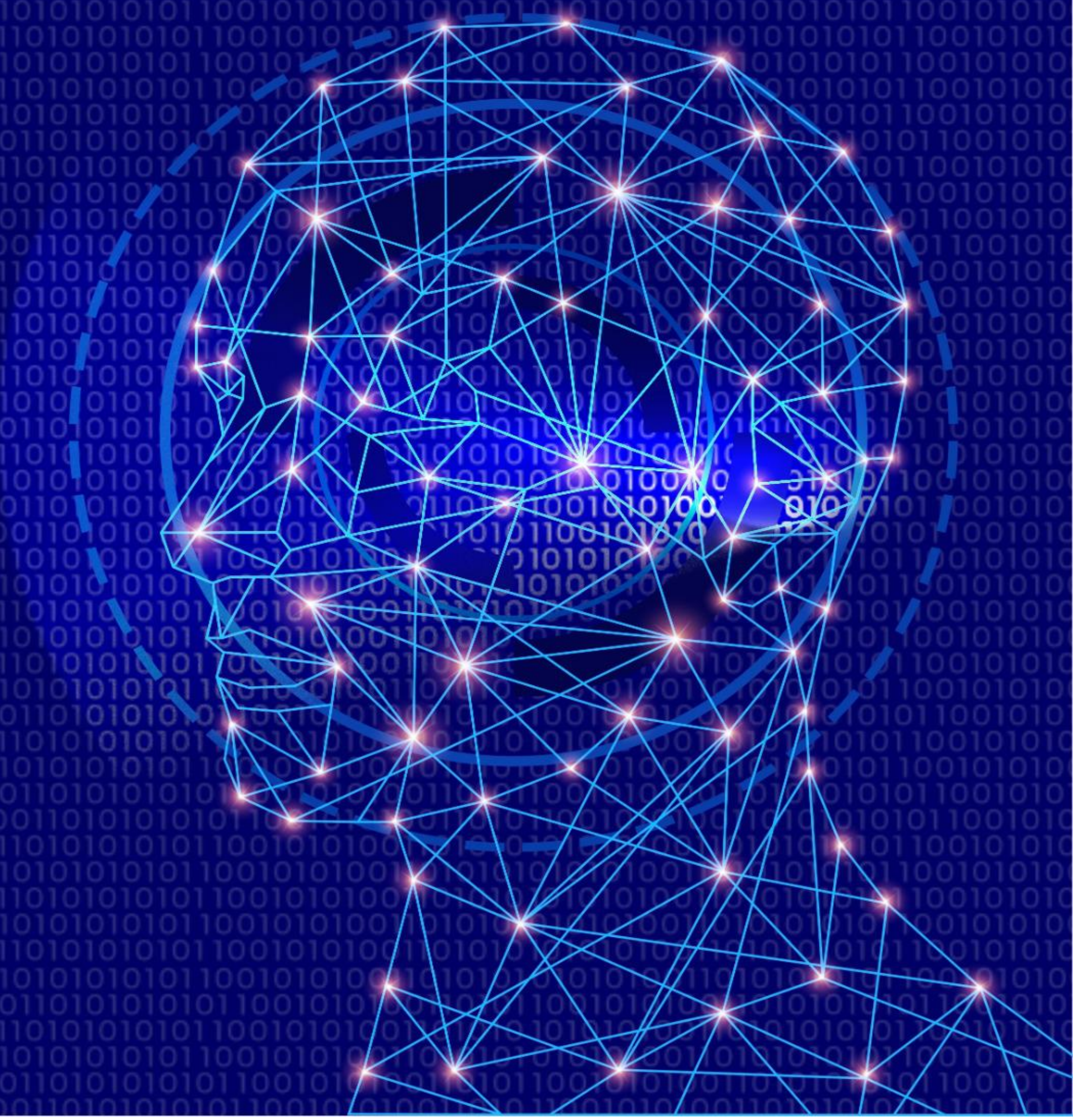
International Journal of

ADVANCES IN ARTIFICIAL INTELLIGENCE RESEARCH

AAIR

Volume 1, Issue 1, 2021



International Journal of
ADVANCES IN ARTIFICIAL INTELLIGENCE RESEARCH
AAIR

Advances in Artificial Intelligence Research

https://dergipark.org.tr/aair

Date of Publication	January, 2021
Language	English
Frequency	Published twice in a year
Graphic designer	Özden Işıktaş
Correspondence Address	Muğla Sıtkı Koçman University, Faculty of Technology, Information Systems Engineering, 48000 Kötekli/MUĞLA
Phone	0 506 4887818 – 0252 211 5526
Correspondence Mail	osmanozkaraca@mu.edu.tr

International Journal of ADVANCES IN ARTIFICIAL INTELLIGENCE RESEARCH
AAIR

Table of Contents

Advances in Artificial Intelligence Research (AAIR) **Vol. 1 (No.1), pp. 1-5, 2021**
www.dergipark.com/aair/ **Published online: Jan 15, 2021**

Artificial Intelligence Techniques Used in Project Management

Çetin Elmas[1*], Jahid Babayev [2]

[1] Gazi University, Technology Faculty, Electrical Electronics Engineering Department, Turkey; [0000-0001-9472-232]
[2] Kyiv National University of Construction and Architecture, Kyiv, Ukraine; [0000-0003-4633-8261]

Abstract

Artificial intelligence is defined as the ability of a machine to mimic intelligent human behavior and therefore attempts to simulate human cognition capability through symbol manipulation and symbolically structured knowledge bases. Because of many uncertain factors, complicated influence factors in project management, every project has its individual character and generality. Over the last decade, the development and application of artificial intelligence in project management has given good grounds for expecting of achievements, which are mainly used in project evaluation, diagnosis, decision-making and prediction. This paper presents artificial intelligence techniques used in project management. It tries to gather the recent advances and trends on artificial intelligence techniques used in Project Management.

Keywords: *Project management; artificial intelligence; expert systems; fuzzy logic; genetic algorithms; artificial neural network.*

1. Introduction

Artificial intelligence (AI) is essentially defined as the ability of a machine to mimic intelligent human behavior and therefore attempts to simulate human cognition capability through symbol manipulation and symbolically structured knowledge bases. AI was developed based on the interaction of various disciplines namely computer science, information theory, cybernetics, linguistics and neurophysiology [1]. AI have been called "soft computing" by Lotfi Zadeh [2], known father of Fuzzy Logic (FL). In his view, soft computing is an approach that mimics the human mind to reason and learns in an environment of uncertainty and impression. The term cognitive computing is often used interchangeably with AI.

The goal of project management (PM) is to produce a successful product or service. Often this goal is hampered by omissions and commissions from management, project managers, team members and others involved in the projects [3, 4]. PM was influenced by many uncertainties that could not be solved by applying a set of standard procedures but also depends on the knowledge and the experience of practitioners. These are irrational, incomplete and inaccurate and cannot be treated by conventional tools or methods. PM is an incredibly complex field, where no one approach solves all problems. PM involves a multitude of risks and losses, and it is vital to seek some kind of solutions [5]. A research by Liquid Planner presented the finding that managing project costs (49.5%) was the biggest problem faced by manufacturing project managers in 2017. Hitting deadlines (45.8%) and sharing information across teams (43.9%) weren't far behind [6]. According to a study by PMI, for every $1B invested in the US, $122M was wasted due to lacking project planning and performance [7]. Geneca study reveals that up to 75% of business and IT executives anticipate their software projects will fail [8].

Over the last decade, the development and application of AI in PM has given good grounds for expecting of achievements, which are mainly used in project evaluation, diagnosis, decision-making and prediction [9]. Thus, it is aimed that the use of AI in PM for performing management and administration tasks without human influence. One of the biggest challenges in PM is having enough data to know how well projects perform with the desired outcomes, objectives and goals [10]. Using predictive analytics and other aspects of ML, AI can use data that organizations gather about their projects to determine teams' completion rates and determine the likelihood of delivering products on time. This paper presents AI techniques used in PM. It tries to gather the recent advances and trends on AI techniques used in PM.

2. Artificial Intelligence Techniques

The section of this paper outlines some AI techniques that are most applicable to PM management: such as Artificial Neural Networks (ANNs), Fuzzy logics, Expert Systems (ESs), Genetic Algorithm (GA).

2.1. Artificial Neural Networks

An ANN is a type of ML which models itself after the human brain. A "neuron" in an ANN is a mathematical function that collects and classifies information according to a specific architecture. ANNs have

*Corresponding author
E-mail address: cetinelmas@hotmail.com

Received: 27/Oct/2020; Received in revised form: 5/Nov/2020; Accepted: 25/Nov/2020.

been central sources of inspiration for a large number of original techniques covering a vast field of applications [11, 12]. An example of an ANNs can be seen from **Figure 1**.

An ANN contains layers of interconnected nodes. Each node is a perceptron and is similar to a multiple linear regression. The perceptron feeds the signal generated by a multiple linear regression into a possibly non-linear activation function. Hidden layers fine-tune the input weightings until the ANN error rate is minimal. As an analysis and solution of complex problems, especially in the non-linear problem, the ANN is an important tool, and the potential of the ANN is increasingly perceived in the scope of PM.

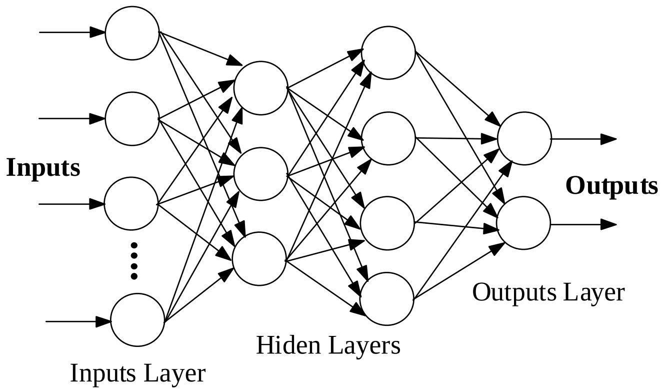


Figure 1. *An example of an ANNs*

2.2. Fuzzy Logic

The idea of FL was first advanced by Lotfi Zadeh in the 1960s. FL is essential to the development of human-like capabilities in software, so the AI system could find a solution in the face of an unfamiliar task. FL can be used to describe how information is processed inside human brains. The approach of FL imitates the way of decision making in humans that involves all intermediate possibilities between digital values YES and NO [13, 14]. An example of a FL can be seen from **Figure 2**.

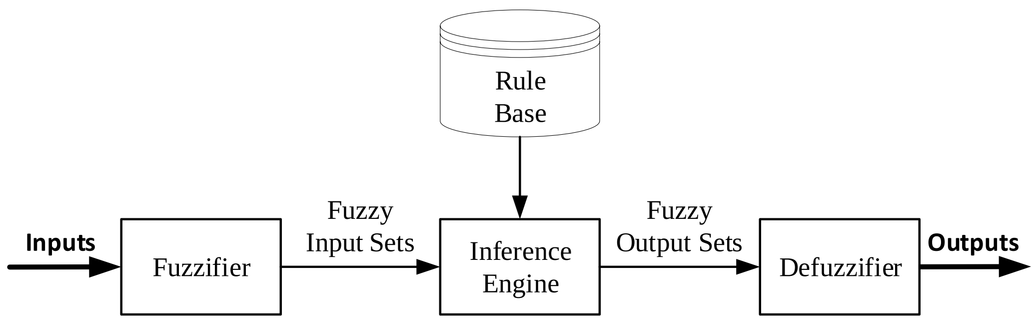


Figure 2. *An example of a FL*

As seen from the **Figure 2**, FL consists of three basic steps;

1. Fuzzification is a process of transforming crisp values into grades of membership for linguistic terms of fuzzy sets. The membership function is used to associate a grade to each linguistic term.

2. Inference engine defines the behavior of a system by using rules on a linguistic level.

3. Defuzzification is the process of producing a quantifiable result in Crisp logic, given fuzzy sets and corresponding membership degrees. It is the process that maps a fuzzy set to a crisp set.

With FL it is possible to simulate the risk and uncertainty that are always associated with projects. The fuzzy model has many advantages for project managers, including speeding up decision-making, effective PM, simulation of potential development projects, and more.

2.3. Expert System

An Expert System (ES) is a computer program that uses AI to simulate the judgment and behavior of a human or organization that has expertise and experience in a particular field. The power of an ES is based on its knowledge base - an organized collection of facts and heuristics about the system domain. An ES is created in a process known as knowledge engineering, where knowledge of the domain is acquired by human experts and other sources of Knowledge Engineers [15, 16]. An example of a ES can be seen from **Figure 3**.

The accumulation of knowledge in knowledge bases from which the inference engine can draw conclusions is the hallmark of an expert system. The ESs are capable of deriving a solution, predicting results and suggesting alternative options to a problem. ES can be applied areas include, scheduling, planning, risk estimation and classification. ES also help the PM to arrive at quick and proper decisions as well as identify ways to take corrective actions.

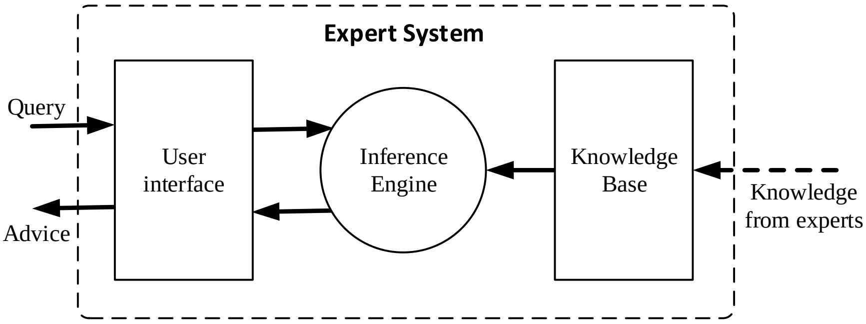


Figure 3. *An example of a ES*

2.4. Genetic Algorithms

A GA is a search heuristic inspired by Charles Darwin's theory of natural evolution. This algorithm reflects the natural selection process of selecting the most suitable individuals for reproduction to produce offspring of the next generation. A GA is a form of AI based on inductive learning technique that was first introduced by Holland (1975). The GA is used to solve both constrained and unconstrained optimization problems. GAs are excellent for searching through large and complex data sets [17, 18]. An example of a GA can be seen from **Figure 4**.

The process starts with a group of people called a population. Each individual is a solution to the problem to be solved. The fitness function determines how fit an individual is. It gives each individual a fitness rating. The probability that an individual will be selected for reproduction is based on their fitness score. The idea of the selection phase is to select the fittest individuals and let them pass on their genes to the next generation. Two pairs of persons are selected based on their fitness scores. Crossover is the most important phase in a GA. For each pair of parents to be mated, a crossing point is randomly selected from the genes. In certain newly formed offspring, some of their genes may be subject to a low probability chance mutation. The algorithm ends when the population has converged. Then it is said that the GA has provided a number of solutions to the problem. With GA it is possible to simulate the risk and uncertainty that are always associated with projects. With the application of GAs, it is possible to solve resource levelling, optimization and management problems. Scheduling and facility layout are also the more established areas for GA applications. It can be used to the adaptive assignment of worker and workload control in PM.

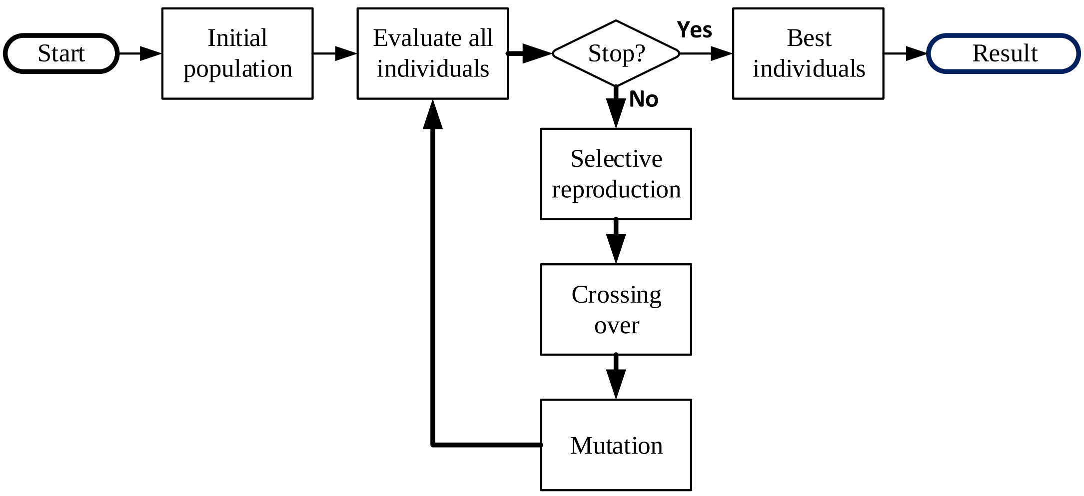


Figure 4. *An example of a GA*

3. Use cases of artificial intelligence in project management

AI can provide a solution to repetitive tasks that burden project managers such as data entry and management, project plan preparation, and so on. These tasks can be performed automatically. When the majority of the administrative tasks are handed over to AI, the project managers have more time and energy to focus on the actual work. It is possible to make estimations, recommendations and optimizations by using AI. AI can make assumptions about the future development of the project by learning from historical PM data. In addition to automation, one of the key functions of AI in PM is to provide meaningful insights into the project by sorting and aggregating data from a variety of sources. AI is able to find connections in data that would not be visible even to the best trained human eye. AI can also help with complex analysis. It can access much more data than a human manager could do alone. For example, the use of AI can help make value and risk analysis less of a burden and time-consuming task for human operators. There are several areas of PM that AI can potentially provide resolutions:

Risk Estimation and Management: Risk management is the main focus when managing projects. Risk management embodies the identification, analysis, planning, tracking, controlling, and communication of risk. AI allows to retrieve parametric information as needed. For example, historical data such as scheduled start and end dates can be used to predict realistic schedules for future projects. AI can calculate the probability that this will happen in the current project and alert accordingly.

Resource Management: Resource management is an important part of PM. It ensures that the project is executed according to the scope and the overview set in the planning phase. Resource allocation is another important aspect of PM. It involves the determination of resource consumption and the distribution of the money used to achieve the objectives. Assigning the right resources to the right department to make sure they have all the techniques they need to meet the deadline is critical to the health of a project. Predictively allocating these resources can be done using the AI, which monitors resource pools and notifies when teams need attention. AI also offer significant opportunities to improve HR functions, such as self-service transactions, recruiting and talent acquisition, payroll, reporting, access policies and procedures. Appling AI to human resources will speed up processes and create more time for the truly human side of the job.

Cost Management: Accurate cost estimation is critical to budgeting, planning, and tracking a project. AI derive lessons from previous data to get an accurate forecast of project costs. AI can increase the quality of work while reducing the cost of labour.

Time Management: Time management is defined as the process of planning and organizing time to use it most productively. Successful implementation and use of time therefore leads to guaranteed success and the achievement of goals. Project Scheduling is the tool that communicates what tasks are to be done and which organizational resources are assigned to accomplish these tasks in what time frame. AI can create an optimal project schedule. If there is a change in project scope or resource plan, AI can also instantly provide a revised schedule.

4. Conclusion

The development and application of AI in PM has given good grounds for expecting of achievements, which are mainly used in project evaluation, diagnosis, decision-making and prediction. This paper presents AI techniques used in PM. It tries to gather the recent advances on AI techniques used in PM. It is also briefly given information about AI techniques such as ANN, FL, ES, GA and their use in PM.

References

[1] Elmas, Ç., Application of Artificial Intelligence, 4. Edition, Seçkin Publications, 2018

[2] Zadeh, L. A. (1996). "Fuzzy logic = computing with words". IEEE Transactions on Fuzzy Systems. 4 (2): 103–111. doi:10.1109/91.493904

[3] Elmas, Ç., and Elmas, A., Modern Project Management, 4. Edition, Seçkin Publications, 2018

[4] Discenza, R. & Forman, J. B. (2007). Seven causes of project failure: how to recognize them and how to initiate project recovery. Paper presented at PMI® Global Congress 2007—North America, Atlanta, GA. Newtown Square, PA: Project Management Institute.

[5] Traylor, R. C., Stinson, R. C., Madsen, J. L., Bell, R. S., & Brown, K. R. (1984). Project management under uncertainty: network paths and completion time. Project Management Journal, 15(1), 66–75.

[6] Sauer, S. [Online]. Available: https://www.liquidplanner.com/blog/stats-2017-project-management-manufacturing-report/ (accessed: October 24th, 2020).

[7] Project Management Institute [Online]. Available: https://www.pmi.org/-/media/pmi/documents/public/pdf/learning/thought-leadership/pulse/the-essential-role-of-communications.pdf (accessed: October 24th, 2020)

[8] Geneca [Online]. Available: https://www.prnewswire.com/news-releases/up-to-75-of-business-and-it-executives-anticipate-their-software-projects-will-fail-117977879.html (accessed: October 24th, 2020)

[9] Johnsonbabu, A., Reinventing the role of Project manager in the Artificial intelligence era, Project Management National Conference, India, 15-17 September, 2017

[10] ISO 21500. (2012). Guidance on Project Management. Geneva: International Organization for Standardization, 2012.

[11] Waziri, B. S., Bala, K. and Bustani, S. A. (2017). Artificial Neural Networks in Construction Engineering and Management. International Journal of Architecture, Engineering and Construction, 6(1), 50-60. Doi: 10.7492/IJAEC.2017.006

[12] Ha, L. H., Hung, L., & Trung, L. Q. (2018). A risk assessment framework for construction project using artificial neural network. Journal of Science and Technology in Civil Engineering (STCE) - NUCE, 12(5), 51-62. https://doi.org/10.31814/stce.nuce2018-12(5)-06

[13] Celani de Souza, H. J., Salomon, V., Silva, C. E. S., Campos de Aguiar, D. (2012), Project Management Maturity: an Analysis with Fuzzy Expert Systems, Brazilian Journal of Operations & Production Management, Volume 9, Number 1, 2012, pp. 29-41, http://dx.doi.org/10.4322/bjopm.2013.003

[14] Mazlum, M., Güneri, A. F., (2015), CPM, PERT and Project Management with Fuzzy Logic Technique and Implementation on a Business Procedia - Social and Behavioral Sciences, Volume 210, Pages 348-357. https://doi.org/10.1016/j.sbspro.2015.11.378

[15] Zgurowsky, M. Z., Kovalenko, I. I., Kondrak, K., Kondrak, E. (2001), Expert Systems in Project Management, Journal of Automation and Information Sciences 33(1):7. DOI: 10.1615/JAutomatInfScien.v33.i1.110

[16] Liao S-H (2005) Expert system methodologies and applications—a decade review from 1995 to 2004. Expert Syst Appl 28:93–103

[17] Carl K. C., Christensen, M. J., Tao Z. (2001), Genetic Algorithms for Project Management. Annals of Software Engineering 11(1):107-139. DOI: 10.1023/A:1012543203763

[18] Kuehn, M., Zahid, T., Voelker, M., Zhou, Z., Rose, O. (2016). Investigation of Genetic Operators And Priority Heuristics for Simulation Based Optimization Of Multi-Mode Resource Constrained Multi-Project Scheduling Problems (MMRCMPSP), ECMS 2016 Proceedings, 30th European Conference on Modelling and Simulation, Regensburg Germany. doi:10.7148/2016-0481

Advances in Artificial Intelligence Research (AAIR) **Vol. 1 (No. 1), pp. 6-12, 2021**

www.dergipark.com/aair/ **Published online: Jan 15, 2021**

Speech recognition based on Convolutional neural networks and MFCC algorithm

Arzo Mahmood [1], Utku Köse [2*]

[1] Computer engineering department, Suleyman Demirel University; [0000-0002-9652-6415]
[2] Computer engineering department, Suleyman Demirel University; [0000-0001-8101-4970]

Abstract

In this paper, an automatic speech recognition system based on Convolutional neural networks and MFCC has been proposed, we have been investigated some deep models' architecture with various hyperparameters options such as Dropout rate and Learning rate. The dataset used in this paper collected from Kaggle TensorFlow Speech Recognition Challenge. Each audio file in the dataset contain one word with one second length the total words in the dataset is 30 categories with one category for background noise. The dataset contains 64,721 files has been separated into 51,088 for the training set, 6,798 for the validation set and 6,835 for the testing set. We have evaluated 3 models with different hyperparameters configuration in order to choose the best model with higher accuracy. The highest accuracy achieved is 88.21%.

Keywords: *Convolutional neural network; FFT; MFCC; Speech recognition; Features extraction.*

1. Introduction

The automatic speech recognition is the process of recognizing the spoken words by human to a readable machine format like text, or command. This technology lets users to control their digital devices using their voice instead of using another input tool such as keyboard or mouse. The field of the speech recognition has been developed during the past decades because of its wide range of applications in many fields of life [1], the main applications of the technology are the call centers, dictation solutions and assistive applications and mobile and embedded devices.

Most of automatic speech recognition systems extract the features from the acoustic signal instead of using the full speech signal due to the large variations in the speech these variations include the pitch and speed of voice background noise, emotions and expressions. Interact with computer speech, keyboard, mouse, touchpad, etc. is helpful for people who have difficulty dealing with normal interface like. Speech recognition [2], is the process of converting a speech signal into words or phonemes. The main purpose of ASR is to overcome all difficulties encountered in the field of speech recognition such as different speech patterns, fuzzy environmental noise and the like [3, 4]. Modern speech recognition systems use deep learning techniques [5,6]. They are used to represent features and to model the language [7,8]. Better results are achieved by the recently popular convolution neural networks [9,10]. New frameworks are being created for the fastest open-source deep learning speech recognition framework [11]. Work is underway to improve their efficiency compared to existing ones such as ESPNet, Kaldi, and OpenSeq2Seq. There are also solutions in which the architecture of the Recurrent Neural Network (RNN) is used to obtain lightweight and high accuracy models that can run locally [12]. This will allow the use in real time. There are works on algorithms implemented in the frequency domain that allow speech analysis by identifying the intended fundamental frequency of the human voice, even in the presence of subharmonics [13]. The popular algorithm for features extraction used is the Mel-Frequency Cepstral Coefficients (MFCCs) [14] which is inspired from human ear and working on the Mel-space frequencies.

In this paper, we present a speech recognition system based on Convolutional neural network and Mel-frequency cepstral coefficients. The MFCC algorithm used to extract the unique features of each speech signal and then we used these features to train the CNN algorithm which also do features extraction [15]. The Purpose of using MFCC algorithm is to reduce the complexity of the model and achieve higher recognition accuracy. The dataset used in this study is the Kaggle TensorFlow Speech Recognition Challenge [16], the dataset contains a command words and non-command words spoken by various subjects each speech signal is one second length. The total dataset that we used contains 64,721 audio files separated into 51,088 training set, 6,798 validation set and 6,835 testing set. The total command words files are 23,682 and non-command words are 41,039. We evaluated three deep models with various hyperparameters options.

*Corresponding author
E-mail address: utkukose@sdu.edu.tr, janamohammed22@gmail.com

Received: 12/July/2020; Received in revised form: 25/Nov/2020; Accepted: 25/Nov/2020.

2. Methods

2.1. MFCCs (Mel frequency cepstral coefficients)

MFCCs is the popular and most used Feature extraction algorithm in the field of automatic speech recognition. The algorithm proposed in the 1980's by Davis and Mermelstein[17]. Before the introduction of the MFCC algorithm, the Linear Prediction Coefficients (LPC) and the Linear Prediction Cepstral Coefficients (LPCCs)[18] where the most used methods in that time and were used together with Hidden Markov models[19] in speech recognition system on that time. The Calculation of the MFCC features is done by following steps:

1. The Algorithm works by framing the signal into short frames, and calculate the power spectrum periodogram estimate for each frame of the signal.
2. Applying the Mel-space filter banks on the power spectra and sum the filters energies.
3. Calculate the Logarithm of the filter banks energies and calculate the DCT (Discrete cosine transform) of the logarithms.
4. The DCT coefficients must be between 2-13, so the algorithm will discard the others.
5. Sometimes the frame energy, Delta and Delta-Delta features is appended to each feature vector.

Fig. 1 shows the Block diagram of the MFCC algorithm.

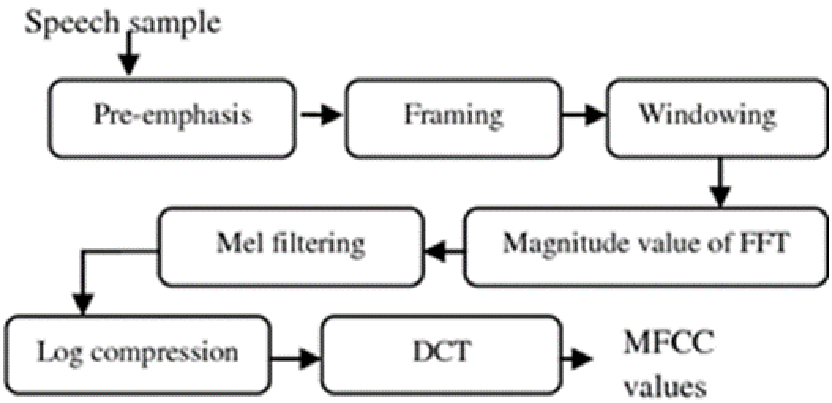


Figure 1: *Block diagram of the MFCC algorithm.*

As shown in the block diagram the pre-emphasis purpose is to amplify the higher frequencies in the input speech signal and increase the magnitude within the spectrum of the frequencies because of the high frequencies tend to have a small magnitude compared to the lower ones. The pre-emphasis filter can be represented mathematically as following:

$$y = x(t) - \alpha x(t-1)$$

Where the y is the output speech signal, x is the input signal and α is the coefficient which is typically between 0.95 – 0.97. The Pre-emphasis is useful in the FFT (Fast Fourier transform) process because of the issues with the acoustic signal values.
As described above the framing is the following step after the pre-emphasis which is divide the acoustic signal into sub-frames that have a short interval(20-40ms) and it used because of the changes in the frequencies happens in short times (milliseconds) and for other reason it's not logical to apply the FFT on the whole speech signal.

After dividing the speech signal into sub-frames, the hamming window can be represented mathematically as following:

$$w_n = 0.54 - 0.46cos(\frac{2\pi n}{N-1})$$

where N is the window length. Fig. 2 shows the hamming window.

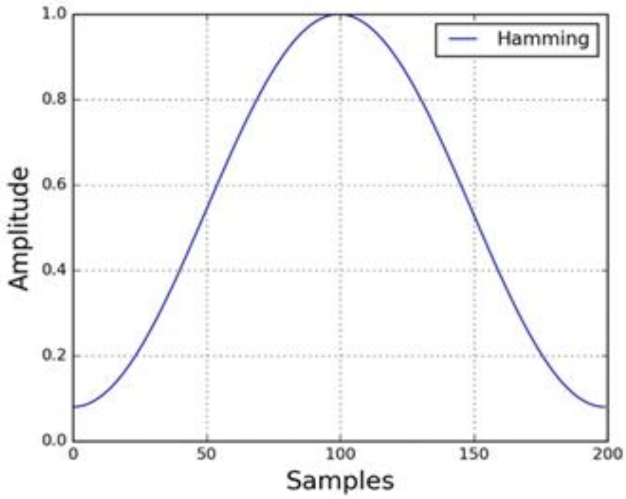


Figure 2: *Hamming window applied to speech signal.*

After applying the hamming window, the Fast Fourier transform is applied to calculate the frequency spectrum on each frame then the power spectrum is calculated as following:

$$P = \frac{|FFT(x_i)|^2}{N}$$

where N is the number of FFT as typically 256 or 512 and xi is represent the ith sub-frame of signal x. The Final step in the MFCC is filters bank which is computed by applying 40 triangular filter on the mel-scale. Each filter has a triangular response which has a value of one and decrease linearly to zero. Fig. 3 shows the Mel-scale filters bank response.

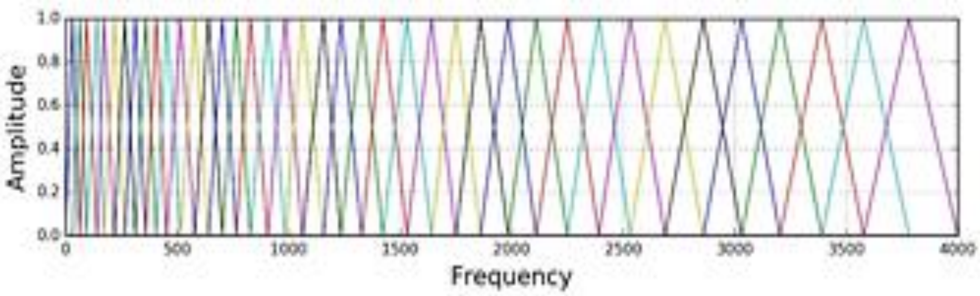


Figure 3: *The Response of the triangular mel-scale filter bank.*

The Discrete Cosine Transform (DCT) applied to the output of the mel-scale filter banks because their output is highly correlated which is an issue to the classification and machine learning algorithm to deal with. The DCT decorrelate the output and compress the filters representations.

2.2. DCNN (Deep Convolutional Neural Networks)

The DCNN are type of multi-layer perceptron. It inspired by the visual cortex of animals. The main application of the CNNs is the image processing but it has been used in many other fields like voice and video processing. The algorithm was proposed [20]. the Architecture of the CNN consists many types of layers, the main layer is the convolution layer. The convolution layer purpose is to extract features from the input data, which preserves the spatial relationship between data points by learning features using small squares of input data [21]. The other important layer is the Pooling layer which is used to reduce the dimension of the data by combining the output of the features map into single value in the next layer. Typically, the pooling size used is 2x2[22] [23]. The Last layer in each CNN network is the fully connected layer which its purpose connects each neuron in the layer to every neuron the following layer. The principle of the fully connected layer is similar to the multi-layer perceptron.

In this study, we designed three architecture of CNN network in order to classify speech signal based on its MFCC features. Table 1, Table 2 and Table 3 shows the architecture of each model.

Table 1. *Model 1 Architecture.*

Layer	Input Shape	Output Shape	Weights	Activation
Input layer	79x12	79x12	0	None
ZeroPadding1D	79x12	80x 12	0	None
Conv1D	80x 12	15x 50	6050	ReLU
Dropout	15x 50	15x 50	0	None
Conv1D	15x 50	2x100	50100	ReLU
Dropout	2x100	2x100	0	None
Average Pooling	2x100	1x100	0	None
Fully Connected Layer	1x100	1, 11	1111	Softmax

Table 1. *Model 2 Architecture.*

Layer	Input Shape	Output Shape	Weights	Activation
Input layer	79x12	79x12	0	None
Conv1D	79x12	39x20	740	ReLU
Dropout	39x20	39x20	0	None
Conv1D	39x20	19x20	1220	ReLU
Dropout	19x20	19x20	0	None
Conv1D	19x20	9x20	1220	ReLU
Dropout	9x20	9x20	0	None
Conv1D	9x20	4x20	1220	ReLU
Dropout	4x20	4x20	0	None
Conv1D	4x20	1x20	1220	ReLU
Dropout	1x20	1x20	0	None
Fully Connected Layer	1x20	1x11	231	Softmax

The purpose of this study is to provide an algorithm that understands a small selection of simple audio commands. The selection of commands the algorithm should understand should be (Yes, No, Down,up, right, left, off, on, go, stop). The purpose of the work is to Objectively work to minimize the number of layers in the architecture to maintain some simplicity within the model and to minimize runtime, using convolutional layers with a wide-enough convolution window and stride to identify patterns and using pooling layers to reduce dimensionality between convolutional layers.

Each of the network uses 1-dimensional convolutional layers that slide along the time axis, convoluting MFCCs and reducing the size of the first dimension of the audio data. The idea behind each of these networks is to recognize patterns among MFCCs across time. Differentiating features among these three models were the size of the convolution windows, the overlapping stride of the windows, the number of filters, and the number of layers.

The three model architectures that introduced are (1) Large Windows/Few Layers/Many Filters - this model consists of 1 padding layer, 2 convolutional layers with window size of 10 and stride of 5 each, an average pooling layer, and a dense output layer. The first and second convolutional layers have 50 and 100 filters, respectively. Dropout layers have been added after each convolutional layer. (2) Small Windows/Fewer Filters - this model consists of 5 sets of convolutional layers with window size of 3 and strides of 2 followed by a dense output layer. Each convolutional layer has 20 filters. Dropout layers have been added after each convolutional layer. (3) Moderate Windows/Increasing Filters - this model consists of a set of 1 padding and 2 convolutional layers with window size 4 and stride 2, followed by another set of 1 padding and 3 convolutional layers with small window sizes. The number of filters increase with each additional layer until the final dense output layer. Dropout layers have been added after each convolutional layer.

Hyperparameters that changed with each model were the dropout rate (0%,25%,50%) and the learning rate (0.01, 0.05, 0.10). Therefore, the total number of models evaluated was 81.

2.3. DATASET

The algorithm trained and tested using the Speech Commands Dataset released by Google on August 3, 2017. The data contains 64,727 one-second audio clips of 30 short words. The audio files were crowdsourced by Google with the goal of collecting single-word commands (rather than words as said and used in conversation).

A group of 20 core words audio files were recorded and repeated 5 times by the most of speakers. An additional group 10 words were recorded to help distinguish unrecognized words; most speakers recorded these words once. The core words consist of (Yes, No, Down,up, right, left, off, on, go, stop) and the numbers zero through nine. Auxiliary words consist of "Bed", "Bird", "Cat", "Dog", "Happy", "House", "Marvin", "Sheila", "Tree" and "Wow".

This algorithm will take as inputs: a file of PCM-encoded data to be decoded into a 16-bit [16000, 1] integer tensor and Output will be a [1, 11] tensor representing the prediction of the algorithm. Values will be between 0 and 1.

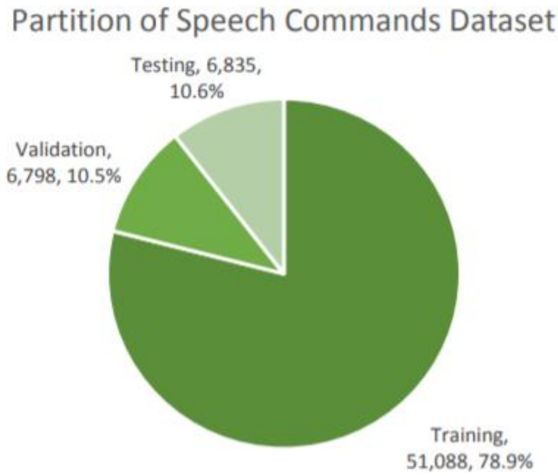


Figure 4. *The Chart show the Dataset separation into Training,validation and testing subsets.*

3. Results

The three-model architecture that presented in this paper, trained using the dataset. The program has been implemented using python and Keras deep learning library with TensorFlow backend. The Table below shows the Test results of the Models.

Table 3. *Test results of each model with hyperparameters values.*

Dropout rate	*Learning Rate*	*Model 1*	*Model 2*	*Model 3*
0.00	0.01	84.61%	82.27%	83.61%
	0.05	84.96%	82.11%	82.79%
	0.10	82.93%	82.44%	83.44%
0.25	0.01	87.96%	72.28%	83.44%
	0.05	88.21%	74.48%	83.79%
	0.10	88.21%	74.92%	82.91%
0.50	0.01	84.80%	62.44%	66.99%
	0.05	85.41%	62.44%	67.17%
	0.10	85.21%	62.44%	65.85%

Model architecture 1 was vastly superior to the other two models with all scores above the average of the testing data. This suggests that a greater convolution window, stride, and number of filters may render direct improvement in classification accuracy. A dropout rate of 0.25 was better than both 0 and 0.5 which isn't surprising considering that a rate of 0 leads to overfitting of test data and a substantial dropout rate will impede training as backpropagated calculations will fail to persist. This suggests an appropriate range of dropout rate should be narrower and skewed toward lower values greater than 0. In general, a learning rate of 0.05 tested better than rates at 0 and 0.1, suggesting that models tested in a narrower range including 0.05 may train and test better.

Discussion

Many researches and studies on speech recognition have been done in the literature. M. Karakaş, Using Mel Frequency Cepstral Coefficients and Dynamic Time Bending Algorithms "OPEN", "CLOSE", "START" and "STOP" on MATLAB, an average accuracy of 88.5% and an average accuracy of 82% were obtained independently of the speaker [24] . Fezari meat. get. used RSC 364 board for speech recognition and PIC 16F876 as microprocessor. Experiments with regular and disorganized speech outside the laboratory and regular and disorganized speech resulted in average success rates of 85%, 73%, 78% and 65%, respectively [25]. P. Leechor et al. in. Visiual Basic 6 user interface used Hidden Markov Model user kit. In a noisy environment, when a remote-controlled car was controlled with voice commands, it achieved 98% accuracy, while in a very noisy room it decreased by up to 44% [26]. V. A. Petrushin used the Artificial Neural Networks algorithm for speech recognition. According to the calls made to the call center in the study, 30 people tried to test 5 different emotions and achieved 70% success [27]. used in this article the dataset contains 64,721 files has been separated into 51,088 for the training set, 6,798 for the validation set and 6,835 for the testing set. The difference of our article we have evaluated 3 models with different hyperparameters configuration in order to choose the best model with higher accuracy. The highest accuracy achieved is 88.21%.

Conclusion

This research paper has been proposed an automatic speech recognition system based on two algorithms for features extraction, firstly the unique features of the speech acoustic signal has been extracted using MFCCs and feed theses features for the CNN algorithm for further features learning and classification. The Study compared three model architectures of the CNN in order to see the best results of the model with various options of hyperparameters and layers. The study shows that the using of MFCC as a feature extraction and feed these features for the CNN model for further features extraction will improve the accuracy and reduce the complexity of the model.

References

[1] M. A. Anusuya and S. K. Katti. “Speech Recognition by Machine, A Review”. In: International Journal of Computer Science and Information Security, IJCSIS, Vol. 6, No. 3, pp. 181-205, December 2009, USA (Jan. 2010).

[2] S. Sinha, S.S. Agrawal, A. Jain. “Continuous density hidden markov model for Hindi speech recognition”, GSTF J. Comput., 3(2) (2018).

[3] O. Abdel-Hamid, A.R. Mohamed, H. Jiang, G. Penn. “Applying convolutional neural networks concepts to hybrid NN-HMM model for speech recognition Acoustics”, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on, IEEE (2012, March), pp. 4277-4280.

[4] O. Abdel-Hamid, A.R. Mohamed, H. Jiang, L. Deng, G. Penn, D. Yu. “Convolutional neural networks for speech recognition” IEEE/ACM Trans. Audio Speech Lang. Process., 22(10) (2014), pp. 1533-1545.

[5] Mohamed, A.R.; Dahl, G.E.; Hinton, G.E. Acoustic Modeling Using Deep Belief Networks. IEEE Trans. Audio Speech Lang. Process. 2012, 20, 14–22. [CrossRef]

[6] Yu, D.; Seide, F.; Li, G. Conversational Speech Transcription Using Context-Dependent Deep Neural Networks. In Proceedings of the 12th Annual Conference of the International Speech Communication Association, Florence, Italy, 27–31 August 2011.

[7] Tüske, Z.; Golik, P.; Schlüter, R. Acoustic modeling with deep neural networks using raw time signal for LVCSR. In Proceedings of the 15th Annual Conference of the International Speech Communication Association, Singapore, 14–18 September 2014.

[8] Arisoy, E.; Sainath, T.N.; Kingsbury, B.; Ramabhadran, B. Deep Neural Network Language Models. In Proceedings of the NAACL-HLT 2012 Workshop: Will We Ever Really Replace the N-gram Model? On the Future of Language Modeling for HLT; Association for Computational Linguistics: Montréal, QC, Canada, 2012; pp. 20–28.

[9] Sainath, T.N.; Mohamed, A.R.; Kingsbury, B.; Ramabhadran, B. Deep convolutional neural networks for LVCSR. In Proceedings of the 2013 IEEE International Conference on Acoustics, Speech and Signal Processing, Vancouver, BC, Canada, 26–31 May 2013; pp. 8614–8618.

[10] Mitra, V.; Wang, W.; Franco, H.; Lei, Y.; Bartels, C.; Graciarena, M. Evaluating robust features on deep neural networks for speech recognition in noisy and channel mismatched conditions. In Proceedings of the Fifteenth annual conference of the international speech communication association, Singapore, 14–18 September 2014.

[11] Pratap, V.; Hannun, A.; Xu, Q.; Cai, J.; Kahn, J.; Synnaeve, G.; Liptchinsky, V.; Collobert, R. wav2letter++: The

Fastest Open-source Speech Recognition System. arXiv 2018, arXiv:1812.07625.
[12] De Andrade, D.C. Recognizing Speech Commands Using Recurrent Neural Networks with Attention. Available online: https://towardsdatascience.com/recognizing-speech-commands-using-recurrent-neuralnetworks-with-attention-c2b2ba17c837 (accessed on 27 December 2018).
[13] Andrade, D.C.; Trabasso, L.G.; Oliveira, D.S.F. RA Robust Frequency-Domain Method For Estimation Of Intended Fundamental Frequency In Voice Analysis. Int. J. Innov. Sci. Res. 2018, 7, 1257–1263.
[14] Han, Wei, et al. "An efficient MFCC extraction method in speech recognition." *2006 IEEE international symposium on circuits and systems*. IEEE, 2006.
[15] Jiang, Fei, et al. "An event recognition method for fiber distributed acoustic sensing systems based on the combination of MFCC and CNN." *2017 International Conference on Optical Instruments and Technology: Advanced Optical Sensors and Applications*. Vol. 10618. International Society for Optics and Photonics, 2018.
[16] Warden, Pete. "Speech commands: A dataset for limited-vocabulary speech recognition." *arXiv preprint arXiv:1804.03209* (2018).
[17] S. Davis and P. Mermelstein. “Comparison of parametric representations for monosyllabic word recognition in continuously spoken sentences”. In: IEEE Transactions on Acoustics, Speech, and Signal Processing 28.4 (Aug. 1980), pp. 357–366.
[18] Harshita Gupta and Divya Gupta. “LPC and LPCC method of feature extraction in Speech Recognition System”. In: 2016 6th International Conference - Cloud System and Big Data Engineering (Confluence). IEEE, Jan. 2016.
[19] D.J. Mashao, Y. Gotoh, and H.F. Silverman. “Analysis of LPC/DFT features for an HMM-based alphadigit recognizer”. In: IEEE Signal Processing Letters 3.4 (Apr. 1996), pp. 103–106.
[20] Y. Lecun et al. “Gradient-based learning applied to document recognition”. In: Proceedings of the IEEE 86.11 (1998), pp. 2278–2324.
[21] Hamed Habibi Aghdam and Elnaz Jahani Heravi. “Traffic Sign Detection and Recognition”. In: Guide to Convolutional Neural Networks. Springer International Publishing, 2017, pp. 1–14.
[22] Dan Claudiu Ciresan et al. “Convolutional Neural Network Committees for Handwritten Character Classification”. In: 2011 International Conference on Document Analysis and Recognition. IEEE, Sept. 2011.
[23] Krizhevsky, Alex, Ilya Sutskever, and Geoffrey E. Hinton. "Imagenet classification with deep convolutional neural networks." Advances in neural information processing systems. 2012.
[24] M. Karakaş, "Computer Based Control Using Voice Input", Yüksek Lisans Tezi, Dokuz Eylül Üniversitesi, Eylül 2010.
[25] M. Fezari, M.B. Salah, "A Voice Command System for Autonomous Robots Guidance", IEEE AMC-06 0-7803-9511, 2006.
[26] P. Leechor, C. Pornpanomchai, P. Sukklay, “Operation of a Radio Controlled Car by Voice Commands”, 2010 2nd International Conference on Mechanical and Electronics Engineering (ICMEE 2010), 2010.
[27] V.A. Petrushin, "Emotion in Speech Recognition and Application to Call Centers", Andersen Consulting.

Advances in Artificial Intelligence Research (AAIR) **Vol. 1 (No.1), pp.13-18, 2021**
www.dergipark.com/aair/ **Published online: Jan 15, 2021**

Classification of Death Related to Heart Failure by Machine Learning Algorithms

Remzi Gürfidan[1,*], Mevlüt Ersoy[2]

[1] Isparta University of Applied Science, Yalvac Technical Sciences Vocational School; [0000-0002-4899-2219]
[2] Süleyman Demirel University, Computer Engineering; [0000-0003-2963-7729]

Abstract

The increase in the number of individuals with heart diseases and deaths associated with these diseases tops the list of causes of death. Early detection and treatment can reduce the risk of death of candidates with heart disease and people with heart disease. With the expansion of artificial intelligence technology in the field of health in recent years, artificial intelligence models with prediction and classification capability that will contribute positively to patients and health workers are being developed.

In this study, the heart disease mortality status was classified according to the clinical data and life information of the patients included in the heart failure data set. The aim of this study is to evaluate the mortality associated with heart disease based on the clinical data and life information of the patients and to guide patients and doctors to early diagnosis or early treatment methods. Classification processes were performed with different machine learning algorithms and success rates were shown. Different algorithms have been tested to achieve success rates between 73% and 83%. Among the tried algorithms, the most successful classification process is provided by the Support Vector Machine (SVM) algorithm.

Keywords: *Machine learning; healthcare; hearth failure; support vector machine.*

1. Introduction

Heart disease is common throughout the world and is at the top of diseases that pose a high risk to human life. According to the Health Statistics report of the Ministry of health of the Republic of Turkey, the cause of 46.2 percent of deaths in the world other than infectious diseases in 2012 was stated as cardiovascular diseases. The report shows that this rate is increasing. Deaths due to cardiovascular diseases are estimated to be 22.2 million in 2030 [1]. In studies conducted on ready data groups, prediction and classification processes are commonly performed by machine learning algorithms. The results obtained may vary depending on the selected algorithm and the characteristics of the data set being studied.

In this study, experimental studies were conducted on the classification of death conditions due to heart disease using machine learning algorithms according to the measurement values and life information obtained from individuals. The data set used in this study was taken from the University of California Irvine Machine Learning Repository [2], “Heart failure clinical records Data Set 2020” is used by various researchers [3,4] and can be accessed from online data mining repository of the University of California. This dataset was used in this research stud for designing machine-learning-based system for heart failure classification. In the data set, 12 arguments are defined as input data. The expected result as output from the system is the classification of death conditions due to the individual's heart condition as a result of the algorithms subjected to the input values. 33% of the 300 data lines in the data set were allocated as test data and trainings were conducted and 83% success rate was achieved as the highest value.

2. Literature Review

Machine learning algorithms are often used in academic studies in recent years due to the successful prediction and classification results they show on ready-made data sets. Machine learning occurs in different fields of study such as health [5,6], cryptology [7], time series [8,9]. There are many studies in the literature on the diagnosis and classification of heart diseases. Most of these studies were carried out using machine learning methods [10-14]. Mohan and etc. used a hybrid machine learning method where random forest and linear regression algorithms were combined to predict heart disease. There are 303 data in the data set they used in their study and the success rate of the model they trained is 88 % [15]. Haq and etc. also used a hybrid machine learning method for the classification of heart diseases. They used classifiers such as Support Vector Machine algorithm (SVM), K-Nearest Neighbor algorithm, Logistic Regression algorithm within the hybrid model. As a model success, they reached 89% [16]. Kukar and etc. used machine learning algorithms for the classification of the diagnosis of ischemic heart diseases. In their study, they used ECG (electrocardiogram),

*Corresponding author
E-mail address: remzigurfidan@isparta.edu.tr

Received: 10/August/2020; Received in revised form: 2/September/2020; Accepted: 23/October/2020.

sequential ECG test during controlled exercise, myocardial scintigraphy, and finally coronary angiography images as data sets. The model they developed in their study provides 84,448% accuracy [17].

3. Proposed Model

The data set contains 13 clinical features. Of these properties, the first twelve properties are considered as independent variables, and the last property as dependent variables. The proposed model is subjected to training to independent variables and predicts the dependent variable part. Since the predicted value is 0 or 1, the operation performed is classification. Table 1 shows the properties within the data set.

Table 1. *Dataset Features and Descriptions*

Features	Description	Feature Type
Age	Age of The Patient	Years
Anaemia	Decrease of Red Blood Cells or Hemoglobin	Boolean
High Blood Pressure	If the Patient Has Hypertension	Boolean
Creatinine Phosphokinase	Level of The Cpk Enzyme in The Blood	Mcg/L
Diabetes	Percentage of Blood Leaving the Heart at Each Contraction	Percentage
Ejection Fraction	Platelets in The Blood	Kiloplatelets/Ml
Platelets	Woman or Man	Binary
Sex	Level of Serum Creatinine in The Blood	Mg/Dl
Serum Creatinine	Serum Sodium: Level of Serum Sodium in The Blood	Meq/L
Serum Sodium	Smoking: If the Patient Smokes or Not	Boolean
Smoking	Follow-Up Period	Days
Time	Follow-Up Period	Days
[Target] Death Event	If the Patient Deceased During the Follow-Up Period	Boolean

There is a total of 300 data lines in the data set. 99 of these data sets were randomly allocated as test data and 201 as training data. Six different classification algorithms have been tried on the data set in order to obtain the best result of the training. The mathematical models of each algorithm, the classification success confusion matrix values obtained from the training are shown in tables.

3.1. Support Vector Machine (SVM)

The hypothesis function called "h". X and y parameters are classification dimensions. The point above or on the hyperplane will be classified as class +1, and the point below the hyperplane will be classified as class -1. This math model shown in Equation 1.

$$h(x_i) = \begin{cases} -1, if\ w.x + b < 0 \\ +1, if\ w.x + bx \geq 0 \end{cases} \quad (1)$$

n parameter is being the number of features had and w is a point on the hyperplane. use on the soft-margin classifier since choosing a sufficiently small value for lambda yields the hard-margin classifier for linearly-classifiable input data. The mathematical model that enables these operations to be executed is shown in Equation 2.

$$\left[\frac{1}{n}\sum_{i=1}^{n} \max\left(0,1 - y_i(w.x_i - b)\right)\right] + \gamma\|w\|^2 \quad (2)$$

SVM algorithm was applied to the studied data and an accuracy value of 0.83 was obtained. The confusion matrix of the classification process performed at the end of the model training is shown in Table 2.

Table 2. *Confusion Matrix for SVM Algorithm*

Confusion Matrix	False (0)	True (1)	Total
False (0)	63	7	70
True (1)	11	18	29
Total	74	25	99

The data shown in the columns on the confusion matrix show the actual data and the data shown in the rows show the classification results of the test data. Of the 99 randomly selected test data, 74 are "0" data, 25 are "1" data. The trained model classified 63 of its false - false classifications as correct and 7 incorrectly, and 18 of its true - true classifications as correct and 11 incorrectly.

3.2. Logistic Regression Algorithm

Given a row of data (x, y) in the data set, x is a matrix of values with m instances and n properties, and Y is a vector with m instances. The purpose of the algorithm is to train the model to predict which class the values to be given to it belong to in the future. Primarily, have been created a weight matrix with random initialization. Then have been multiply it by features. The mathematical model of the mentioned operations is shown in Eq. 3.

$$a = w_0 + w_1 x_1 + w_2 x_2 + \cdots + w_n x_n \quad (3)$$

This is followed by calculating Eq. 4 the cost for that iteration.

$$cost(w) = -\frac{1}{m}\sum_{i=1}^{i=m} y_i \log(y_i) + (1 - y_i)\log(1 - y_i) \quad (4)$$

P function is defined probability and math model shown in Eq. 5.

$$P(y = 1|x; w) \ \& \ P(y = 0 \ |x; w) \quad (5)$$

Logistic Regression algorithm was applied to the studied data and an accuracy value of 0.82 was obtained. The confusion matrix of the classification process performed at the end of the model training is shown in Table 3.

Table 3. *Confusion Matrix for Logistic Regression Algorithm*

Confusion Matrix	False (0)	True (1)	Total
False (0)	63	7	70
True (1)	10	19	29
Total	73	26	99

The data shown in the columns on the confusion matrix show the actual data and the data shown in the rows show the classification results of the test data. Of the 99 randomly selected test data, 73 are “0” data, 26 are “1” data. The trained model classified 63 of its false - false classifications as correct and 7 incorrectly, and 19 of its true - true classifications as correct and 10 incorrectly.

3.3. Decision Tree Classifier Algorithm

Firstly, Compute the entropy for the data set. Entropy is calculated by the H method shown in Equation 6. Entropy H(S) is measure of the amount of uncertain in the dataset. S is the current set for which entropy is being calculated. C = {True, False} is set of classes in S. P function is the proportion of the number of elements in class c to the number of elements in set S.

$$H(S) = \sum_{c \in C} -p(c) log_2 p(c) \quad (6)$$

Decision Tree Classifier algorithm was applied to the studied data and an accuracy value of 0.73 was obtained. The confusion matrix of the classification process performed at the end of the model training is shown in Table 4.

Table 4. *Confusion Matrix for Decision Tree Classifier Algorithm*

Confusion Matrix	False (0)	True (1)	Total
False (0)	58	12	70
True (1)	15	14	29
Total	73	26	99

The data shown in the columns on the confusion matrix show the actual data and the data shown in the rows show the classification results of the test data. Of the 99 randomly selected test data, 73 are “0” data, 26 are “1” data. The trained model classified 58 of its false - false classifications as correct and 12 incorrectly, and 14 of its true - true classifications as correct and 15 incorrectly.

3.4. K-Nearest Neighbor Algorithm (KNN)

The basic principle of K-nearest neighbor algorithm in classification problems is that a selected algorithm K can detect the closest neighbor of the hidden data point. Then, assigning the most obviously classified one to the hidden data point. The data numbers refer to all K neighboring classes. The Euclidean equation shown in Equation 7 is used to measure distances.

$$d(x,x') = \sqrt{(x-x_1')^2 + \cdots + (x-x_n')^2} \tag{7}$$

Finally, the input x gets assigned to the class with the largest probability. The variable x is defined to indicate a property and y to indicate the target. The K in KNN is a hyperparameter, must decide get the most suitable fit for the data set.

$$P(y=j|X=x) = \frac{1}{K}\sum_{i\in A} I\left(y^{(i)}=j\right) \tag{8}$$

KNN algorithm was applied to the studied data and an accuracy value of 0.73 was obtained. The confusion matrix of the classification process performed at the end of the model training is shown in Table 5.

Table 5. *Confusion Matrix for K-Nearest Neighbor Algorithm*

Confusion Matrix	False (0)	True (1)	Total
False (0)	63	7	70
True (1)	19	10	29
Total	82	17	99

The data shown in the columns on the confusion matrix show the actual data and the data shown in the rows show the classification results of the test data. Of the 99 randomly selected test data, 82 are “0” data, 17 are “1” data. The trained model classified 63 of its false - false classifications as correct and 7 incorrectly, and 10 of its true - true classifications as correct and 19 incorrectly.

3.5. Linear Discriminant Analysis Algorithm

Population π_i the probability density function of x is multivariate normal with mean vector μ_i and variance-covariance matrix Σ (same for all populations). normal probability density function is shown Eq. 9.

$$P(X|\pi_i) = \frac{1}{2\pi^{\frac{p}{2}}\,|\sum i|^{\frac{1}{2}}}\, exp\left[-\frac{1}{2}(X-\mu_i)'\frac{1}{\sum i}(X-\mu_i)\right] \tag{9}$$

According to the Naive Bayes classification algorithm, have been classified the population for which $P(\pi_i)$ $P(X|\pi_i)$ is the maximum. Linear Discriminant Analysis algorithm was applied to the studied data and an accuracy value of 0.82 was obtained. The confusion matrix of the classification process performed at the end of the model training is shown in Table 6.

Table 6. *Confusion Matrix for Linear Discriminant Analysis Algorithm*

Confusion Matrix	False (0)	True (1)	Total
False (0)	64	6	70
True (1)	12	17	29
Total	76	23	99

The data shown in the columns on the confusion matrix show the actual data and the data shown in the rows show the classification results of the test data. Of the 99 randomly selected test data, 76 are “0” data, 23 are “1” data. The trained model classified 64 of its false - false classifications as correct and 6incorrectly, and 17 of its true - true classifications as correct and 12 incorrectly.

3.6. Gaussian Naive Bayes Algorithm

In Bayes Theorem, the property vector X = (x_1, x_2, ..., x_n) is denoted by the given class variable C_k. The Naive Bayes classification problem have been formulated like Eq. 10.

$$C' = \operatorname{argmax} P(C_k) \prod_{i=1}^{n} P(x_i|C_k) \tag{10}$$

Gaussian Naive Bayes algorithm was applied to the studied data and an accuracy value of 0.78 was obtained. The confusion matrix of the classification process performed at the end of the model training is shown in Table 7.

Table 7. *Confusion Matrix for Gaussian Naive Bayes Algorithm*

Confusion Matrix	False (0)	True (1)	Total
False (0)	67	3	70
True (1)	19	10	29
Total	86	13	99

The data shown in the columns on the confusion matrix show the actual data and the data shown in the rows show the classification results of the test data. Of the 99 randomly selected test data, 86 are “0” data, 13 are “1” data. The trained model classified 67 of its false - false classifications as correct and 3 incorrectly, and 10 of its true - true classifications as correct and 19 incorrectly.

4. Discussion

The accuracy value of the model trained with machine learning takes a value between 0 and 1. The closer to 1, the higher the success of the model. The accuracy values obtained as a result of the training of the model trained according to different algorithms are shown graphically in Figure 1. When the obtained accuracy values were examined, the highest success was obtained from the model trained with SVM algorithm. LR and LDA follow this success.

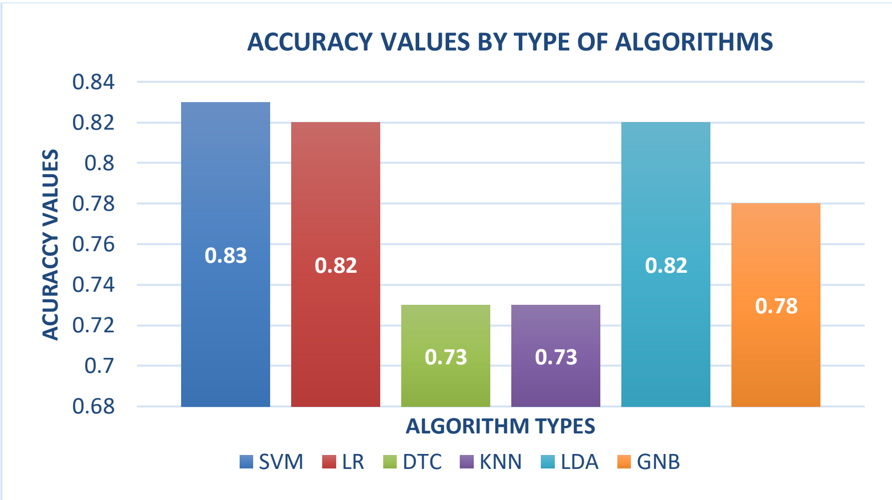


Figure 1. *Accuracy values by type of algorithms*

The 83 percent success rate measured in the developed model cannot be considered as bad, but considering the algorithms applied in this study, higher successes were expected from the developed models. The reason for the success rate to remain at this level is considered to be the number of data in the data set. 201 data were presented to the models as training data. As the number of data in the data set increases, the learning ability of the model will naturally improve and the accuracy value will increase accordingly.

5. Conclusion

In this study, experimental studies were conducted on the classification of heart failure related death conditions using different machine learning algorithms according to the measurement values and life information obtained from individuals. The heart_failure_clinical_records data set was used in the study. In the data set, 12 arguments are defined as input data. The expected result as output from the system is to be able to classify the individual's death conditions due to heart disease as a result of algorithms subjected to input values. Of the 300 rows of data in the dataset, 33% of test data is divided into 67% of training data. The highest accuracy value obtained from different algorithms has been increased to 83%. In future studies, it is aimed to increase the amount of data in the data set and increase the final success rate to over 90%.

References

[1] Türkiye Cumhuriyeti Sağlık Bakanlığı Sağlık İstatistikleri Yıllığı, 2015

[2] Davide Chicco, Giuseppe Jurman: "Machine learning can predict survival of patients with heart failure from serum creatinine and ejection fraction alone". BMC Medical Informatics and Decision Making 20, 16 (2020).

[3] Ahmad, T., Munir, A., Bhatti, S. H., Aftab, M., & Raza, M. A. (2017). Survival analysis of heart failure patients: A case study. PloS one, 12(7), e0181001.

[4] Chicco, D., & Jurman, G. (2020). Machine learning can predict survival of patients with heart failure from serum creatinine and ejection fraction alone. *BMC medical informatics and decision making*, *20*(1), 16.

[5] Zemmal, N., Azizi, N., Sellami, M., Cheriguene, S., Ziani, A., AlDwairi, M., & Dendani, N. (2020). Particle Swarm Optimization Based Swarm Intelligence for Active Learning Improvement: Application on Medical Data Classification. Cognitive Computation, 1-20.

[6] Hsu, C. N., Liu, C. L., Tain, Y. L., Kuo, C. Y., & Lin, Y. C. (2020). Machine Learning Model for Risk Prediction of Community-Acquired Acute Kidney Injury Hospitalization from Electronic Health Records: Development and Validation Study. Journal of *Medical Internet Research*, *22*(8), e16903.

[7] Al Shibli, M. (2020). Hybrid Artificially Intelligent Multi-Layer Blockchain and Bitcoin Cryptology (AI-MLBBC): Anti-Crime-Theft Smart Wall Defense. In Encyclopedia of Criminal Activities and the Deep Web (pp. 1089-1111). IGI Global.

[8] Jiang, Y., Bao, X., Hao, S., Zhao, H., Li, X., & Wu, X. (2020). Monthly Streamflow Forecasting Using ELM-IPSO Based on Phase Space Reconstruction. Water Resources Management, 1-17.

[9] He, L., Chen, S., Liang, Y., Hou, M., & Chen, J. (2020). Infilling the missing values of groundwater level using time and space series: case of Nantong City, east coast of China. Earth Science Informatics, 1-15.

[10] Yin, H. (2020). Smart Healthcare Via Efficient Machine Learning (Doctoral dissertation, Princeton University).

[11] Anand, H., Anand, A., Das, I., Rautaray, S. S., & Pandey, M. (2020, July). Hridaya Kalp: A Prototype for Second Generation Chronic Heart Disease Detection and Classification. In International Conference on Innovative Computing and Communications (pp. 321-329). Springer, Singapore.

[12] Pouriyeh, S., Vahid, S., Sannino, G., De Pietro, G., Arabnia, H., & Gutierrez, J. (2017, July). A comprehensive investigation and comparison of Machine Learning Techniques in the domain of heart disease. In 2017 IEEE Symposium on Computers and Communications (ISCC) (pp. 204-207). IEEE.

[13] Buettner, R., & Schunter, M. (2019, October). Efficient machine learning based detection of heart disease. In 2019 IEEE International Conference on E-health Networking, Application & Services (HealthCom) (pp. 1-6). IEEE.

[14] Parthiban, G., & Srivatsa, S. K. (2012). Applying machine learning methods in diagnosing heart disease for diabetic patients. International Journal of Applied Information Systems (IJAIS), 3(7), 25-30.

[15] Mohan, S., Thirumalai, C., & Srivastava, G. (2019). Effective heart disease prediction using hybrid machine learning techniques. IEEE Access, 7, 81542-81554.

[16] Haq, A. U., Li, J. P., Memon, M. H., Nazir, S., & Sun, R. (2018). A hybrid intelligent system framework for the prediction of heart disease using machine learning algorithms. Mobile Information Systems, 2018

[17] Kukar, M., Kononenko, I., Grošelj, C., Kralj, K., & Fettich, J. (1999). Analysing and improving the diagnosis of ischaemic heart disease with machine learning. *Artificial intelligence in medicine*, *16*(1), 25-50.

Advances in Artificial Intelligence Research (AAIR) **Vol. 1 (No. 1), pp. 19-28, 2021**
www.dergipark.com/aair/ **Published online: Jan 15, 2021**

Comparison of KNN and DNN Classifiers Performance in Predicting Mobile Phone Price Ranges

Ercüment Güvenç [1, a], Gürcan Çetin [1, b*], Hilal Koçak [1, c]

[1] Mugla Sıtkı Koçman University, Technology Faculty, Dept. of Information System Engineering, MUGLA, Turkey

[a] [0000-0003-0053-9623], [b] [0000-0003-3186-2781], [c] [0000-0003-2602-8557]

Abstract

The aim of this study was to compare the classification performances of K-nearest neighbors (KNN) and Deep Neural Networks (DNN) models in a dataset. For this purpose, the "mobile price forecast" dataset has been selected. It includes 20 different features of mobile phones such as battery power, Bluetooth function, memory capacity, screen size. The problem presented in the dataset is to determine the price range class before the mobile phones are released. Such a forecast will help companies that manufacture mobile devices to estimate the price of their mobile phones in a more convenient method to compete against their competitors in the market. In the implementation phase of the study, the KNN and DNN models were created in Python 3.6 with the Sklearn and Keras libraries. The classification performances of the models were determined using F-1 score, precision, recall and accuracy measurements. As a result of the study, validation data was classified with 92% accuracy using the trained DNN model. In addition, at another stage of the study, the price range for 1000 devices with different features was determined by using a test dataset that was not labeled, and the results produced by both models were compared.

Keywords: *Classification; Deep Neural Networks; KNN; Mobile Phone Prices.*

1. Introduction

In recent years, data classification applications have spread too many areas such as image processing [1], natural language processing [2], energy optimization [3], medical science [4], risk analysis [5] and macro-economic forecasts [6]. The main purpose of the classification process is to predict what an image is, or to determine what the available data means in a data set with a large number of different categories of data. At the base of the algorithms developed for this purpose is the training of the models by using training data, and then the classification of new data through these trained models.

Examples of machine learning-based algorithms include logistic regression (LR), Support Vector Machine (SVM), K-nearest neighbor (KNN), Random Forest (RF), and artificial neuron networks (YSA). The classification performances of these algorithms on various data sets have been studied in many studies in the literature. Some of them are based on comparing newly developed algorithms with existing algorithms, while some are studies in which different algorithms are evaluated by comparing different datasets. Pondhu and Kummari [7] used machine learning techniques in the process of gender classification in their work. As a result of the study, they showed that Ann performed better than SVM with its well-adjusted parameters. A study on text classification was conducted by Aydogan and Karci in 2019 [8]. In the study, it was stated that SVM performed better in the classification of Turkish texts than in Naive Bayes.

The KNN algorithm is also one of the simplest and most widely used classification algorithms in machine learning algorithms. The KNN algorithm conforms to the multiclass tag classification problem and has a good generalization ability [1]. KNN algorithm is a lazy algorithm and works as an ideal estimator that memorizes data perfectly [9]. Looking at examples of applications of the KNN algorithm in the literature, it can be seen that it applies to the problem of image classification [1], text classification [10], file classification [11] and classification of epilepsy from EEG signals [12].

On the other hand, Deep Neural Network (DNN) has been become a machine learning method that has been mentioned very rapidly in data classification recently. The DNN is a model of neural networks in which the number of layers in artificial neural networks increases and becomes deeper and wider [13]. The processing speeds of DNN have considerably increased thanks to the Graphics Processor Unit (GPU) performing the vector and matrix operations very quickly. DNN algorithm has been applied to classification problems in almost all areas in the literature for example the classification of fungal species [13], acoustic scene classification [14] and classification of Alzheimer's disease [4].

It has been shown in these studies that KNN and DNN algorithms are successfully applied to many classification problems. However, revealing the success rates of KNN and DNN algorithms on the same data set will help researchers working in this field to choose the most suitable model for classification problems.

*Corresponding author
E-mail address: gcetin@mu.edu.tr

Received: 27/December/2020; Received in revised form: 02/January/2021; Accepted: 11/January/2021.

The main difference between the KNN and DNN models is that the KNN algorithm does not have a training stage unlike other supervised algorithms. In this study, classification achievements of DNN and KNN models were tested based on this difference. For this purpose, models were created using KNN and DNN classification methods on the "Mobile Price Forecast" dataset. By comparing the estimation performance of the obtained models, it was examined which algorithm gave more successful results in the dataset used. The classification performances of the models were determined using F-1 score, precision, recall and accuracy measurements. In addition, at the end of the study, both models were given a test data that was not labeled with price data, and the classification estimates made by the models were compared.

The following sections of the study are organized as follows; Technical background about KNN and DNN architecture, evaluation measures and dataset are presented in Section 2. While the developed model are explained in Section 3, the test results were evaluated in Section 4.

2. Material and Method

2.1. Dataset

The data set used in the study is the "Mobile Price Classification" training and test dataset, which includes the features of mobile phones and gives the prices of the phones classified according to these features [15]. The training data set consists of 21 columns and 2000 rows. The first 20 columns show the features of the phones such as RAM, 4G, Bluetooth, Battery power, Dual Sim vb., and the 21st column shows the price class of that phone. On the other hand, the second file designated as test data contains 20 columns and 1000 rows of data. In the test dataset, there are the features of the phones in 20 columns, and they are not in what price class.

In Figure 1, distribution graphs and values of battery power, Bluetooth, clock speed, dual sim and front camera megapixel features are given in a part of the training dataset. According to Figure 1, the battery power values of mobile phones are between 501-1998. Likewise, whether a device has Bluetooth capability or not in the data set is labeled with 0-1 values. Also, according to Figure 1, it is seen that the front camera megapixels of mobile phones are labeled between 0-19, and the clutter in the data set is at the value indicated by label 0.

# battery_power	# blue	# clock_speed	# dual_sim	# fc
Total energy a battery can store in one time measured in mAh	Has bluetooth or not	speed at which microprocessor executes instructions	Has dual sim support or not	Front Camera mega pixels
501 – 1998	0 – 1	0.5 – 3	0 – 1	0 – 19
842	0	2.2	0	1
1021	1	0.5	1	0
563	1	0.5	1	2
615	1	2.5	0	0
1821	1	1.2	0	13
1859	0	0.5	1	3

Figure 1. *Example part of Training Dataset*

2.2. K-Nearest Neighbors

K-NN is a classification method based on finding the closest neighbors of the unclassified sample and making predictions according to the classes with high similarity [16]. It is called the lazy learning method or case-based learning method because scanning the data set one by one to find the nearest neighbors reduces the performance of the algorithm [17]. Due to this disadvantage, the k-NN algorithm has a slow running time, especially in large volumes of data [18].

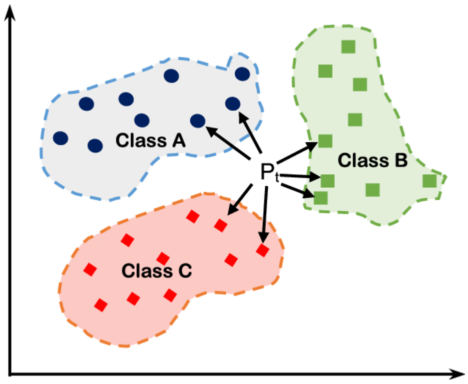


Figure 2. *Visualization of the closest neighbors* [19]

KNN assigns the unclassified sample in a class according to its distance from the previously classified data points [20]. In the Figure 2, the unknown data point P is included in a class according to the minimum distance from the selected k adjacent data points [19]. With this feature, it is among the supervised learning algorithms. Measurement methods used in determining the similarity between data points: Euclidean Distance Eq. (1), Manhattan Distance (2), Chi Square (3), cosine similarity [21].

$$d(x, y) = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2} \quad (1)$$

$$m(x, y) = \sum_{i=1}^{n} |x_i - y_i| \quad (2)$$

Euclidean Distance and Manhattan Distance are methods also known as Minkowski Distance Methods and where; *xi* and *yi* indicates the points in Cartesian coordinates, whereas *n* indicates the Euclidean space.

$$x^2 = \sum \frac{(O-E)^2}{E} \quad (3)$$

Where; *O* indicates the observed value for each cell, and *E* indicates the expected value. In Chi Square measurement. It was observed that the accuracy rate decreased in data sets with a lot of outlier data because the entire data set contributed to the classification [22].

$$\cos Q = \frac{x.y}{\|x\|.\|y\|} \quad (4)$$

Where; *x.y* indicates the product of *x* and *y* vectors, ||*x*|| or ||*y*|| indicate length of *x* and *y* vectors.

2.3. Deep Neural Networks

Artificial neural networks are an engineering approach that simulates the parallel processing of millions of interconnected neurons in human brain [23] [24]. Artificial neural networks detect relationships and patterns in dataset and acquire knowledge by experiencing from samplers of previous occasions like humans do, not from conventional programming techniques [25].

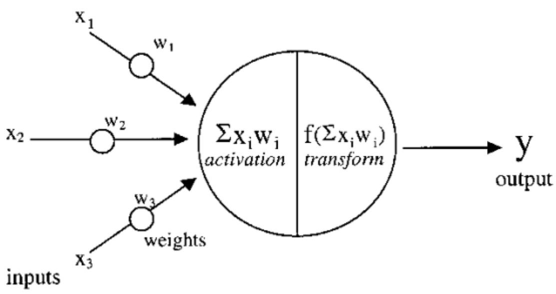


Figure 3. *The Structure of an Artificial Neural* [25]

The inputs, which are the signals reaching the neuron, are summed by multiplying by the connection weights and passed through the objective function to generate an output, as shown in Figure 3 [26]. The structures in which learning takes place by applying the transfer function to the sum of the weighted input values are called artificial neural network [27]. In the most commonly used artificial neural networks; input layers are linked to hidden layers, and hidden layers are linked to the output layer [28]. Wilamowski et al. reported that single hidden layer is insufficient to solving non-linear problems [29]. Also, as seen in the Figure 4, neural networks that have more than one hidden layer besides the input and output layers are called deep neural networks [30].

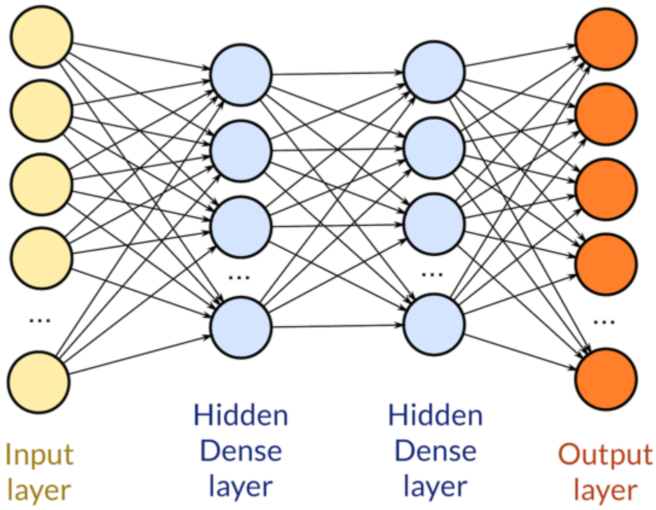


Figure 4. *Deep Neural Network Architecture [30]*

In living beings, the visual process takes place gradually, such as distinguishing the light coming to the eye firstly from the edge, then the size and then the color [31]. In deep neural networks inspired by this biological process, more complex features are learned in each progressive layer, along hidden layers [32] [33]. With the feed forward method, higher-level features are learned by weighing and transmitting information along the connections. The model is trained by updating the weights that were initially selected as very small values. Loss and cost functions are calculated from the predicted value, i.e. the output values, obtained by forward propagation. In the ongoing process called backpropagation, the weights are updated to minimize the cost function which is an initially big value [34]. Learning and predicting occurs by solving classification or regression problems by performing forward and backward propagations sequentially.

2.4. Evaluation Metrics

The Accuracy, precision, recall, F1-score and supports methods used in the evaluation of the study results are explained in this section. Where; TP indicates true positive estimations, TN indicates true negative estimations, FP indicates false positive estimations and FN indicates false negative estimations.

Accuracy: Considering all samples, the ratio of correct predictions to the total number is accuracy. It is given in Eq (5).

$$\frac{TP+TN}{TP+TN+FP+FN} \quad (5)$$

Precision: It shows how many of the positively predicted values were actually positive. It is given in Eq(6).

$$\frac{TP}{TP+FP} \quad (6)$$

Recall: It shows how many samples that should be predicted positively were predicted positively. It is given in Eq (7).

$$\frac{TP}{TP+TN} \quad (7)$$

F1 Score (F- Measure): F Measure is taken as the harmonic mean of recall and precision to take into account every situation that may be encountered. It is given in Eq (8).

$$\frac{2\ x\ Precision\ x\ Recall}{Precision+Recall} \quad (8)$$

Support: Support value shows how frequently samples are passed in the data. It is given in Eq (9).

$$\frac{Number\ of\ considered\ items}{Number\ of\ total\ samples} \tag{9}$$

3. Prediction of Mobile Phone Prices

In the study, KNN and DNN models were used to estimate the price range of mobile phones. Sklearn library was used in Python to determine the price class of the test data according to the KNN model, and Keras library working on the Tensor Flow platform for the DNN model was used.

Figure 5 shows the stages carried out in the study for the classification of mobile phone prices. First of all, in the preprocessing stage, the training data set is divided into 80% training and 20% validation data. In addition, at this stage, the data was scaled to be in the same range with the Feature Scaling method. During the learning phase, training of the DNN models was carried out by using the training data. On the other hand, KNN is a lazy learning algorithm and it has no learning phase. Later, the validation of the finally models was tested by using the validation data. Finally, the estimation of mobile phone price ranges was made by giving unlabeled test data to both models.

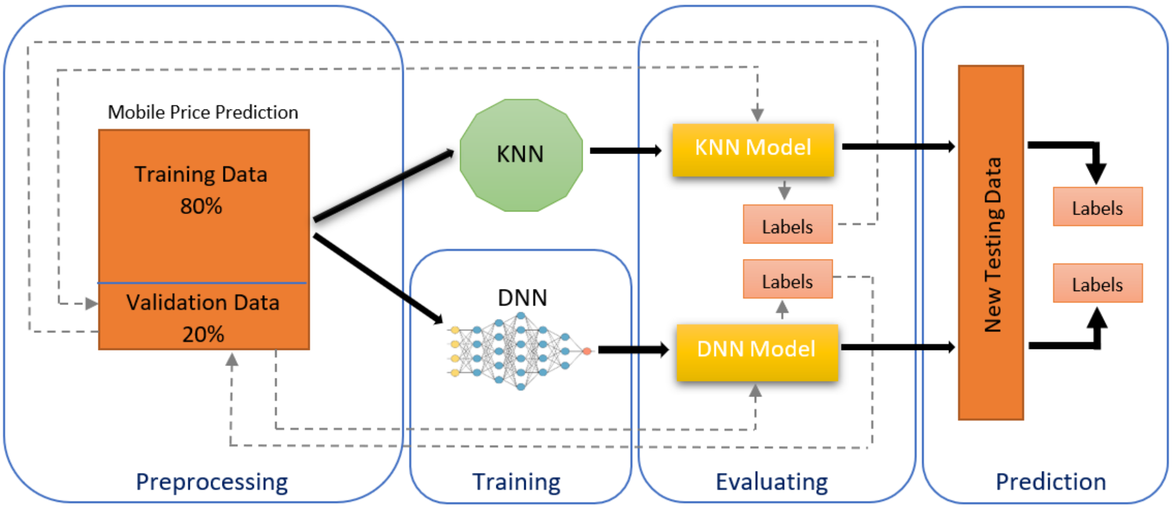


Figure 5. *Mobile phone price estimation stages with KNN and DNN methods*

3.1. KNN Model

The effective and important parameters in the performance of the K-NN algorithm are the number of neighbours (k), the distance criterion and the weighting method. For this reason, the operations performed according to the KNN algorithm for classifying problem of the mobile phones prices can be listed as follows.

(i) The k parameter determines how many nearest neighbours will be used to classify the new value. In the model, the k value is selected as 10.

(ii) Distance values are calculated. The Euclidean distance method was used in the study.

(iii) Uniform is selected as the weighting parameter. This means that each of the k neighbours has equal voting rights, regardless of their distance from the target point.

The classification chart given in Figure 6 was obtained when the KNN model was run according to the parameters determined in the study. According to the chart, it can be seen that mobile phone prices are successfully classified in 4 groups.

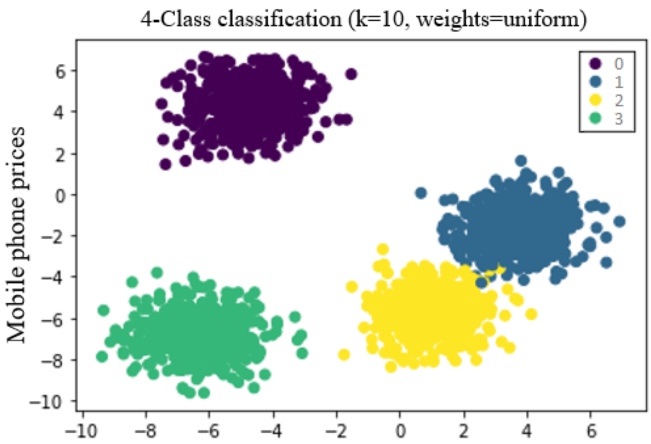


Figure 6. *KNN Classification Graphic*

The Confusion matrix obtained as a result of the classification process with the KNN model is given in Figure 7. As an example, according to Figure 7, 106 of the class 2 mobile phones were correctly identified, and a total of 14 (11 data as class 1, 3 data as class 3) were incorrectly identified. In addition, the most successful estimate was made for the price range determined by class 0. According to the forecast results, 92 data were correctly classified, while 2 data were incorrectly classified and labelled with a value of class 1.

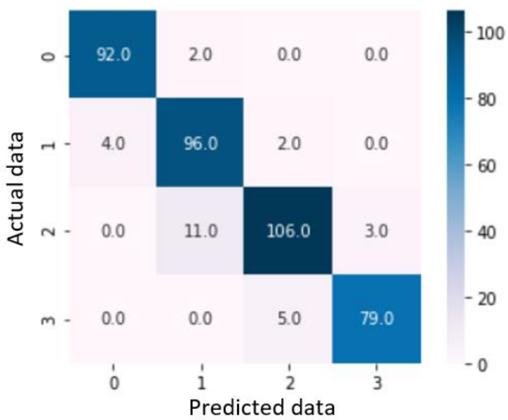


Figure 7. *Confusion Matrix of the KNN Model*

According to the values obtained from the Confusion Matrix given in Figure 7, The evaluation criteria and values showing the classification performance of the KNN algorithm are given in Figure 8. The f1-score score was considered as a priority to decide which model had the best classification performance. According to F1-score values, validation data was estimated with 93% accuracy in the model created by using the KNN algorithm. On the other hand, the fact that the precision and recall values are close to 1 in a model indicates that the performance of the model increases. According to the results obtained, the precision/recall value for each class is quite close to 1. Moreover, weighted avg. supports this situation with a value of 0.93. However, the precision value was higher than the recall value in 2 and 3 labeling. This means that the estimate of other classes is not mixed with this class, but the actual number of estimates that must be for this class is low.

	precision	recall	f1-score	support
0	0.96	0.98	0.97	94
1	0.88	0.94	0.91	102
2	0.94	0.88	0.91	120
3	0.96	0.94	0.95	84
accuracy			0.93	400
macro avg	0.94	0.94	0.94	400
weighted avg	0.93	0.93	0.93	400

Figure 8. *Classification Report of the KNN Model*

3.2. DNN Model

Important parameters that are effective in the performance of DNN algorithm are activation function, optimization algorithm, loss function and epoch. At the application stage of the study, the DNN model was trained for different possible values of these parameters and values with the best classification performance were given in the study.

(i) Activation functions to be used in the layers of the neural network are determined by taking into account the desired output states when creating a DNN model with Keras. In the study, ReLu (Rectified Linear Unit) activation function was used in the input and hidden layers of the model. In addition, the Softmax function is preferred because a categorical classification is performed at the output layer.

(ii) The main component of DSA training is the optimization algorithm. The optimization algorithm defines how a model's parameters are updated. In the study, the Adam (Adaptive moment) algorithm was selected as an optimization algorithm with a learning rate of 0.001.

(iii) The loss function determines the performance of a model and its value is asked to close to 0. Categorical crossentropy was used as a loss function in the study.

(iv) In the study, the model that gave the best classification results was reached in the values of 50 epoch numbers and 20 batch size.

In the DNN model prepared for the classification of mobile phone prices, 20 attributes contained in the dataset refer to the inputs of the model. In the model, the hidden layers are designed to be 16 and 8-dimensional, respectively, and the output layer is designed to be 4 outputs for 4 price classes. The Confusion matrix obtained as a result of the classification process with the DNN model is given in Figure 9. As an example, according to figure 9, 109 of the price Class 2 mobile phones were correctly identified, and a total of 11 (5 data as class 1, 6 data as class 3) were incorrectly identified. In addition, the most successful estimate was made for the price range determined by class 3. According to the forecast results, 82 data were correctly classified, while only 2 data were incorrectly classified and labelled with a value of class 2.

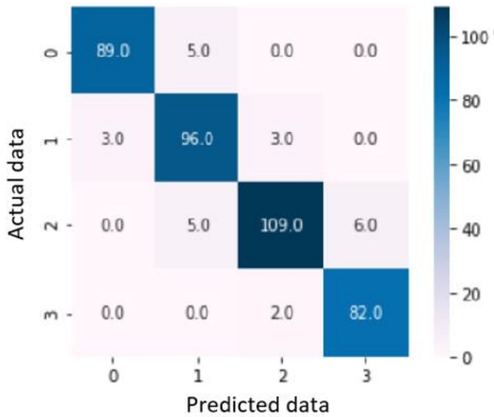


Figure 9. *Confusion Matrix of the DNN Model*

According to these values obtained from the Confusion Matrix given in Figure 9, the criteria and values showing the classification performance of the DNN algorithm are given in Figure 9. According to F1-score values, validation data was estimated with 94% accuracy in the model created with the DNN algorithm. Also, according to the results obtained, the precision/recall value for each class is quite close to 1. Moreover, weighted avg. supports this situation with a value of 0.94. However, the precision value was higher than the recall value in 0 and 2 labeling. This means that the estimate of other classes is not mixed with these classes, but the actual number of estimates that must be for these classes is low.

	precision	recall	f1-score	support
0	0.97	0.95	0.96	94
1	0.91	0.94	0.92	102
2	0.96	0.91	0.93	120
3	0.93	0.98	0.95	84
accuracy			0.94	400
macro avg	0.94	0.94	0.94	400
weighted avg	0.94	0.94	0.94	400

Figure 10. *Classification Report of the DNN Model*

4. Results and Discussions

According to validation data, the achievements of the KNN and DNN models in classifying mobile phone prices were realized with 93% and 94% respectively. Confusion matrix values of models compared to class 0, the KNN model estimated the price class with the best accuracy, the class 1 with equal accuracy in both models, and the class 3 and class 4 with the DNN model predicted more accuracy.

At the latest stage of the study, both models, whose validity was proven, were given mobile phone data that was not labelled with a price class, and tested which price class to estimate for mobile phones. Test data with 1000 different mobile phone features were used here. According to the estimated values of the KNN and DNN models for mobile phones whose price is not clear; the percentage scatter chart of the same and different values is given in Figure 11. According to figure 11, they found the same results for 905 out of 1000 data in both algorithms, while they determined different price classes for 95 mobile phone data. In this case, the models showed a 9.5% difference in determining the price class.

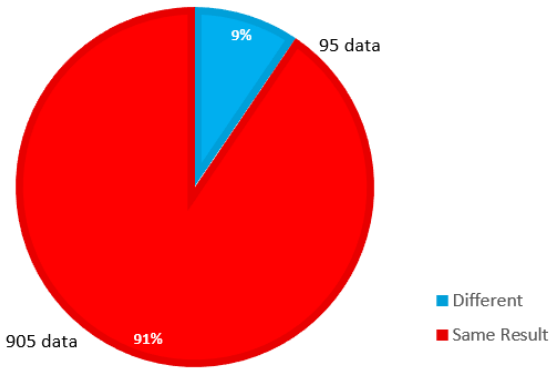


Figure 11. *Comparison of Classification Similarities of DNN and KNN Model*

A graph of the values obtained by the DNN and KNN models in their estimates of the test data is given in Figure 12 for the first 100 data. Looking at the graph, as an example, according to the data in the 20th data row, the KNN algorithm determined the price class of the mobile phone as 2, while the DNN algorithm determined it as 1. Likewise, for the first 100 data, this difference was reflected in the row of the 31, 35, 59, 67, 79, 96 and 100 data.

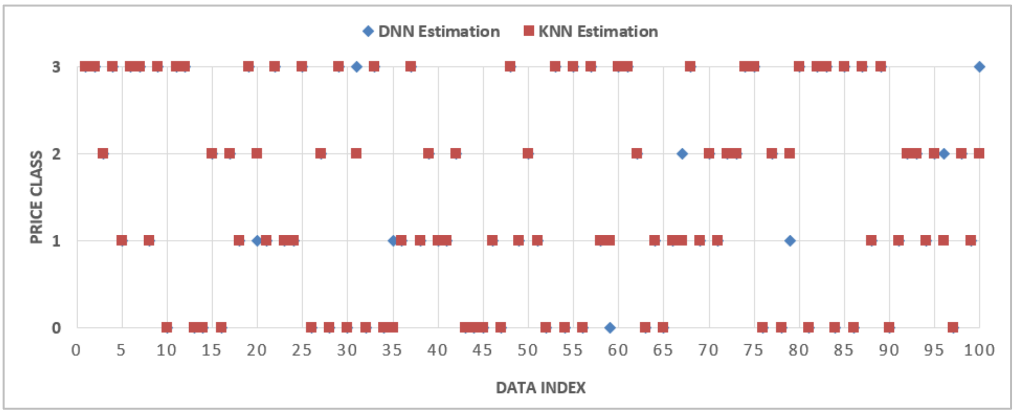


Figure 12. *Comparison of Classification Results of the DNN and KNN Model for first 100 Data*

Looking at the regression results between the classification results made by the KNN and DNN models, it was found that there was a positive linear relationship between the results. For classification data, the linear curve equation was found to be Y = 0.0259 + 0.959 X and R2 value was found to be 0.93. This reveals that the regression fit for both models is good.

5. Conclusions

In the study, the classification achievements of the KNN and DNN models for the mobile phone price classification problem were examined on a data set with the main features that stand out in determining the prices of mobile phones. For this purpose, the data set is primarily divided into training, verification and test data. According to the results obtained from the validation data, KNN was able to classify the data with 93% and DNN 94% accuracy. The study also examined the classification results of both models on a test data with unlabelled data. A 9.5% difference was revealed when comparing different classification values for both algorithms.

According to the results of the study, both models appeared to have high performance in terms of classification skills, but the DNN model, a supervised learning method, showed higher performance. This high performance showed that DNN classifiers are a strong model, taking into account the results given in the literature in general.

Declaration of interest

The authors declare that there is no conflict of interest.

References

[1] Guo J., Wang X., "Image Classification Based on SURF and KNN", *International Conference on Computer and Information Science (ICIS)*, Beijing, China, 2019.

[2] Öztürk A., Durak U., and Badıllı F., "Twitter Verilerinden Doğal Dil İşleme ve Makine Öğrenmesi ile Hastalık Tespiti", *Konya Mühendislik Bilimleri Dergisi,* vol 8(4), pp. 839 - 852, 2020.

[3] Uğuz S., Oral O., and Çağlayan N., "PV Güç Santrallerinden Elde Edilecek Enerjinin Makine Öğrenmesi Metotları Kullanılarak Tahmin Edilmesi", *Uluslararası Mühendislik Araştırma ve Geliştirme Dergisi ,* vol 11(3), pp. 769-799, 2019.

[4] Manzak D., Çetinel G., and Manzak A., "Automated Classification of Alzheimer’s Disease using Deep Neural Network (DNN) by Random Forest Feature Elimination", *The 14th International Conference on Computer Science & Education* , Toronto, Canada, 2019.

[5] Paltrinieri N., Comfort L., ve Reniers G., "Learning about risk: Machine learning for risk assessment", *Safety Science* , vol 118, pp. 475-486, 2019.

[6] Maehashi K., and Shintani M., "Macroeconomic forecasting using factor models and machine learning: an application to Japan", *Journal of the Japanese and International Economies, vol* 58, 2020.

[7] Pondhu L. N. and Kummari G., "Performance Analysis of Machine Learning Algorithms for Gender Classification", *2nd International Conference on Inventive Communication and Computational Technologies* , 2018.

[8] Aydoğan M. and Karci A., "Makine Öğrenmesi ve Transfer Öğrenme ile Türkçe Metin Sınıflandırma", *International Conference on Artificial Intelligence and Data Processing* , Malatya, Turkey, 2019.

[9] Taneja S., and Gupta C., "An Enhanced K-Nearest Neighbor Algorithm Using Information Gain and Clustering", *Fourth International Conference on Advanced Computing & Communication Technologies*, 2014.

[10] Li H., Jiang H., Wang D., and Han B., "An Improved KNN Algorithm for Text Classification", *Eighth International Conference on Instrumentation and Measurement, Computer, Communication and Control*, 2018.

[11] Sarma M. S., Srinivas Y., Abhiram M., Prasanthi M. S. and Ramya M. S. L., "KNN File Classification for Securing Cloud Infrastructure", *2nd IEEE International Conference On Recent Trends In Electronics Information & Communication Technology*, India, 2017.

[12] Manjusha M., and Harikumar R., "Performance Analysis of KNN Classifier and K-Means Clustering for Robust Classification of Epilepsy from EEG Signals", *International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)* , 2016.

[13] Ser G., and C. T. Bati, "Derin Sinir Ağları ile En iyi Modelin Belirlenmesi: Mantar Verileri Üzerine Keras Uygulaması", *Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi , vol* 29(3), pp. 406-417, 2019.

[14] Paseddula C. and Gansgashetty S. V., "DNN based Acoustic Scene Classification using Score Fusion of MFCC and Inverse MFCC", *IEEE 13th International Conference on Industrial and Information Systems (ICIIS)*, 2018.

[15] Mobile Price Prediction | Kaggle, [Online]. Available: https://www.kaggle.com/iabhishekofficial/mobile-price-classification. [Accessed: 5 10 2020].

[16] Cai Y. L., Ji D. and Chai D., "A KNN Research Paper Classification Method Based on Shared Nearest Neighbor", *NTCIR*, 2010.

[17] Padraig C. and Delany S. J., k-Nearest Neighbour Classifiers, 2007.

[18] Guo G., Wang H., Bi Y. and Greer K., "KNN Model-Based Approach in Classification", *Lecture Notes in Computer Science*, vol 2888, pp. 986-996, 2003.

[19] Atallah D., Badawy M., El-Sayed A. and Ghoneim M., "Predicting kidney transplantation outcome based on hybrid feature selection and KNN classifier", *Multimedia Tools and Applications,* vol 78, p. 20383–2040, 2019.

[20] Cover T. and Hart P., "Nearest neighbor pattern classification", *IEEE Transactions on Information Theory, vol* 13(1), pp. 21-27, 1967.

[21] Yu L. H., Huang M. W., S. W. Ke and Tsai C. F., "The distance function effect on k-nearest neighbor classification for medical datasets", *SprigerPlus, vol* 5, 2016.

[22] Bhattacharya G., Ghosh K. and Chowdhury A., "kNN Classification with an Outlier Informative Distance Measure", *International Conference on Pattern Recognition and Machine Intelligence*, 2017.

[23] Mishra M. and Srivastava M., "A view of Artificial Neural Network", *International Conference on Advances in Engineering & Technology Research (ICAETR)*, 2014.

[24] Brian R., "Pattern Recognition and Neural Networks", Cambridge University Press, 1996.

[25] Kustrin S. and Beresford R., "Basic concepts of artificial neural network (ANN) modeling and its application in pharmaceutical research", *Journal of pharmaceutical and biomedical analysi, vol* 22, pp. 717-727, 2000.

[26] Ion R. M., Munteanu D. and Cocina G. C., "Concept of artificial neural network (ANN) and its application in cerebral aneurism with multi walls carbon nanotubes (MWCNT)", *Materials Science,* 2009.

[27] Sarvepalli S. K., "Deep Learning in Neural Networks: The science behind an Artificial Brain", Liverpool Hope University, Liverpool, 2015.

[28] Imran S., Jamil A., Shah S. and Kashif F. "Impact of Varying Neurons and Hidden Layers in Neural Network Architecture for a Time Frequency Application", *IEEE International Multitopic Conference*, Islamabad, 2006.

[29] Wilamowski B. M., Chen Yixin and Malinowski A., "Efficient algorithm for training neural networks with one hidden layer", *International Joint Conference on Neural Networks.*, Washington, DC, USA, 1999.

[30] Bayraci S. and Susuz O., "Deep Neural Network (DNN) Based Classification Model In Application To Loan Default Prediction", *Theoretical and Applied Economics* , vol 26(621), pp. 75-84, 2018.

[31] Serre T., Kreiman G. and Kouh M., "A quantitative theory of immediate visual recognition", *Progress in Brain Research,* vol 165, pp. 33-56, 2007.

[32] Glorot X. and Bengio Y., "Understanding the difficulty of training deep feedforward neural networks. Journal of Machine Learning Research", *Proceedings Track,* vol 9, pp. 249-256, 2010.

[33] Sze V., Chen Y., Yang T. and Emer J. S., "Efficient Processing of Deep Neural Networks: A Tutorial and Survey", *Proceedings of the IEEE,* vol 105(12), pp. 2295 - 2329, 2017.

[34] Rumelhart D E., Hinton G. E. and Williams R. J., "Learning representations by back-propagating errors", *Nature,* vol 323(6088), p. 533–536, 1986.

[35] Huang Y., Shiyu S, Xiusheng D and Zhigang C, "A study on Deep Neural Networks framework", *IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC)*, 2016.

Advances in Artificial Intelligence Research (AAIR) Vol. 1 (No. 1), pp.29-42, 2021
www.dergipark.com/aair/ Published online: Jan 15, 2021

Industry 4.0 Approaches in Food and Bio Industry: Recent Developments and Future Trends

Semih Latif İpek[1,*], Dilek Göktürk[2]

[1] Department of Food Engineering, Adana Alparslan Türkeş Science and Technology University,[0000-0002-4661-7765]
[2] Department of Bioengineering, Adana Alparslan Türkeş Science and Technology University,[0000-0002-1195-5828]

Abstract

The application of the Industry 4.0 concept is essential to increase the productivity and efficiency of industry that includes food manufacturing, bioprocessing, retailing, marketing, and so forth. With Industry 4.0, food industrial processes can also be optimized and handled in a coordinated manner. Industry 4.0 has pioneered the communication of industrial objects with technological elements. However, Industry 4.0 includes high level of uncertainty and complexity. Therefore, more research is needed related to Industry 4.0 in today's fast changing environments. The primary aim of this study is to present the future avenues of research related to food industry and Industry 4.0. The paper provides good opportunities for further studies of digital enablers in Industry 4.0. In the paper, four key digital enablers including internet of things, cloud computing, additive manufacturing and 3D printing, industrial big data are taken into account. This paper can help researchers to determine potential areas requiring the essential research in the field of application of Industry 4.0. To improve productivity and resource efficiency, Industry 4.0 tools (e.g. artificial intelligence) can also be integrated into precision agriculture that enhances the circularity of food systems.

Keywords: *Industry 4.0; Food and bio industry; Internet of things; Cloud computing; Additive manufacturing; 3D printing.*

1. Introduction

In today's industrialized world, food industry is one of the primary sectors to provide foodstuff to satisfy the increasing demand. Food industry is responsible for nutrient supplying from farm to dish in the best way possible. Food processing, fermentation, packaging, safety, storage, marketing, and shelf-life are among the area of interest in the food industry field. Although food industry is a primary sector for world's economy, food companies need to cope with the low price pressure on food materials, environmental risks on food production and constant need for high technology and innovation in production systems. In this respect, food companies invest in research and development to reduce food costs and eliminate food waste. Beside production technologies, production trends constantly change as people focused on healthy eating, customized and fresh food products. To remain competitive in food and bio industry, the data of personal preferences about food consumption is of crucial for food and bio companies. At this point, Industry 4.0 can be used to meet these needs mentioned above.

Industry 4.0 was born with a need to meet requirements of today's globalized world in which the three first industrial revolutions are linked to mechanical power (Industry 1.0), mass production (Industry 2.0) and digital revolution (Industry 3.0) [1]. Due to the augmentation of the overall standards of industrialization, informatization and manufacturing digitization, there has been a growing need to Industry 4.0 for accomplishing efficiency, competency, and competitiveness in global market [2]. The idea of Industrial 4.0 could be described in several ways. Fundamentally, all things related to data are connected with each other. From this perspective, integration of data and information is of crucial [3].

In fast changing environments, implementing Industry 4.0 can be a response to the current challenges. For example, food industry is evolving rapidly and technology plays a crucial role. Scientific and technological improvements facilitate better adaptation of consumer demands to the food processing. In the food industry, constant pressure is available on price and this induces the innovation in food processing technologies. Interconnected machines allow greater flexibility for adaptation of customer demands on specification of food and bio products [4]. Nowadays, food properties, origin, freshness, microbiological and chemical aspects of product safety are important issues for customers. Developing a level of expected quality for all these requirements is complicated. Therefore, the aim of this study is to give an inclusive opinion of Industry 4.0 idea with the purpose of investigating the challenges, issues, components, benefits, and progress in food and bio industry. The paper begins with literature research related to the Industry 4.0 approaches in food and bio industry. Then, digital enablers are explained in Industry 4.0 and the most relevant digital enablers are outlined. Finally, the study ends with the conclusions.

*Corresponding author
E-mail address: dgokturk@atu.edu.tr

Received: 7/July/2020; Received in revised form: 18/August/2020; Accepted: 1/September/2020.

2. Literature Review

In terms of food and bio industry, Industry 4.0 means equipping food and bioprocessing plants with high technology computers. In this way, machines can understand what is going on around them and connect with each other. Using Industry 4.0 concepts, prediction of production faults and determination of production parameters to adopt changing production standards can be performed. Proposed system can be cost-effective and enables high quality production by providing fast, efficient and flexible processes with the Industry 4.0.

The food industry has provided an important link between the supply chain and farmers. In addition, biotechnology can be employed to increase the quality of the food supply chain for the manufacturing, processing, storage, and so on. Thongpull et al. [5] explained the duty of food analysis and a hand-held fixed multi-sensor system. In the study, hierarchical Support Vector Machine (SVM) classification concept was employed for lab-on-spoon data. Lee et al. [6] portrayed inno-service ideas cyber-physical frameworks from each the problem-analysis aspect and resolution-analysis perspective. In addition, they presented the ideas of cyber-physical systems from each the problem-analysis facet and resolution-analysis perspective. The paper was supported the varied outputs obtained from a wise IoT-based commerce district development project conducted in Taiwan. Silva and Silva [7] proposed an Ipanera, scalable Internet of thing (IoT) design to regulate the class of water of Aquaponics and Hydroponics design that enable Industry 4.0. The proposed methodology showed that the inspection of water quality was affected by sticking to Industry 4.0 standards. For water quality control, the requirement of fuzzy logic controllers was analyzed. In addition, the necessary components were defined to successfully implement Industry 4.0 in systems. Pilinkienė et al. [8] presented a case study of European Union food industry by modeling completely different supply network situations, and enforced a fight strategy supported the Industry 4.0 concept. The paper used lean manufacturing and Radio-Frequency Identification (RFID) technology to increase the efficiency of supply chain. In the study, inefficient transport, storage and recovery operations for the supply chain were analyzed. Kocsis et al. [9] developed a smart service using the principle of Industry 4.0 and IoT. Furthermore, an autonomous grocery delivery fleet was considered. Autonomous vehicles were used to deliver grocery in urban areas. In proposed smart service concept, products were firstly ordered. Then, an electric vehicle was used for autonomous transportation. Considering the customer availability and traffic conditions, route rescheduling was made during the transportation.

Computer-based tools can be used to improve the current food system. Tufano et al. [10] designed centralized kitchen using computer-based multidisciplinary decision-support tool. Proposed decision-support system enabled food service managers to configure food service production plant while emphasizing the interdependencies between decisions and decision-makers. Industry 4.0 methodology was developed by Bakir et al. [11] for small and medium-sized enterprises. The proposed solution offered a network of heterogeneous industrial plants and processes with low costs and low effort. In addition, more transparent and reliable production can be obtained from proposed system thanks to the related and structured data sets. Demartini et al. [12] proposed the methodology of manufacturing value modeling to identify which factors have an effect on the utilization of Industry 4.0. Considering the Industry 4.0 approach in the food industry, various steps were identified and prioritized in the food sector.

Mantravadi et al. [13] presented the information sharing between a wholesaler and meat-manufacturers. To ensure critical product-centric data for wholesaler, the system of manufacturing operations management can be used. The interdependencies of the enterprises were explained in the study. Also, enterprise integration was described in the Industry 4.0 context. Simon et al. [14] proposed a new model considering Industry 4.0 standards. The proposed model was related to customized mass production management in the food industry. In the model, an entire product range was manufactured without changing the production line. Furthermore, the production of fruit yoghurt was given an example. Ahmed et al. [15] presented the characteristics of software defined networks taking industrial automation into consideration. The new network increased the scalability and efficacy of the network. In the study, two approaches were also suggested for flow formation. Moreover, Monte Carlo simulation was employed to verify the analytical model. Gružauskas et al. [3] presented that by applying the autonomous vehicles technique, CO_2 emission levels can be minimized. In the study, the relationships between sustainability and cost performance were explained. Furthermore, Industry 4.0 methodology has been discussed in the process of developing a plan for productivity.

To improve productivity and resource efficiency, Industry 4.0 tools can be integrated into precision agriculture [16]. For example, Valecce et al. [17] proposed the IoT based system for smart agriculture. Miranda et al. [18] developed new technologies using sensing, smart and sustainable product development reference system. In the study, production life cycle of agri-food was defined. In turn, Agri-Food 4.0 which involves automation, networking, and digitalization was launched. The value of renewable energies and the use of capital in the sector were also stated.

Blockchain technology is a new digital technology to ensure data integrity and prevent tampering. Zhao et al. [19] presented traceability system that applied blockchain technology in agri-food. To improve knowledge sharing and services among members in agri-food chain, various blockchain technologies were utilized. In addition, blockchain technology can be combined with IoT and big data to increase privacy, transparency, and efficiency in agri-food information security. Also, the challenges of blockchain were analyzed using a holistic perspective. Furthermore, future research directions were identified to implement blockchain in agri-food value chain. Kamble et al. [20] employed interpretive structural modeling to define the relationship among various factors. In addition, the decision-making research and assessment laboratory (DEMATEL) was used to measure the digital impacts of the quantitatively selected variables. In the report, increasing obstacles in the retail that influences the integration of IoT were found. Tanrıseven et al. [21] presented the concepts to design future kitchens. Energy-saving induction-constructed food processing has been developed for automated kitchens. The proposed kitchens had many novelties including IoT, adaptive power adjustment, and augmented reality technology.

In literature, researches on Industry 4.0 presented the importance of integration of technology to provide a great opportunity for implementations in food and bio industry. For example, Nukala et al. [22] focused on the utilization of IoT in food chains. The study addressed core IoT supporting technology such as cloud computing, wireless sensor networks, recognition of radio frequencies, and data analytics. Luque et al. [4] presented the bibliographic review related to Industry 4.0 in the food industry. The study stated that Industry 4.0 based framework is necessary for not only the industry in general, but also for Andalusian food industry. Ojo et al. [23] studied and evaluated the essential components of Industry 4.0 and efficient management of the food chains. A case study was also discussed on the food supply chain network, which requires Industry 4.0. The importance of the integration of Industry 4.0 was given. Furthermore, the effect of Industry 4.0 on food supply chain was clarified. Introini et al. [24] presented a literature review related to the implementation of Industry 4.0 in the traceability of the food chains. Hasnan and Yusoff [25] focused on the technological advancements that include Industry 4.0 in the food industry. Bader and Rahimifard [26] explored the advantages and disadvantages of industrial robots in food sector. Also, the future projections of industrial robots were outlined for higher uptake.

It is very critical for any food company to cope with its competitors in changing business environment. There are still many unanswered questions about how Industry 4.0 integrated with food and bio industry. Though technologies for Industry 4.0 are of great concern to both academics and professionals, the growing body of study on food manufacturing and Industry 4.0 remains scarce. There is no clear approach accessible in publications to work well for all kinds of issues in the food industry. Therefore, academicians and practitioners are tried to find systematic way for food industry to integrate Industry 4.0. The connection between the food manufacturing and Industry 4.0 is discussed throughout this article, taking into account four main technology enablers. In addition, three important questions are answered as follows. Which digital enablers are widely used in food application? Which method(s)/system(s)/tool(s) are widely used by digital enablers? What areas should researchers explore in digital enablers in Industry 4.0? The suggested review adds depth to the Industry 4.0 in food and bio industry. It can provide an attractive opportunity to determine the future research for this field.

3. Basic Digital Enablers in Industry 4.0

Industry 4.0 contains many disciplines that influence each other. Luque et al. [4] presented the most proper digital enablers in Industry 4.0 including IoT and cloud computing, additive manufacturing and 3D printing, industrial big data, vision technologies, automation and intelligent robotics, and cybersecurity. In this paper, four most proper digital enablers in Industry 4.0 are analyzed. In the following subsection, each digital enabler is briefly explained. In addition, the relationship between digital enabler and Industry 4.0 is given.

3.1. IoT

Internet is used for various tasks such as web browsing and social networking applications. Furthermore, internet is important to access the global information and communication infrastructure. In addition to internet use, embedding of electronics into everyday physical objects creates new opportunities for the Information and Communication Technologies (ICT) sector. The term IoT is broadly used within such perspective [27]. IoT has a big impact on several aspects of everyday-life and behavior of potential users that can be considered as its main strength [28]. ‘‘Internet of Things” paradigm is given in Figure 1.

Table 1. *The analysis of IoT in food industry.*

Author(s)	Application	Basic method(s)/system(s)/tool(s) used in the study	Future research
Thongpull et al. [5]	Food Analysis	• Intelligent Cognitive System with Self-X, • Hierarchical SVM, • Automated Feature Selection	• use advanced magnetic induction spectroscopy concepts and electronics
Ray et al. [29]	Fruit Quality Measurement	• loT based Cloud Platform, • Ripening Index Chart	• implement the proposed design in fruit processing industries
Ruan and Shi [30]	Fruit E-Commerce Delivery	• Learning-by Doing Mechanism, • Interval Comparison Technique	• gather e-fulfillment data
Verdouw et al. [31]	Food Supply Chain	• FIspace Platform Architecture	• quantify the impact of virtualization, • use generic technologies and Software as a Service (SaaS)-approaches
Shih and Wang [32]	Cold Chain Management	• IoT based Time-Temperature Indicator System, • Critical Control Point Criteria, • Control Charts	• fuse big data mining with the IoT, • increase the cool storage products ratio
Seo et al. [33]	Food Contamination Monitoring	• Pocket-Sized Immunosensor System, • Android Application Program	• use same concept in surveilling infectious diseases, • apply same concept to the management of biosensing data
Wang and Yue [34]	Food Safety	• Information Sharing Model based IoT, • Association Rule Mining, • Apriori Method	• adopt fuzzy set theory, • test the pre-warning system for other chains
Accorsi et al. [35]	Food Supply Chain	• Simulation Gaming Tool embedding the IoT	• state on the application of proposed method for important real-world environments
Kong et al. [36]	Perishable Food Supply Chain	• IoT enabled Auction, • Cloud Auction Robot Enabled Execution System	• analyze the effects of products category size, storage assignment and the auction trolley chain length, • use big data analytics tools,
Zhang et al. [37]	Perishable Food Supply Chain	• IoT and Cloud Service Platform, • IoT based Information Sharing	• extend the cloud platform
Li et al. [38]	Prepackaged Food Supply Chain	• Extensible Markup Language based Method, • IoT-based Tracking and Tracing Platform	• evaluate proposed system in more real-life cases, • explore data analytics tools to support the operational optimization, • develop awarning system to reduce the occurrence of food incidents
Wu et al. [39]	Food Manufacturing Line	• PicknPack Research Program	• use data analysis method, • extend the system optimization to enterprise level
Desai et al. [40]	Grocery Monitoring System	• Wireless Sensor Network, • ThingSpeak channel	• implement machine learning algorithms for predictive analysis, • utilize for budgeting the monthly expense on food and other commodities
Bonaccorsi et al. [41]	Smart Freezer	• HighChest IoT Devices, • Task Analysis Method	• equip system with a barcode printer, • increase the energy efficiency of system by using the defrosting procedure, • enable mobile access to storage information
Meng et al. [42]	Food Packaging Line	• PicknPack, • Industrial IoT System, • Zyre-Based Messaging Protocol	• apply high-level intelligence obtained from big data
Mededjel et al. [43]	Food Traceability System	• Cloud and Fog Computing, • Electronic Product Code Information Service	• implement the various modules of the proposed system to support different types of traceability queries
Morillo et al. [44]	Meal Distribution	• Wireless Sensor Networks, • Flooding Routing, • Routing based on Static Neighbors,	• improve the IoT-based monitoring system, • improve the App executed on the smartphone

Table 1. *The analysis of IoT in food industry. (Continue)*

Wen et al. [45]	Food Waste Management	• Management Platform, • Global Positioning System, • Geographic Information System	• assess the stakeholders using formal evaluation instruments, • design the new tags, • use the dynamic and automatic weight sensor, • encourage the information-sharing and trust-building
Kim et al. [46]	3D Printed Food	• Piston Type Extrusion Method with IoT, • Hagen-Poiseuille Equation	• gather further data to construct more database
Tsang et al. [47]	Food Distribution	• IoT based Route Planning System, • Taguchi Method, • Genetic Algorithms	• focus on other kinds of phase change materials, • apply the proposed system to other environmentally-sensitive products, • Integrate more data mining and artificial techniques
Liu et al. [48]	Food Traceability System	• Enterprise Oriented IoT Information Service, • Electronic Product Code Information Service, • Trust Service for the IoT, • IoT Directory Service, • IoT Name Service	• integrate digital signature and verification
Chaudhari and Chandak [49]	Cold Storage Warehousing	• Apache Spark Service, • International Business Machines (IBM) IoT Real-Time Insights, • Watson Machine Learning Service, • IBM Bluemix	• work on the modeling of system to predict more complex events, • test proposed system on other IoT scenarios, • test proposed system on high-velocity data
Chiang et al. [50]	Fish Meat Quality Monitoring	• Complementary-Metal–Oxide–Semiconductor • Simulation	• incorporate proposed chip into IoT devices for fish markets
Sundaravadivel et al. [51]	Food Monitoring System	• Smart-Log, • Application Program Interfaces, • Optical Character Recognition Method, • Waikato Environment for Knowledge Analysis	• utilize the proposed system as an essential consumer electronic device
Sundaravadivel et al. [52]	Food Monitoring System	• 5-layer Perceptron Neural Network, • Bayesian Network-Based Method, • Application Program Interfaces, • Optical Character Recognition Method, • Waikato Environment for Knowledge Analysis	• Integrate Smart-Log with physiological monitoring mechanisms
Lin et al. [53]	Food Safety Traceability System	• Electronic Product Code Information Services, • MongoDB	• optimize the peer-to-peer network mode, • optimize the consensus algorithm of the blockchain, • set up information clipping function
Mondal et al. [54]	Food Supply Chain	• Blockchain inspired IoT, • Proof-of-Object Based Consensus Model	• strengthen the hardware security
Ray et al. [55]	Fruit Ripening Quality Index	• IoT based Cloud Service	• provide a more compact sized embedded system in wearable form factor, • use dew computing
Jilani et al. [56]	Food Quality	• Labview Program, • Local-Cloud Approach	• use the sensor as an embedded device
Jagtap and Rahimifard [57]	Food Supply Chain	• IoT based Food Waste Tracking System	• use advanced image processing systems, • eliminate the dependency on human confirmation
Jagtap et al. [58]	Food Waste Monitoring	• Deep Learning, • Convolutional Neural Network	• overcome various kinds of food waste at higher speed

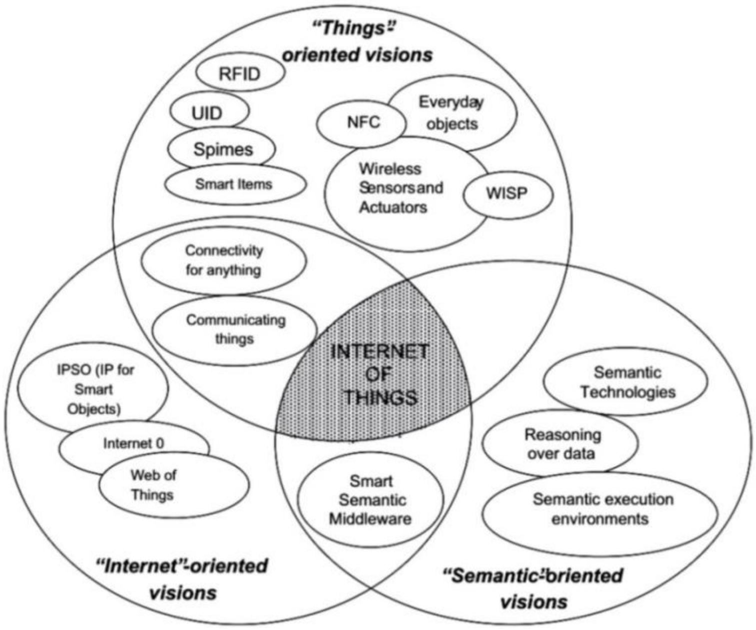


Figure 1. *''Internet of Things" paradigm [28].*

IoT is widely used in food industry that includes all aspects of related to food such as food manufacturing, storage and processing, food distribution, marketing, and consumption. IoT has the ability to manage the traceability and visibility. Furthermore, it has potential to cope with controllability problems. The more efficient and sustainable food supply chain can be provided with the help of the IoT. It can be said that the food industry is rapidly transformed with the IoT technologies. Food industry is also becoming more advanced, sophisticated, and efficient to cope with the challenges of food security, food safety, and food quality [59].

While many studies have been conducted on usage of technology in the food sector, there is still the need to frame it in the whole value chain and towards the IoT perspective. The food application of IoT, basic method(s)/system(s)/tool(s) used in the study and future research direction are given in Table 1 to provide better understanding of IoT in food industry.

3.2. Cloud computing

Cloud computing can be described as a platform for fast and on-demand customer-friendly connection to a shared database of programmable computer resources. It is seen as the development of different type of technologies that are combined to alter the organizational approach for building information technology infrastructure of organizations [60]. To successful cloud computing adoption for your organization, the cloud adoption lifecycle model can be employed. It provides guide for organizations to begin thinking about cloud. This model provides a baseline to support your adoption of cloud computing. Details about cloud computing can be found in [61]. Google, Amazon, and Microsoft are some of large cloud computing information technology vendors. The cloud computing application has increased the information technology expectations of companies. In addition, the utilization of cloud computing can provide substantial and significant economic savings in food industry. The basic method(s)/system(s)/tool(s) used in the study and future research direction are given in Table 2 to provide better understanding of cloud computing in food industry. In Table 2, cloud computing is used in the food recognition system, food traceability, rice mapping, grain warehouse monitoring, food recognition, and food recommender system.

3.3. Additive manufacturing (AM) and 3D printing (3DP)

AM is a process of injecting elements and pieces of manufactured feedstock content into components (parts). The AM processes can be classified as liquid, solid, and powder based types. AM processes offer many benefits. Some of them can be given as follows: (i) no tool design is required, (ii) no separate machines are required, (iii) material waste is reduced and final cost is minimized [62].

3DP is a classical disruptive technique. 3DP has many advantages over other manufacturing methods. Therefore, the using of 3DP gradually increases. 3DP is reckoned to play a significant role through the dramatic increase in resource efficiency. In addition, overall carbon emissions can be lowered. The effect of 3DP can go beyond rebalancing the global economy and transforming the manufacturing process [63].

Portanguen et al. [64] presented the application of AM methods for the development of biobased products. The 3D-printed biobased products were analyzed. The results of the study demonstrated that 3D-printed products continue to further develop and progress. Also, the problems of meat-based food have yet to be solved. The main challenge for the coming years will be the use of 3DP printing to evolve meat products or products that combine alternative sources of protein that remain completely structured without the use of additives. Godoi et al. [65] presented the current 3DP methods for designing food materials. Material supply was used to classify the methods. Multi-component method optimization and comprehensive product review should be assessed to incorporate AM technologies in the food industry. Nachal et al. [66] presented implementations of the 3DP in food processing. The report reviewed latest developments in the 3D food printing, with an emphasis on the characteristics of content supply appropriate for printing and food printing strategies.

Table 2. *The analysis of cloud computing in food industry*

Author(s)	Application	Basic method(s)/system(s)/ tool(s) used in the study	Future research
Pouladzadeh et al. [67]	Food Recognition	• Cloud-Based Virtualization Mechanism, Deep Convolutional Neural Networks, Amazon Web Services	• embed the virtual network computing server configurations inside proposed android application, • use much bigger data for the training algorithm
Cao and Truong [68]	Grain Warehouse Monitoring	• IoT Cloud based Platform, • Not only Structured Query Language (NoSQL) database, • MongoDB/Cassandra	• apply proposed conceptual frameworks for similar areas
Rehman et al. [69]	Food Recommender System	• Cloud Based Food Recommendation, • Diet-Right Model, • Ant Colony Optimization	• focus on the recommendations breakdown for different timings of the day, • consider the amount of nutrition in different food items as per timing and daily needs of the patients, • develop group food recommendation
Liu et al. [70]	Food Recognition System	• Deep Learning-based Model, • Edge Computing-Based Service Computing Paradigm, • Pre-trained GoogLeNet by ImageNet, • Convolutional Neural Network, • Apache HttpClient, • Django Web Development Framework, • Bounding-Box Strategy	• analyze new deep learning algorithms, • integrate proposed system into a real-world mobile devices and edge/cloud computing-based system
Dandage [71]	Food Traceability	• Cloud Service and Web Application Programming Interface (API)'s, • Web-Based Traceability Portal	• develop the government database for public, • develop Web servers and Web API both modern technological web development application to communicate over internet with seamless access, • use Web API as the best way for integration with mobile or other website
Liang et al. [72]	Rice Mapping	• Multi-Year Training Sample Normalization, • Linear Regressions, • Google Earth Engine Cloud Computing Platform, • Classification and Regression Tree, • Analysis of Variance (ANOVA)	• Combine the sample normalization model and cloud-computing geospatial data platforms in similar future projects

The application of AM and 3D printing, basic method(s)/system(s)/tool(s) used in the study and future research direction is given in Table 3. The AM and 3DP are generally applied in product printing, packaging, processing, recrystallization and quality monitoring.

3.4. Big Data

Web technologies, which are recognized as part of the development of ICT, have at any time collected scientific or non-scientific info. The collected data can be used in the research studies as well as in many fields. The concept of “Big Data” has emerged with the rapid increase of data in terms of velocity, variety, volume and the support of technology to produce new solutions [73]. Big data can be analyzed considering four dimensions. First dimension is volume that is related to the scale of data. The second dimension is the velocity at which data is rising and therefore the study of streaming data is challenging. Third dimension is the variety defining the different forms of information to be used for study. Final dimension is veracity that is related to the uncertainty or inaccuracy of the data. In addition to these, value can be utilized to characterize the data quality [74]. Big data analytics lifecycle can be summarized as given in Figure 2.

Table 3. *The analysis of AM and 3DP in food industry.*

Author(s)	Application	Basic method(s)/system(s)/tool(s) used in the study	Future research
Wu et al. [75]	Food Quality Monitoring	• Smart Cap Liquid Chromatography Sensor, • Network Analyzer	• improve the measured quality factor by optimizing the materials
Severini et al. [76]	Food Printing	• Farinograph Test, • Response Surface Methodology, • Texture Analyzer	• perform exact setting of all printing parameters, • analyze the rheological features and their relationship considering the printing variables
Bogue [77]	Food Quality Monitoring	• Micro-Stereolithography Technique, • Network Analyser, • Smart Cap	• investigate 3DP in sensor manufacturing
Kouzani et al. [78]	Food Printing	• EnvisionTEC GmbH Bioplotter, • Solidworks	• improve health and well-being of printing, • improve economic condition of printing
Mantihal et al. [79]	Food Printing Optimization	• Rotary Screw Extrusion Method, • Controlled Stress Rheometer, • Texture Analyzer,	• develop printability optimization of edible inks using the results of the study, • investigate internal support structures considering thickness and textural properties of chocolate
Yang et al. [80]	Food Constructs	• Texture Profile Analysis, • Mean Comparisons, • Nuclear Magnetic Resonance Analysis	• use proposed system for other gel and starch items in 3D printing
Lanaro et al. [81]	Food Printing	• Differential Scanning Calorimetry, • Rheometer, • Image Analysis Program ImageJ, • Simulation	• introduce a screwthread extrusion process or a pressure driven pump, • undertake further testing of chocolate
Holland et al. [82]	Food Recrystallization	• Pendant Drop Method, • Curve Fitting Approach, • Xray Computed Tomography System, • Median Filter	• test experimental powders, • provide the product hardness and breakdown profile of the structures
Tohic et al. [83]	Food Additive Manufacturing	• Texture Profile Analysis, • Dynamic Oscillatory Rheology, • Confocal Laser Scanning Microscopy	• investigate the fundamental principles considering food microstructures, and sensory attributes
Vancauwenberghe et al. [84]	Food Simulants	• Regression Models, • Central Composite Experimental Design, • Open-Source Computer Aided Manufacturing (CAM) Software Slic3r, • X-ray Computed Tomography, • TA.XTPlus Texture Analyzer Device	• compare the 3DP of more complex objects, • investigate important properties for consumer acceptance, • validate the prediction methods
Kim et al. [85]	Food Printing, Food Ink	• Stress-Controlled Rheometer, • Texture Analyzer, • Confocal Laser Scanning Microscopy	• use Xanthan gum to create a standardized food ink preparation method
Lee et al. [86]	Food-Ink System	• Scanning Electron Microscopy, • Oscillatory Frequency Sweep Test, • Controlled Stress Rheometer	• analyze the particle size for the 3DP direction of food, • analyze the particle size to optimize food material in 3DP
Vancauwenberghe et al. [87]	Food Manufacturing	• Evans Blue Exclusion Staining Technique, • Open-Source CAM Software Slic3r, • TA.XTPlus Texture Analyzer	• explore the formulation by encapsulating diverse type of filler, • develop models to improve the cell density, • address the edibility of the products

Table 4. *The analysis of big data in food industry.*

Author(s)	Application	Basic method(s)/system(s)/tool(s) used in the study	Future research
Lukyamuzi et al. [88]	Food Insecurity	• Naive-Bayes, • Neural Networks, • k-Nearest Neighbors, • SVM	• explore web data for studying the disasters, • explore the proposed approach experimentally
Navickas and Gružauskas [89]	Food Supply Chain	• Competitiveness Maximization Methodology	• conduct a deeper analysis, • apply the clustering method to optimize the distribution process
Geng et al. [90]	Food Safety	• HTML Analysis and Text Density, • Adaptive Method based on Multiple Reference Factors	• employ link based search strategy
Alfian et al. [91]	Perishable Supply Chain	• Three Sigma, • Density-based Spatial Clustering of Applications with Noise	• compare the other outlier detection methods with larger datasets, • use the document-based NoSQL database for sensor data processing
Ji et al. [92]	Food Supply Chain	• Bayesian Network, • Deduction Graph Model,	• apply big data in different areas of the food chains
Irani et al. [93]	Food Security and Food Waste	• Cause-Effect Models, • Simulations, • Fuzzy Cognitive Map	• extend the number of scenarios, • use Delphi method, • present unpack food waste at a granular level, • extend the proposed system to other food waste contexts
Singh et al. [94]	Food Supply Chain	• Fuzzy DEMATEL, • Fuzzy Analytic Hierarchy Process, • Fuzzy Technique for Order of Preference by Similarity to Ideal Solution Method	• Undertake similar studies considering the other domains of food industry and non-food industries, • evaluate the suppliers considering the uncertainties in the decision maker's judgment, • applying group decision making approaches, • apply multi-objective optimization techniques
Singh et al. [95]	Food Supply Chain	• SVM, • Hierarchical Clustering with Multiscale Bootstrap Resampling, • Naive Bayes	• capture a larger volume of tweets using Twitter Firehose, • perform the proposed analysis on other food supply chains
Li et al. [96]	Food Data Analysis	• Mysql Database, • Python + Matplotlib, • Raspberry Pi-based Website	• make different program improvements for different schools across the country, • expand the access to data, • get more data analysis conclusions, • conduct differential analysis to find out the differences and commonalities of different schools, • establish a wide range of student diet databases
Mishra and Singh [97]	Food Supply Chain	• Descriptive Analysis, • Content Analysis, • Parsing Method	• use an enhanced list of keywords, • employ Twitter analytics for longer time duration, • apply to other domains of food supply chain
Xu et al. [98]	Nutrition Analysis	• iPlate System Equipped with RFID	• ensure decision support for the restaurant, • accomplish the whole calculation of dietary nutrition, • use more factors into nutrition calculation
Parvin et al. [99]	Food Security System	• Information and Communication Technology Tools, • Intrusion Detection System, • Semantic Annotation Methods	• validate the applicability of the proposed food security architecture

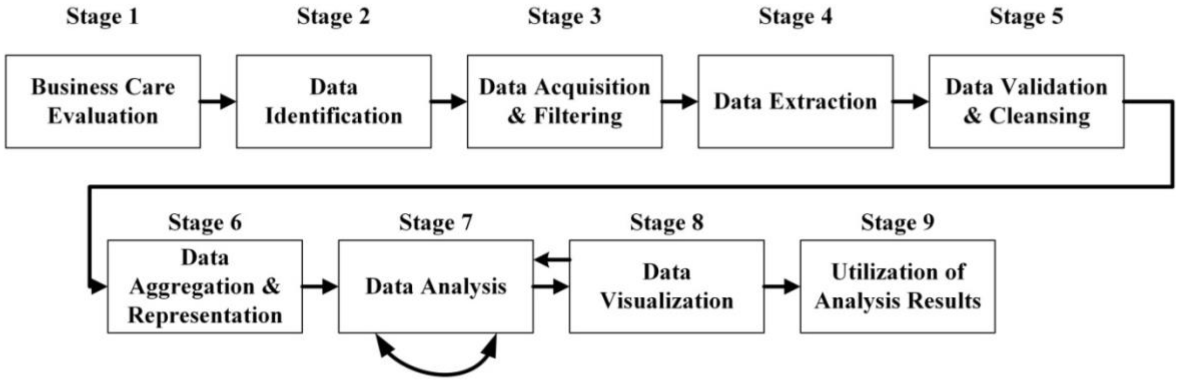


Figure 2. *The analytics lifecycle of big data [100].*

A special infrastructure needs to be designed to create decision support systems at the strategic level of the companies. At this point, data warehouse constitutes the technical infrastructure of decision support systems. The data warehouse ensures an opportunity to assemble non-integrated applications. In the last decade, a new class of data management systems, often referred to as NoSQL systems, has emerged and is developing rapidly today [73]. The reasons for using NoSQL databases are design simplicity, horizontal growth and accessibility. Since the data structures of NoSQL databases are different from relational databases, some operations performed within the database can be faster. Differences between relational databases and NoSQL databases can be found in [101]. Venkatraman et al. [101] presented that NoSQL is more appropriate than Structured Query Language (SQL) in big data analytics applications. Recently, NewSQL databases have been introduced as an alternative to NoSQL and traditional relational databases. NewSQL database systems maintain the basic features of relational databases, but are different from structures exhibited by traditional systems such as Oracle and SQL. Properties of NewSQL databases can be found in [102]. Briefly, the choice of the database may vary depending on the problem structure and the business, and this selection is an important determinant of the overall system outputs.

Food and bio companies have to make use of big data to provide benefit for their customers and employees. Big data can increase the visibility across the industry, ensures an integrated view of customer interaction and operational performance, and provides real-time insights to companies. Integration of big data analytics in systems can enable unprecedented opportunities to food industry for many cases such as traceability system, product security system. Food big data can also help companies provide a credible product quality and new market development.

The application of big data basic method(s)/system(s)/tool(s) used in the study and future research direction is given in Table 4 to provide better understanding of big data in food industry. Big data has been used extensively in food applications such as product security, waste control, raw material, supply chain, cold chain configuration design, perishable supply chain, nutrition analysis.

4. Conclusions

Industry 4.0 is important in industrial environment. The fact that food and bio companies are particularly demanding the transition to Industry 4.0 is emerging from some points that need solutions. These include; discrepancies between planned and actual production times, delays, defective production, inventory control problems, high direct and indirect costs, product perishability problem, and so forth. It is also expected that labor market profile will improve. Also, the high quality products and global competitiveness can be increased with the introduction of Industry 4.0. Thus, it makes a significant contribution to overcoming the challenges of the food and bio industry quickly and profitably. Therefore, Industry 4.0 serves as a gateway to food industry's future.

In this paper, the review for the current and future concept of Industry 4.0 in food and bio industry is presented. Also, the further studies of digital enablers in Industry 4.0 including IoT, cloud computing, AM and 3DP, and big data are briefly given to contribute for the sustainable competitive advantage of the sector. This study provides basic information about the digital enablers and Industry 4.0 that enable us to connect humans, objects and systems to cope with dynamic problem in real-time. This paper helps determine potential research topic related to digital enablers in Industry 4.0 and can be suitable during application of Industry 4.0. The main advantage of this study is that four key digital enablers including IoT, cloud computing, AM and 3DP, industrial big data are analyzed in the field of application of Industry 4.0 for food and bio industry. This study can be extended considering other digital enablers in Industry 4.0 such as vision technologies, automation and intelligent robotics, and cybersecurity. In the light of previous studies, it can be said that future of the food and bio industry will be more flexible, more intelligent, smarter, and more adaptive to ensure the sustainable competitive advantage of the sector. In addition, robotics, autonomous, and unmanned systems make a substantial contribution to overcoming the challenges of the food and bio industry.

Declaration of interest

The authors declare that there is no conflict of interest.

References

[1] Ben-Daya, M, Hassini, E, Bahroun, Z. "Internet of things and supply chain management: a literature review", International Journal of Production Research 57 (2019) 4719-4742.

[2] Xu, LD, Xu, EL, Li, L. ""Industry 4.0: state of the art and future trends", *International Journal of Production Research* 56 (2018) 2941-2962.

[3] Gružauskas, V, Baskutis, S, Navickas, V. "Minimizing the trade-off between sustainability and cost effective performance by using autonomous vehicles", *Journal of Cleaner Production* 184 (2018) 709-717.

[4] Luque, A, Peralta, ME, De Las Heras, Córdoba, A. "A. State of the Industry 4.0 in the Andalusian food sector", *Procedia Manufacturing* 13 (2017) 1199-1205.

[5] Thongpull, K, Groben, D, König, A. "A design automation approach for task-specific intelligent multi-sensory systems–Lab-on-spoon in food applications", *tm-Technisches Messen* 82 (2015) 196-208.

[6] Lee, C-H, Chen, C-H, Lee, Y-C, Xu, G, Li, F, Zhao, X. "Accelerating retail-innovation design for smart services via foresight approach and case-based design", *Transdisciplinary Engineering: A Paradigm Shift* (2017) 813-820.

[7] Silva, PCP, Silva, PCA. "Ipanera: An industry 4.0 based architecture for distributed soil-less food production systems", In: Proceedings of the 1st Manufacturing & Industrial Engineering Symposium, Colombo, 22-22 October, (2016) 1-5.

[8] Pilinkienė, V, Gružauskas, V, Navickas, V. "Lean thinking and Industry 4.0 competitiveness strategy: Sustainable food supply chain in the European Union", In: Trends and Issues in Interdisciplinary Behavior and Social Science, CRC Press, (2017) 15-20.

[9] Kocsis, M, Buyer, J, Sußmann, N, Zöllner, R, Mogan, G. "Autonomous grocery delivery service in urban areas", In: 2017 IEEE 19th International Conference on High Performance Computing and Communications, IEEE 15th International Conference on Smart City, IEEE 3rd International Conference on Data Science and Systems (HPCC/SmartCity/DSS), Bangkok, 18-20 December, (2017) 186-191.

[10] Tufano, A, Accorsi, R, Garbellini, F, Manzini, R. "Plant design and control in food service industry. A multi-disciplinary decision-support system", *Computers in Industry* 103 (2018) 72-85.

[11] Bakir, D, Bakir, R, Engels, F. "Industry_Integrator as retrofit solution for digital manufacturing methods in existing industrial plants" *Procedia Manufacturing* 17 (2018) 1009-1014.

[12] Demartini, M, Pinna, C, Tonelli, F, Terzi, S, Sansone, C, Testa, C. "Food industry digitalization: From challenges and trends to opportunities and solutions", *IFAC-PapersOnLine* 51(2018) 1371-1378.

[13] Mantravadi, S, Møller, C, Christensen, FMM. "Perspectives on real-time information sharing through smart factories: visibility via enterprise integration", In: 2018 International Conference on Smart Systems and Technologies, Osijek, 10-12 October, (2018) 133-137.

[14] Simon, J, Trojanova, M, Zbihlej, J, Sarosi, J. "Mass customization model in food industry using industry 4.0 standard with fuzzy-based multi-criteria decision making methodology", *Advances in Mechanical Engineering* 10 (2018) 1-10.

[15] Ahmed, K, Blech, JO, Gregory, MA, Schmidt, HW. "Software defined networks in industrial automation", *Journal of Sensor and Actuator Networks* 7 (2018) 33.

[16] Tseng, M-L, Chiu, ASF, Chien, C-F, Tan, RR. "Pathways and barriers to circularity in food systems", *Resources, Conservation & Recycling* 143 (2019) 236-237.

[17] Valecce, G, Strazzella, S, Radesca, A, Grieco, LA. "Solarfertigation: Internet of things architecture for smart agriculture", In: 2019 IEEE International Conference on Communications Workshops, Shanghai, China, 20-24 May, (2019) 1-6.

[18] Miranda, J, Ponce, P, Molina, A, Wright, P. "Sensing, smart and sustainable technologies for Agri-Food 4.0", *Computers in Industry* 108 (2019) 21-36.

[19] Zhao, G, Liu, S, Lopez, C, Lu, H, Elgueta, S, Chen, H, Boshkoska, BM. "Blockchain technology in agri-food value chain management: A synthesis of applications, challenges and future research directions", *Computers in Industry* 109 (2019) 83-99.

[20] Kamble, SS, Gunasekaran, A, Parekh, H, Joshi, S. "Modeling the internet of things adoption barriers in food retail supply chains", *Journal of Retailing and Consumer Service* 48 (2019) 154-168.

[21] Tanrıseven, S, Uğur, N, Kanak, A, Ergün, S. "ERINOKS: Energy-efficient induction-based food processing for optimized kitchens", In: 2019 IEEE International Symposium on Circuits and Systems, Sapporo, Japan, 26-29 May, (2019) 1-5.

[22] Nukala, R, Panduru, K, Shields, A, Riordan, D, Doody, P, Walsh, J. "Internet of things: A review from 'Farm to Fork'", In: 2016 27th Irish Signals and Systems Conference, Londonderry, 21-22 June, (2016) 1-6.

[23] Ojo, OO, Shah, S, Coutroubis, A, Jiménez, MT, Ocana, YM. "Potential impact of industry 4.0 in sustainable food supply chain environment", In: 2018 IEEE International Conference on Technology Management, Operations and Decisions, Marrakech, Morocco, 21-23 November, (2018) 172-177.

[24] Introini, SC, Boza, A, Alemany Díaz MME. "Traceability in the food supply chain: review of the literature from a technological perspective", *Dirección y Organización* 64 (2018) 50-55.

[25] Hasnan, NZN, Yusoff, YM. "Short review: application areas of Industry 4.0 technologies in food processing sector", In: 2018 IEEE Student Conference on Research and Development, Selangor, Malaysia, 26-28 November, (2018) 1-6.

[26] Bader, F, Rahimifard, S. "Challenges for industrial robot applications in food manufacturing", In: Proceedings of the 2nd International Symposium on Computer Science and Intelligent Control, September, (2018) 1-8, Available online: https://doi.org/10.1145/3284557.3284723.

[27] Miorandi, D, Sicari, S, De Pellegrini, F, Chlamtac, I. "Internet of things: Vision, applications and research challenges", *Ad Hoc Networks* 10 (2012) 1497-1516.

[28] Atzori, L, Iera, A, Morabito, G. "The internet of things: A survey", *Computer Networks* 54 (2010) 2787-2805.

[29] Ray, PP, Pradhan, S, Sharma, RK, Rasaily, A, Swaraj, A, Pradhan, A. "IoT based fruit quality measurement system", In: 2016 Online International Conference on Green Engineering and Technologies, Coimbatore, 19 November, (2016) 1-5.

[30] Ruan, J, Shi, Y. "Monitoring and assessing fruit freshness in IOT-based e-commerce delivery using scenario analysis and interval number approaches", *Information Sciences* 373 (2016) 557-570.

[31] Verdouw, CN, Wolfert, J, Beulens, AJM, Rialland, A. "Virtualization of food supply chains with the internet of things", *Journal of Food Engineering* 176 (2016) 128-136.

[32] Shih, C-W, Wang, C-H. "Integrating wireless sensor networks with statistical quality control to develop a cold chain system in food industries", *Computer Standards & Interfaces* 45 (2016) 62-78.

[33] Seo, S-M, Kim, S-W, Jeon, J-W, Kim, J-H, Kim, H-S, Cho, J-H, Lee, W-H, Paek, S-H. "Food contamination monitoring via internet of things, exemplified by using pocket-sized immunosensor as terminal unit", *Sensors & Actuators, B: Chemical* 233 (2016) 148-156.

[34] Wang, J, Yue, H. "Food safety pre-warning system based on data mining for a sustainable food supply chain*", Food Control* 73 (2017) 223-229.

[35] Accorsi, R, Bortolini, M, Baruffaldi, G, Pilati, F, Ferrari, E. "Internet-of-things paradigm in food supply chains control and management", *Procedia Manufacturing* 11 (2017) 889-895.

[36] Kong, XTR, Zhong, RY, Xu, G, Huang, GQ. "Robot-enabled execution system for perishables auction logistics", *Industrial Management & Data* 117 (2017) 1954-1971.

[37] Zhang, Y, Zhao, L, Qian, C. "Modeling of an IoT-enabled supply chain for perishable food with two-echelon supply hubs", *Industrial Management & Data* 117 (2017) 1890-1905.

[38] Li, Z, Liu, G, Liu, L, Lai, X, Xu, G. "IoT-based tracking and tracing platform for prepackaged food supply chain", *Industrial Management & Data* 117 (2017) 1906-1916.

[39] Wu, Z, Meng, Z, Gray, J. "IoT-based techniques for online M2M-interactive itemized data registration and offline information traceability in a digital manufacturing system", *IEEE Transactions on Industrial Informatics* 13 (2017) 2397-2405.

[40] Desai, H, Guruvayurappan, D, Merchant, M, Somaiya, S, Mundra, H. "IoT based grocery monitoring system", In: 2017 Fourteenth International Conference on Wireless and Optical Communications Networks, Mumbai, 24-26 February, (2017) 1-4.

[41] Bonaccorsi, M, Betti, S, Rateni, G, Esposito, D, Brischetto, A, Marseglia, M, Dario, P, Cavallo, F. "'HighChest': An augmented freezer designed for smart food management and promotion of eco-efficient behavior", *Sensors* 17 (2017) 1357.

[42] Meng, Z, Wu, Z, Gray, J. "A collaboration-oriented M2M messaging mechanism for the collaborative automation between machines in future industrial networks", *Sensors* 17 (2017) 2694.

[43] Mededjel, M, Belalem, G, Neki, A. "Towards a traceability system based on cloud and fog computing*", Multiagent and Grid Systems* 13 (2017) 47-68.

[44] Morillo, P, Orduña, JM, Fernández, M, García-Pereira, I. "Comparison of WSN and IoT approaches for a real-time monitoring system of meal distribution trolleys: A case study", *Future Generation Computer Systems* 87 (2018) 242-250.

[45] Wen, Z, Hu, S, De Clercq, D, Beck, MB, Zhang, H, Zhang, H, Fei, F, Liu, J. "Design, implementation, and evaluation of an Internet of Things (IoT) network system for restaurant food waste management", *Waste Management* 73 (2018) 26-38.

[46] Kim, NP, Eo, J-S, Cho, D. "Optimization of piston type extrusion (PTE) techniques for 3D printed food", *Journal of Food Engineering* 235 (2018) 41-49.

[47] Tsang, YP, Choy, KL, Wu, CH, Ho, GTS, Lam, HY, Tang, V. "An intelligent model for assuring food quality in managing a multi-temperature food distribution centre", *Food control* 90 (2018) 81-97.

[48] Liu, Y, Liu, S, Wang, J, Qian, K, Shi, Y, Zheng, L, Chen, F, Kong, N. "A credible food traceability system based on domain name system security extensions", *International Journal of Online Engineering* 14 (2018) 111-125.

[49] Chaudhari, MP, Chandak, MB. "Predictive analytics for anomaly detection in internet of things enabled smart cold storage warehousing", *HELIX* 8 (2018) 3941-3945.

[50] Chiang, C-T, Lu, Y-K, Lin, L-T. "A CMOS Fish spoilage detector for IoT applications of fish markets", *IEEE Sensors Journal* 18 (2018) 375-381.

[51] Sundaravadivel, P, Kesavan, K, Kesavan, L, Mohanty, SP, Kougianos, E, Ganapathiraju, M. "Smart-log: An automated, predictive nutrition monitoring system for infants through the IoT", In: 2018 IEEE International Conference on Consumer Electronics, Las Vegas, NV, USA, 12-14 January, (2018) 1-4.

[52] Sundaravadivel, P, Kesavan, K, Kesavan, L, Mohanty, SP, Kougianos, E. "Smart-Log: A deep-learning based automated nutrition monitoring system in the IoT", *IEEE Transactions on Consumer Electronics* 64 (2018) 390-398.

[53] Lin, Q, Wang, H, Pei, X, Wang, J. "Food safety traceability system based on blockchain and EPCIS", *IEEE Access* 7 (2019) 20698-20707.

[54] Mondal, S, Wijewardena, KP, Karuppuswami, S, Kriti, N, Kumar, D, Chahal, P. "Blockchain inspired RFID based information architecture for food supply chain", *IEEE Internet of Things Journal* 6 (2019) 5803-5813.

[55] Ray, PP, Dash, D, De, D. "Approximation of fruit ripening quality index for IoT based assistive e-healthcare", *Microsystem Technologies* 25 (2019) 3027-3036.

[56] Jilani, MT, Rehman, MZU, Khan, AM, Chughtai, O, Abbas, MA, Khan, MT. "An implementation of IoT-based microwave sensing system for the evaluation of tissues moisture", *Microelectron Journal* 88 (2019) 117-127.

[57] Jagtap, S, Rahimifard, S. “The digitisation of food manufacturing to reduce waste–Case study of a ready meal factory”, *Waste Management* 87 (2019) 387-397.

[58] Jagtap, S, Bhatt, C, Thik, J, Rahimifard, S. “Monitoring potato waste in food manufacturing using image processing and internet of things approach”, *Sustainability* 11 (2019) 3173.

[59] Kodan, R, Parmar, P, Pathania, S. “Internet of Things for food sector: status quo and projected potential”, *Food Reviews International* (2019), Available online: https://doi.org/10.1080/87559129.2019.1657442.

[60] Gamaleldin, AM. “An introduction to cloud computing concepts”, Software Engineering Competence Center, Available online: https://www.secc.org.eg/Recocape/SECC_Tutorials_An%20Introduction%20to%20Cloud%20Computing%20Concepts.pdf. (Accessed 27 September 2019).

[61] Marks, EA, Lozano, B. “Executive's guide to cloud computing”, John Wiley and Sons, 2010.

[62] Dehghanghadikolaei, A, Namdari, N, Mohammadian, B, Fotovvati, B. “Additive manufacturing methods: a brief overview”, *Journal of Scientific and Engineering Research* 5 (2018) 123-131.

[63] Garrett, B. “3D printing: new economic paradigms and strategic shifts”, *Global Policy* 5 (2014) 70-75.

[64] Portanguen, S, Tournayre, P, Sicard, J, Astruc, T, Mirade, P-S. “Toward the design of functional foods and biobased products by 3D printing: A review”, *Trends in Food Science & Technology* 86 (2019) 188-198.

[65] Godoi, FC, Prakash, S, Bhandari, BR. “3d printing technologies applied for food design: Status and prospects”, *Journal of Food Engineering* 179 (2016) 44-54.

[66] Nachal, N, Moses, JA, Karthik, P, Anandharamakrishnan, C. “Applications of 3D printing in food processing”, *Food Engineering Reviews* 11 (2019) 123-141.

[67] Pouladzadeh, P, Peddi, SVB, Kuhad, P, Yassine, A, Shirmohammadi, S. “A virtualization mechanism for real-time multimedia-assisted mobile food recognition application in cloud computing”, *Cluster Computing* 18 (2015) 1099-1110.

[68] Cao, T-D, Truong, H-L. “Analyzing and conceptualizing monitoring and analytics as a service for grain warehouses”, In: Recent Developments in Intelligent Information and Database Systems. Studies in Computational Intelligence, vol 642. Springer, Cham, 642 (2016) 161-171.

[69] Rehman, F, Khalid, O, Haq, N, Khan, AR, Bilal, K, Madani, SA. “Diet-right: a smart food recommendation system”, *KSII Transactions on Internet and Information Systems* 11 (2017) 2910- 2925.

[70] Liu, C, Cao, Y, Luo, Y, Chen, G, Vokkarane, V, Yunsheng, M, Chen, S, Hou, P. “A new deep learning-based food recognition system for dietary assessment on an edge computing service infrastructure”, *IEEE Transactions on Computers* 11(2018) 249-261.

[71] Dandage, K. “Food traceability through web and smart phone for farmer’s agriculture products in India with help of web API's technology”, *AgroLife Scientific Journal* 7 (2018) 31-42.

[72] Liang, L, Runkle, BRK, Sapkota, BB, Reba, ML. “Automated mapping of rice fields using multi-year training sample normalization”, *International Journal of Remote Sensing* 40 (2019) 7252-7271.

[73] Doğan, K, Arslantekin, S. “Büyük veri: önemi, yapısı ve günümüzdeki durum”, *DTCF Dergisi* 56 (2016) 15-36.

[74] Kune, R, Konugurthi, PK, Agarwal, A, Chillarige, RR, Buyya, R. “The anatomy of big data computing”, *Software: Practice and Experience* 46 (2016) 79-105.

[75] Wu, S-Y, Yang, C, Hsu, W, Lin, L. “RF wireless LC tank sensors fabricated by 3D additive manufacturing”, In 2015 Transducers-2015 18th International Conference on Solid-State Sensors, Actuators and Microsystems, Anchorage, AK, USA, 21-25 June, (2015) 2208-2211.

[76] Severini, C, Derossi, A, Azzollini, D. “Variables affecting the printability of foods: Preliminary tests on cereal-based products”, *Innovative Food Science and Emerging Technologies* 38 (2016) 281-291.

[77] Bogue, R. “3D printing: An emerging technology for sensor fabrication”, *Sensor Review* 36 (2016) 333-338.

[78] Kouzani, AZ, Adams, S, Oliver, R, Nguwi, YY, Hemsley, B, Balandin, S. “3D printing of a Pavlova”, In: 2016 IEEE Region 10 Conference, Singapore, 22-25 November, (2016) 2281-2285.

[79] Mantihal, S, Prakash, S, Godoi, FC, Bhandari, B. “Optimization of chocolate 3D printing by correlating thermal and flow properties with 3D structure modeling”, *Innovative Food Science and Emerging Technologies* 44 (2017) 21-29.

[80] Yang, F, Zhang, M, Bhandari, B, Liu, Y. “Investigation on lemon juice gel as food material for 3D printing and optimization of printing parameters”, *LWT - Food Science and Technology* 87 (2018) 67-76.

[81] Lanaro, M, Forrestal, DP, Scheurer, S, Slinger, DJ, Liao, S, Powell, SK, Woodruff, MA. “3D printing complex chocolate objects: Platform design, optimization and evaluation”, *Journal of Food Engineering* 215 (2017) 13-22.

[82] Holland, S, Tuck, C, Foster, T. “Selective recrystallization of cellulose composite powders and microstructure creation through 3D binder jetting”, *Carbohydrate Polymers* 200 (2018) 229-238.

[83] Tohic, CL, O'Sullivan, JJ, Drapala, KP, Chartrin, V, Chan, T, Morrison, AP, Kerry, JP, Kelly, AL. “Effect of 3D printing on the structure and textural properties of processed cheese”, *Journal of Food Eng*ineering 220 (2018) 56-64.

[84] Vancauwenberghe, V, Verboven, P, Lammertyn, J, Nicolaï, B. “Development of a coaxial extrusion deposition for 3D printing of customizable pectin-based food simulant”, *Journal of Food Engineering* 225 (2018) 42-52.

[85] Kim, HW, Lee, JH, Park, SM, Lee, MH, Lee, IW, Doh, HS, Park, HJ. “Effect of hydrocolloids on rheological properties and printability of vegetable inks for 3D food printing”, *Journal of Food Science* 83 (2018) 2923-2932.

[86] Lee, JH, Won, DJ, Kim, HW, Park, HJ. “Effect of particle size on 3D printing performance of the food-ink system with cellular food materials”, *Journal of Food Engineering* 256 (2019) 1-8.

[87] Vancauwenberghe, V, Mbong, VBM, Vanstreels, E, Verboven, P, Lammertyn, J, Nicolai, B. “3D printing of plant tissue for innovative food manufacturing: Encapsulation of alive plant cells into pectin based bio-ink”, *Journal of Food Engineering* 263 (2019) 454-464.

[88] Lukyamuzi, A, Ngubiri, J, Okori, W. “Towards harnessing phone messages and telephone conversations for prediction of food crisis”, *International Journal of System Dynamics Applications* 4 (2015) 1-16.

[89] Navickas, V, Gružauskas, V. “Big data concept in the food supply chain: Small markets case”, *Scientific Annals of Economics and Busines* 63 (2016) 15-28.

[90] Geng, Z, Shang, D, Zhu, Q, Wu, Q, Han, Y. "Research on improved focused crawler and its application in food safety public opinion analysis", In: 2017 Chinese Automation Congress, Jinan, 20-22 October, (2017) 2847-2852.
[91] Alfian, G, Syafrudin, M, Rhee, J. "Real-time monitoring system using smartphone-based sensors and NoSQL database for perishable supply chain", *Sustainability* 9 (2017) 2073.
[92] Ji, G, Hu, L, Tan, KH. "A study on decision-making of food supply chain based on big data", *Journal of Systems Science and Systems Engineering* 26 (2017) 183-198.
[93] Irani, Z, Sharif, AM, Lee, H, Aktas, E, Topaloğlu, Z, van't Wout, T, Huda, S. "Managing food security through food waste and loss: Small data to big data", *Computers & Operations Research* 98 (2018) 367-383.
[94] Singh, A, Kumari, S, Malekpoor, H, Mishra, N. "Big data cloud computing framework for low carbon supplier selection in the beef supply chain", *Journal of Cleaner Production* 202 (2018) 139-149.
[95] Singh, A, Shukla, N, Mishra, N. "Social media data analytics to improve supply chain management in food industries", *Transportation Research Part E* 114 (2018) 398-415.
[96] Li, X-R, Zhang, J-Y, Huang, Y, Zeng, Z-L, Cheng, DU. "Student food data analysis system", In: 2018 International Conference on Electrical, Control, Automation and Robotics, Xiamen, China, 16-17 September, (2018) 317-321.
[97] Mishra, N, Singh, A. "Use of twitter data for waste minimisation in beef supply chain", *Annals of Operations Research* 270 (2018) 337-359.
[98] Xu, X, Hou, L, Guo, Z, Wang, J, Li, J. "Developing a Chinese food nutrient data analysis system for precise dietary intake management", In: International Conference on Big Data, Lecture Notes in Computer Science, vol 10968. Springer, Cham, (2018) 360-366.
[99] Parvin, S, Venkatraman, S, de Souza-Daw, T, Fahd, K, Jackson, J, Kaspi, S, Cooley, N, Saleem, K, Gawanmeh, A. "Smart food security system using IoT and big data analytics", In: 16th International Conference on Information Technology-New Generations, Advances in Intelligent Systems and Computing, vol 800. Springer, Cham, (2019) 253-258.
[100] Erl, T, Khattak, W, Buhler, P. "Big data fundamentals: concepts, drivers & techniques", Prentice Hall Press, 2016.
[101] Venkatraman, S, Fahd, K, Kaspi, S, Venkatraman, R. "SQL versus NoSQL movement with big data analytics", *International Journal of Information Technology and Computer Science* 12 (2016) 59-66.
[102] Kumar, R, Parashar, BB, Gupta, S, Sharma, Y, Gupta, N. "Apache Hadoop, NoSQL and NewSQL solutions of big data", *International Journal of Advance Foundation and Research in Science & Engineering* 1 (2014) 28-36.