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From The Editor

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EJEAS was established with the intention of promoting scholarly communication all over the world in a more effective manner. Our aim is to establish a publication that will be abstracted and indexed in the Engineering Index (EI) and Science Citation Index (SCI) in the near future. The journal has a short processing period to encourage young scientists.

Prof. Dr. Hasan HEPERKAN
Editor

Research Article

ARTIFICIAL INTELLIGENCE AND BIG DATA IN FRAUD DETECTION[1*]

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ABSTRACT

Artificial intelligence is used for many purposes nowadays. With the developments in technology, the fraudsters develop their methods. On the other hand, artificial intelligence methods are used in fraud detection for increasing the efficiency of corporations. AI and big data play an important role in real time data enrichment, deep learning integration and decisions. There are ten artificial intelligence methods explained which are used for fraud detection. Each method has its unique bases and it can not be said that there is only one optimal method. In this research, the methods are briefly explained, and a comparison is done for accuracy of methods. Supervised machine learning, unsupervised machine learning or semi-supervised machine learning as well as adaptive machine learning techniques against adaptive attacks with the advantage of big data and artificial intelligence are discussed with effectiveness usage for the future applications.

Keywords: *Artificial intelligence, Big data, Fraud detection, Supervised machine learning, Unsupervised machine learning, Adaptive machine learning.*

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1. INTRODUCTION

Fraud can be defined as illegally obtaining services, goods, or money belonging to other people or organizations and it is one of the greatest challenges for business and organizations. All the systems containing financial transactions are subject to fraud and most of its different forms are determined as a kind of crime in laws. Rapidly increasing volume of e-commerce is attracting the fraudsters equipped with new technologies and the technological defense tools against fraud become more crucial every day. Preventing and detecting fraud is becoming more important more than ever.

Fraud detection is always both related to and fed by data mining and text mining even before the emergence of 'Big Data' phenomenon. However, before the Big Data research techniques developed, there were limited set of ways to develop algorithms to analyze huge amounts of data.

In this research paper, it is aimed to present main ideas of the papers which reviewed the most common and most practiced artificial intelligence techniques of fraud detection. Machine learning models for fraud detection as supervised machine learning models (SMLM), unsupervised machine learning models (UMLM) and semi-supervised machine learning models (SSMLM) as well as adaptive machine learning techniques against adaptive attacks are also discussed with the advantage of using big data and artificial intelligence for the future applications.

2. FRAUD TYPES AND DETECTION METHODS

2.1 FRAUD TYPES

Fraud is a broad term that includes many different types. Submitting fake documents while applying for a job can be defined as a fraud. On the other extent, making manipulations in the financial tables of a big multinational corporation can also be defined as a fraud. In this research, we determined the limit of fraud as financial frauds. Financial fraud can be determined with the help of two factors: The financial gain and an illegal method implementation. Limiting the framework to financial fraud gives the advantage of using fiscal terms and scales.

Financial fraud has several subsets. There are mainly three industries vulnerable to never ending fraud attempts. The first is banking. The instruments generally attached to fraud cases are listed as the credit cards, the mortgages and complex cash transactions involving money laundering. Fraud can occur in the appliance or distribution phases of credit transactions. The second sector is insurance. The most probable fraud attacks may be on the healthcare and auto insurance instruments. The last industry involving the greatest risk of fraud is the telecommunication industry. There are mainly two areas in that sector. Namely, subscription fraud in which the fraudsters obtain telecommunication accounts without paying and the other is superimposed fraud, in which the legally registered customers pay the fraudsters' expenses.

Detection of fraud is basically a classification problem and if it is not done efficiently, it may be costly for the firms. Because of that, many artificial intelligence techniques aim to increase efficiency in classification [1]. In AI terms, classification can be defined as predicting of a result with the use of inputs. To implement modelling to classify, there must be a training dataset. By benefitting the training dataset, the success of the model can be measured in a test dataset. There are types of classification namely, binary classification, multi-class classification, multi-label classification and imbalanced classification. Artificial intelligence fraud detection techniques generally use imbalanced classification in which most of the training dataset belong to normal values and the minority is labelled as abnormal. The reason of that is in real life, the fraud cases make up a very small proportion of the whole cases.

Early fraud detection works were mainly built on statistical methods such as logistic regressions and neural networks. After that, data mining techniques were implied. Finally, the hybrid methods are the main way of fraud detection. Therefore, it is very natural that the techniques are evolving and will be improved in the future.

There are mainly two drawbacks to make fraud detection research more challenging for the researchers. The first is fraud detection techniques are mostly specialized for every different companies. The second is that accessing the real-world data is not so easy because of the privacy issues. Therefore, many scholars attempt to make research on different sectors and put weight on comprehensive analysis.

2.2 ARTIFICIAL INTELLIGENCE TECHNIQUES USED FOR FRAUD DETECTION

In this section, the techniques are summarized to maintain a theoretical base.

Bayesian Belief Networks: A Bayesian belief network uses a classifier to calculate for all possible classes and inserts the value X into the class with the highest probability. In this way, the network is shown to classify each sample into a class that it is most likely to belong to [2].

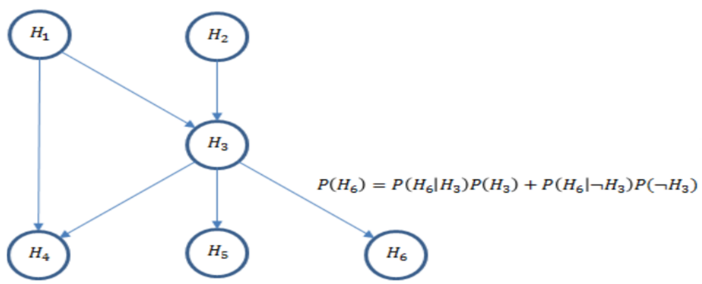

Figure 1: Bayesian Belief Networks Method [3].

Bayesian Belief Networks: A Bayesian belief network uses a classifier to calculate for all possible classes and inserts the value X into the class with the highest probability. In this way, the network is shown to classify each sample into a class that it is most likely to belong to [2].

Logistic Regression: It is statistical method of classifying binary data by using a linear model. It is generally used for predicting of the probability of a case is whether fraudulent or not [4].

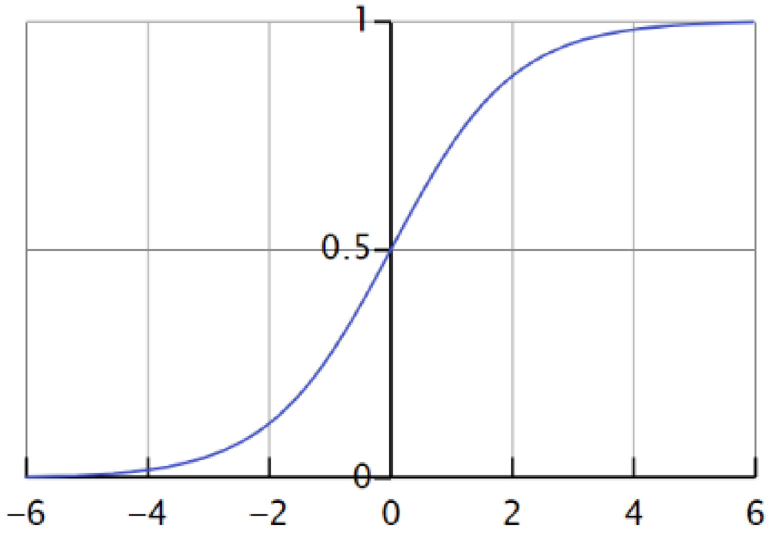

Figure 2: Logistic Regression Method [5].

Neural Network: An artificial network of neurons or nodes is used in this method. The connections of the neurons are modeled as weights. Positive values of weights represent excitatory connection, and the negative values represent inhibitory connections. After all the weights are aggregated, a function controls the amplitude of the output. This technique is known for its relevance to the predictive modelling which is also used to predict the cases are fraudulent or not.

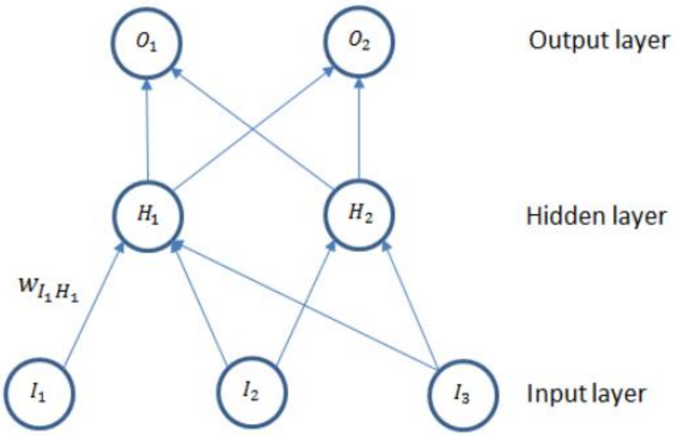

Figure 3: Neural Network Method [3].

Support Vector Machine: This method is a kind of machine learning algorithms and is used for both classification and regression analysis. This method enables complicated non-linear problems to be solved by linear classification without increasing the demand of computational complexity [3].

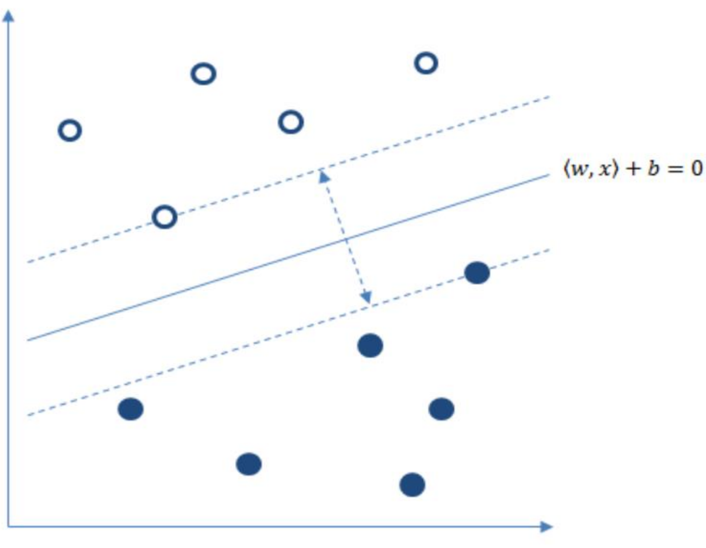

Figure 4: Support Vector Machine Method [3].

Genetic Algorithms and Programming: This method has the aim of solving problems by evolving an initially random set of possible solutions, through the application of operators inspired by natural genetics and natural selection, such that in time the best solutions would last only. In other words, it is the search of the most optimal program among other algorithms. It selects different parts of programs and produces new generation of programs while combining them. Genetic algorithms are like neural networks in that they require no prior knowledge of the problem domain and are capable of detecting underlying relationships between the samples [6].

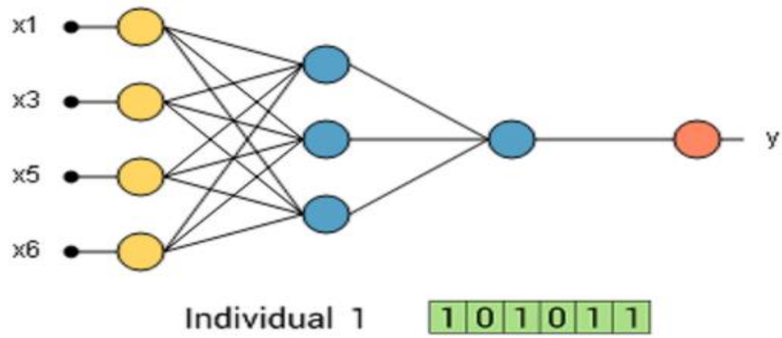

Figure 5: Genetic Algorithms and Programming Method [7].

Decision Trees, Forest: Decision trees are a technique used to make classifications or predictions on data. It uses a tree with internal nodes representing binary choices on attributes and branches representing the outcome of that choice. The nodes are created by artificial intelligence by using the dataset and it makes decision branches until it is eventually sorted into a mutually exclusive subgroup [2].

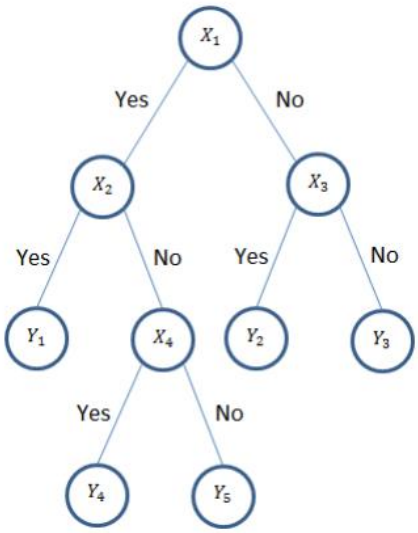

Figure 6: Decision Tree Method [3].

Group Method of Data Handling: It is a deep learning data mining algorithm that calculating optimal solutions through a series of models and increases the accuracy of the model. It has an inductive nature, unlike the other deductive methods. It aims to minimize the coders' influence on result of modelling through a set of several algorithms including parametric, clusterization, analogues complexing, rebinarization and probability algorithms. It finds interpretable relations in dataset and selects effective features.

Text Mining: It is a kind of data mining based on plain text data. It filters out the stop words like 'the', 'is', or 'a'. After that, it reduces the derived forms of words into their roots. Finally, it analyzes the data according to the frequencies of words. It basically transforms the text-based data into a quantitative dataset.

Self-Organizing Map: This method is a kind of artificial neural network method which is built on a single matrix of neurons. A high-dimensional data is reduced into a 2-dimensional matrix form. The difference between self-organizing maps and artificial neural networks is that the first applies competitive learning, whereas the latter applies error-correcting learning.

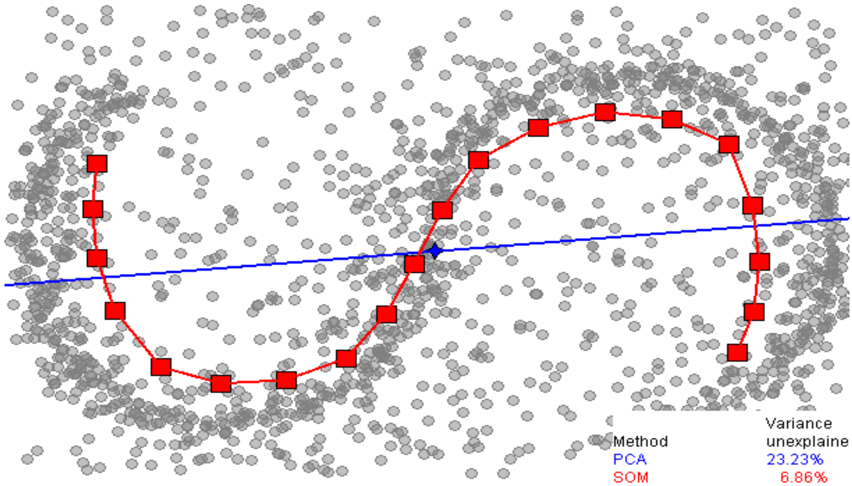

Figure 7: Self-Organizing Map Method [8].

Process Mining: The goal of process mining is to turn event data into insights and actions. Process mining is an integral part of data science, fueled by the availability of data and the desire to improve processes. Process mining techniques use event data to show what people, machines, and organizations are really doing. Process mining uses these event data to answer a variety of process-related questions. Process mining techniques such as process discovery, conformance checking, model enhancement, and operational support can be used to improve performance and compliance [9].

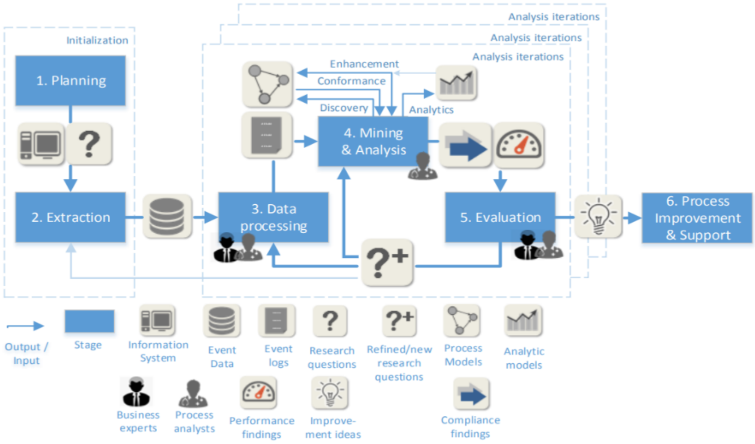

Figure 8: Process Mining Method [10].

Artificial Immune System: It is a class of artificially intelligent, rule-based machine learning systems inspired by the principles and processes of an immune system of clever creatures like humans. The algorithms of this system are modeled very similarly to an immune system and it was inspired by the concept that learning and memory for use in problem-solving. There are four techniques that can be classified as artificial immune system: Clonal selection algorithm, negative selection algorithm, immune network algorithm, dendritic cell algorithm. The first is used for optimization, the second for anomaly detection, third for clustering and visualization, the fourth for multi-scale processing.

Hybrid Methods: They are combinations of the afore-mentioned methods. They can be constructed in a number of ways. The first model's outputs may be applied to another method as an input. One method may be applied as a pre-processing method, while the other makes the essential part. They are constructed to make tailored and specifically targeted solutions.

2.3 OVERVIEWING THE ACCURACY OF METHODS

It is researched that the success of methods in different studies. However, the most comprehensive study was done by West et al. and it shows the comparison of different methods [3]. Interpreting the values in the table, the most accurate methods differ from the datasets. In a study of credit card fraud, the accuracies are very similar. However, when inspecting a dataset of financial statements of manufacturing firms, Bayesian belief networks are more accurate than decision trees and neural networks. In other datasets, the best methods differ also.

Table 1: The comparison made on the accuracies of the methods [3].

Fraud Investigated	Method Investigated	Accuracy
Credit card transaction fraud from a real-world example	Logistic model (regression) Support vector machines Random forests	96.6-99.4% 95.5-99.6% 97.8-99.6%
Financial statement fraud from a selection of Greek manufacturing firms	Decision trees Neural networks Bayesian belief networks	73.6% 80% 90.3%
Financial statement fraud with financial items from a selection of public Chinese companies	Support vector machine Genetic programming Neural network (feed forward) Group method of data handling Logistic model (regression) Neural network (probabilistic)	70.41-73.41% 89.27-94.14% 75.32-78.77% 88.14-93.00% 66.86-70.86% 95.64-98.09%
Financial statement fraud with managerial statements for US companies	Text mining	95.65%
Financial statement fraud with managerial statements for US companies	Text mining Text mining and support vector machine hybrid	45.08-75.41% 50.00-81.97%
Financial statement fraud with managerial statements for US companies	Text mining and decision tree hybrid Text mining and Bayesian belief network hybrid Text mining and support vector machine hybrid	67.3% 67.3% 65.8%
Financial statement fraud with financial items from a selection of public Chinese companies	CDA CART Neural network (exhaustive pruning)	71.37% 72.38% 77.14%

3. MACHINE LEARNING MODELS FOR FRAUD DETECTION

Machine learning can be used with more effectiveness as 1. Supervised Machine Learning Models (SMLM), 2. Unsupervised Machine Learning models (UMLM) and 3. Semi-Supervised Machine Learning Models (SSMLM) against adaptive attacks. Machine learning models need to collect big data to detect fraud. The model analyzes all the input data gathered and extracts the required features. The machine learning model that receives training sets that teach it to predict the probability of fraud. Then, it creates fraud detection machine learning models.

In case of supervised machine learning an algorithm that learns to perform a task from known examples as training data. A supervised learning model is based on predictive data analysis and the accuracy depends on the training set provided for it. SMLM needs large amount of labeled data and has difficulties in detection of unknown data. Labeled data to train the models are the important and quantity of data and quality of the data is the biggest limitation in the supervised machine learning. In a supervised learning model, all input information has to be labeled as good or bad.

On the other hand, unsupervised machine learning will be the future of machine learning for detection of unknown attacks. UMLM has an algorithm that learns to identify linkages and patterns in the data without prior knowledge of what to look for and does not require labeled training data using auto-label and auto-rules generation. Generation large set of features, performing correlation analysis, graph analysis to link fraudulent clusters, identifying attack rings and assigning confidence score and categorizing are the basic steps in UMLM. An unsupervised learning model continuously processes and analyzes new data and updates its models. It learns to notice patterns and decide whether they're parts of legitimate or fraudulent operations. Deep learning in fraud detection is usually associated with unsupervised learning algorithms.

Semi-supervised learning models are somewhere between supervised and unsupervised learning models. SSLM works for cases where labeling information is either impossible or too expensive and requires the labor of human experts.

Effectiveness is increased in SMLM and UMLM with the increasing time however with the advantage of big data, computational time and with the advantage of decision systems in artificial intelligence, these systems can be used effectively for fraud detections.

Adaptive machine learning techniques can also be effective solution for the analysis of datasets and supervised and unsupervised or even semi-supervised machine learning.

4. CONCLUSION

Fraud detection is a very challenging and important subject to explore for increasing efficiency in some industries hence the number of fraud cases increasing with the technology. In this research, the artificial intelligence methods for fraud detection are categorized and reviewed. Some of the methods have statistical approaches, however, some of them have computational approaches. These techniques can be used alone or in a combination. Even though the performances of methods may differ according to datasets, all of them have unique implementations. Every firm can make a hybrid of these methods according to their own needs. Supervised machine learning, unsupervised machine learning or semi-supervised machine learning as well as adaptive machine learning techniques against fraud detection and adaptive attacks with the advantage of big data and artificial intelligence can be used effectively for the future applications.

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Research Article

ARTIFICIAL INTELLIGENCE APPLICATIONS IN SMART CITIES WASTE MANAGEMENT & RECYCLING[1*]

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ABSTRACT

The rates of urbanization have been very rapid in the last 50 years and by 2050 about two-thirds of the world population will be living in cities. In the meantime, cities are becoming smart like everything else with the rapid development of technology. These developments are accompanied by environmental pressures on the urban infrastructure. Among these pressures, one of the most important ones is generation of wastes. Waste generation rates in urban environment/cities are increasing rapidly and use of technology in waste management, and especially recycling, has to be more closely considered. It is now possible to increase the rate of recycling and better waste management with applications of artificial intelligence (AI) and internet of things. In this article, AI applications in the field of waste management and recycling around the world will be discussed. The proposed model for this purpose applies an algorithm used for solving The Minimum Linear Arrangement Problem which is NP-hard. Some examples of applications used in the waste management sector are examined and conclusions, which could be useful for starting a new transformation about recycling and waste management, are reached.

Keywords: *Waste, Waste Management, Recycling, Location Technology, Robotic, Smart City, Artificial Intelligence, Sustainability.*

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1. INTRODUCTION

In this research, artificial intelligence applications applied to waste management and recycling are examined. Any substance or object which the holder discards or intends/required to discard is called waste according to Article 3 of the EU Waste Framework Directive (2008/98/EC). According to this definition waste covers all refuse that could be recycled (referred as waste hereon) and could not be recycled (referred as garbage hereon). The residual material that remains after separating the materials such as paper, cardboard, glass, metal, plastic and which cannot be recycled is called as garbage, which is mostly decomposable food waste or yard waste. In this research, garbage is considered as something that needs to be disposed of, while waste is something that can be reused by separating the substances that make up waste.

Recycling aims to prevent unneeded use of resources and reducing the amount of waste to be disposed by sorting the waste at its source. Recycling and re-use of materials such as iron, steel, copper, lead, paper, plastic, rubber, glass, and electronic will block the depletion of natural resources. This approach will reduce the amount of foreign exchange paid for imported scrap material and save a great deal of energy used by many countries.

Recycling is also an important indicator that shows the development status of nations. While the population and expectations for everyday comforts on the planet are expanding, there is an inescapable expansion in utilization of resources and this puts pressure on our public/common assets (natural resources and environmental quality). Under these conditions, importance of the productive utilization of common assets turns out to be much more obvious. Zero waste policies/legislation and applications have been developed in line with these needs and are on the agenda of Turkey and the world.

2. ARTIFICIAL INTELLIGENCE APPLICATIONS IN WASTE MANAGEMENT

Today, a significant portion of the wastes generated in big cities can be recycled. Recycling and reuse methods that can reduce environmental problems also contribute to the national economies. With the increasing world population, the existence of techniques and models that help people separate recyclable wastes have become imperative for the efficient disposal of waste materials. At this point, Artificial Intelligence technology emerges. If the collection of unwanted materials/refuse is punctual, it enhances a resident's satisfaction. In this model heavy equipment is used by the collecting company's staff for collection of wastes. If waste collection service is satisfactory, residents promote it through the word of mouth [1].

When we examine the artificial intelligence applications that we can address in waste management and recycling, we will see different methods. There are different methods of predicting solid waste generation, which can be broadly classified into five main groups: descriptive statistical models, regression analysis, material flow method, time series analysis and artificial intelligence methods [2].

There are different studies carried out in different regions all over the world by different companies. One of these companies is ZenRobotics. They use robots to separate waste as a recycler/robotic sorting station and the flowchart and characteristics of this station can be seen in Figure 1. In this system, disorganized and mixed data creates a difficult environment for the robot to make predictions and to operate Therefore, specific arrangements have to be made with regard to homogenizing the waste flows. In addition, controls get harder due to external factors such as working environment temperature changes, dust and dirt, so controls on these are also needed.

Another robotic transforming company is AMP Robotics [3]. The working principles of their system can be summarized as follows. They create a database of millions of images. Then, neurons apply a deep learning algorithm to different product groups such as glass, plastic and metal according to their color, size and brand. Furthermore, the algorithm contextualizes the data in order to improve the classification of each material it collects. The collected data also provides transparency to recyclers so that they can optimize their operations and increase recycling rates.

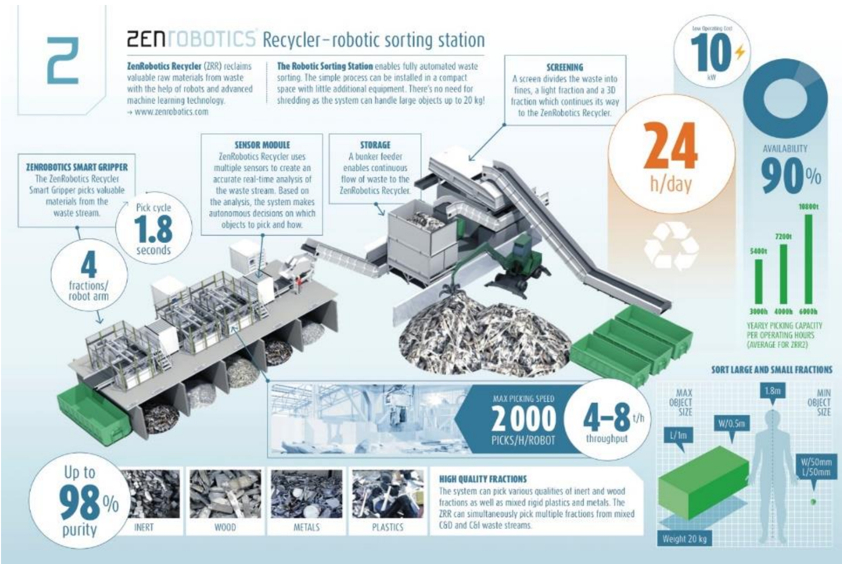

Figure 1: Robotic Sorting Station [4].

There are two basic approaches in using AI in waste management. The first one is the separation of wastes in different parts of the city at dumping places (trash bins). In this approach, waste is created by households, who dump their waste into a smart trash bin, where the smart trash bin collects waste by separating it. This method stands out with the fact that it reduces the cost and does not require an additional process.

The second approach, on the other end of artificial intelligence applications of waste management, is collecting the garbage as a whole and to separate it by going through a process with the help of robotic automation. This method is more difficult to do and requires a high level of artificial intelligence software and engineering.

Currently, a fast development is being experienced in Smart Cities, where engineers, urban planners, architects and city managers are joining forces with the goal of boosting up the efficiency of municipal services and increasing benefits and convenience to their communities [5].

Engineering disciplines, municipal access networks, smart roads provide us some important information to improve the governance of cities. Information is transferred to the relevant units via wireless connections such as smart garbage bins or a prototype with sensor that measures the volume in containers. This data will be used to optimize waste collection and management strategies. AI sensors are a vital improvement over traditional optic option. They can identify the type of material and take into account special considerations. A manufacturer may buy a certain kind of recyclable plastic, for example, but only if it is clean from contaminants. AI sensors can separate out plastics used with chemicals from those that are clean, even if they're the same material [6].

3. MAIN WASTE MANAGEMENT PROCESSES AND ARTIFICIAL INTELLIGENCE

Waste management processes cover various steps starting from collection of waste and ending by final disposal. In this context, a stepwise summary of the process is provided in Table 1 below.

Table 1: Main Processes in Waste Management

Waste Management and Recycling Steps		
Steps	**Details**	**Avg. Time**
Collecting	Separate collection of different types of wastes (e.g. plastic wastes, metals, garbage, etc.) at the source is achieved using various bins/cans such as indoor boxes, cages, containers and piggy banks.	1-3 Days
Classification	This process will allow classification of recyclable waste materials collected separately at the source to be categorized on the basis of glass, metal, plastic and paper. Waste materials under this classification will be ideally delivered to recycling facilities separately.	1 Day

Sorting	The mixed recyclable wastes that arrived with collection vehicles are separated in the separation band. They are separated as paper, metal, glass and plastic wastes. Plastic wastes can be divided into 5 different material types (PET, PE, PP, PS, PVC) and transferred to the recycling industry. Separated wastes form the raw materials for recycling.	6-12 Hours
Pressing	The classified and separated plastic wastes are then turned into bales in the press machine so that they do not take up more space in volume and sent to the storing area.	2-4 Hours
Storing	After the separation process, paper, plastic (including pressed bales), metal and glass wastes are stored separately in the stock area reserved for them and made ready for transfer. They are sent to the recycling facility regularly by the dedicated trucks.	2-3 Week s

In the context of waste management, main discussion here will be on location-based technologies. In a nutshell, the proposed waste collection system is based on waste level data from trashcans in a metropolitan area. The data collected by sensors is sent over the Internet to a server where it is stored and processed [7].

The new trashcans, which are fully equipped by AI and some physical hardware, have some behavioral property. They have some sensors to determine the distance between top and bottom of the can. Thus, it sends information to server about how full it is. The optimization of these cycles is a combinatorial optimization problem. When the objective function of this optimization is to minimize the driving distance (equivalent to minimizing the length of the cycles), the problem is the same as the well known The Traveling Salesman Problem and closely related to the Minimum Linear Arrangement Problem, which are NP-hard [9]. The NP algorithm could be followed from Figure 2.

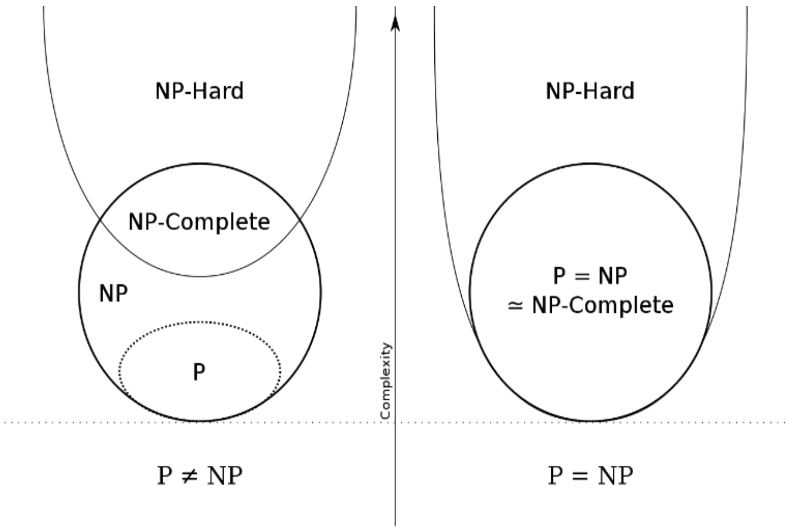

Figure 2: NP Algorithm Chart [10].

The main point in this part is using collected datasets for optimizing daily routines of trashcans collection. The key feature of this system is that it is designed to learn from experience and to make decisions not only on the daily waste level status, but also on future state forecast, traffic congestion, balanced cost-efficiency functions, and other affecting factors that cannot be foreseen without relevant data [8]. Due to the high number of route optimizations required to carry out the iterations, it was decided to use GA, which is relatively fast in providing near-optimal solutions. We understand that it is of great importance for the waste collection crews, who conduct this duty daily, use these technologies and optimize their work.

Last, but not least there are some Artificial Intelligence applications on waste management in Turkey as well. For example, Antalya Municipality uses smart containers. Sensors in these containers measure the filling rate of each container and instantly transfer the data to related person(s). This system also optimizes for unloading containers so that vehicles can use the shortest distance. Figure 3 shows an intelligent recycling terminal in China, which is a good example of use of AI in waste management and encouraging citizens for recycling.

Figure 3: Intelligent Recycling Terminals [12].

Some of the best AI applications used for waste management and recycling in the world are summarized in Table 2 below.

Table 2: Best Applications about Waste Management and Recycling [13]

Waste Management and Recycling Applications		
Applications	**Details**	**Operating System**
IRecycle	Earth 911, which is an organization determined to spread the word about the benefit of recycling waste, launched the iRecycle App. The app helps users locate the nearest recycle centers in their vicinity. Also, the app teaches users the different do-it-yourself (DIY) ways to recycle wastes.	iOS & Android
Gimme 5	There are different types of plastics; some are not recyclable, while some are known to be more profitable when recycled. The plastic type that falls under the latter category is the number 5 plastic which is polypropylene. Gimme 5 is an app that helps users to identify the right recyclable plastics.	iOS
Waste Management App	The Waste Management App is one of the most comprehensive apps for managing waste. It functions as a waste payment app as well as a hub to access local information and policies on waste management. In	iOS

	addition, users can use this app to monitor and track waste pickups.	
RecycleNation	RecycleNation is a mobile app that helps improve recycling rates in the US. Also, the app helps users locate recycling centers on the map as well as their contact information. Furthermore, RecycleNation comes with a news portal that provides users with environmental trends and news.	iOS
My Waste	The My Waste mobile app partners with municipalities all over the world to provide its users up-to-date waste management and recycling news, policies and information. Another feature of the app is the waste collection and recycling dates reminder.	iOS & Android

With the introduction of artificial intelligence applications at every point of our lives, we are stepping into a more livable world by saving money, time and energy on this and other similar practices. Continuity is a solid part of an operation in working up any process. Whatever is done well today can be done better tomorrow. In these environments, collaborative robots equipped with artificial intelligence make purposeful contributions to process improvement from the day they start functioning. With artificial intelligence-based systems that can be integrated into co-conspirator robots, robotic systems do much more than machines for nasty, boring and hazardous jobs.

4. CONCLUSION

With the rapid development in technology, many innovations are applied in our daily life. While some of these developments do not contribute directly to sustainability of natural resources and development, some of them show great importance for human welfare and sustainable development. Artificial intelligence applications in the field of waste management and recycling are among the technological developments that serve for environmental sustainability and human welfare in the long run.

The problems related to climate change/global warming and degradation of environmental quality are mainly due to rapid population increase and associated need for economic growth without giving necessary attention to environmental issues. In this context, use of technology was also focused solely on economic development and missed the need for conservation of natural resources and ecosystem. However, with the new millennium more strict policies and targets were put down by nations and international organizations to stop environmental degradation and to achieve better environmental conditions. In addition, awareness of the public has been exponentially increasing through improved communication technology and municipalities are acting more responsibly concerned with environmental impacts of wastes.

In this regard, AI technologies are being more broadly used especially in developed countries in the field of environmental and specifically waste management. In the management of solid wastes recycling, reuse and recovery are becoming more and more important and technological developments are supporting better application of these techniques. Thus, improvement of AI applications in this field and their more widely use (with decreasing of associated costs) would significantly contribute to environmental protection and would be key factors in sustainable development.

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DIGITAL CONTROLLERS PERFORMANCE ANALYSIS FOR A ROBOT ARM[1*]

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ABSTRACT

The design methodology and performance study of various forms of digital compensators for a robot arm joint control system with sensor feedback are presented in this article. Continuous time (s-plane or w-plane) and Discrete (z-plane) domain parameters are used in the design process. The frequency response characteristics design techniques were investigated, and five basic types of controllers were modelled and simulated using MATLAB: phase-lag, phase-lead, proportional-integral (PI), proportional-derivative (PD), and proportional-integral derivative (PID). Many of the controllers have been set up to maintain a 40-degree phase margin. Both closed loop phase answers, as well as open loop bode plots, have been analyzed. This paper presents a comparison of the controllers based step response characteristics.

Keywords: *Digital controllers, PID controllers, Robot arm, Robot arm controllers, Digital Controllers Performance.*

1. INTRODUCTION

Controllers are needed to assess adjustments in system parameters and to meet performance requirements for steady-state precision, transient reaction, reliability, and disturbance prevention. Analog control systems are stable, with no intrinsic band width limitations or system changes. Due to the tolerances of practical machines, in analog controls, intricate logics are difficult to synthesize, while rendering complex interfaces

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among multiple subsystems is very difficult, and are vulnerable to incorrect designs and limitations. Furthermore, extraneous noise sources can corrupt analog systems significantly. High-tech digital controls since no signal loss occurs in an along to digital (A/D) and digital to analog (D/A) conversions [1], systems are reliable. Furthermore, with a more sophisticated logic implementation, systems are more flexible and accurate. Filters do not encounter external noises, which makes them well-suited for adaptive filtering uses. Fast response and a digital memory interface are possible for digital systems [1]. A physical planet or system is accurately controlled through closed-loop or feedback operation where an output (system response) is adjusted as required by an error signal [2]. The discrepancy between the sponge as determined by sensor input and the target response generates the error signal. The error quantity is processed by a controller or compensator in order to satisfy those output requirements [3]. This paper describes five digital controller design methodologies for a robot control system in real-time. In these design methods, the compensating parameter is the phase margin specified in the plant bode diagram. The design method employs strategies of frequency response that allow for frequency cross-over phase margin (Pm). Phase-lag, PI and PID controllers (lag, lead) were drawn up in accordance with the principle of compensation and the methodologies as defined in [4]. This paper clarified the statistical and conceptual pricing articulated in the references. The primary and illustrative frames and approaches to digital control systems are mentioned in [6]. Digital control systems have been documented for training, theory, simulation and experimental approaches [7],[8]. A closed-loop model has been introduced in [1] and [4] for digital systems control and implementations in the Digital Drive Controller. Regarding to PID controller we citation the information from [5].

2. METHODOLOGY

A sampler, D/A block that is a zero-order hold (ZOH), a servomotor represented by an s-domain transfer mechanism, digital controller block, a power amplifier gain, gears represented by a gain value, and a feedback sensor block comprise the example robot control scheme outlined in this article. A s-domain transfer function presents the uncompensated plant. A/D conversion is started by the sampler and D/A conversion is held at zero order. Controllers must offset the margin of the plant phase and the desired result shall be 40 deg. For each controller, steady-state error, percent overshoot, rise time, and settling time are calculated for output assessment. This paper section by section documents a literature review of digital compensation, an example uncompensated robot arm joint plant, discrete and continuous-time equations with design method, MATLAB simulation results of lag, lead, PI, PD and PID controls, and a comparative study among these five. In order to evaluate design requirements, the digital system was adopted, simulated and extended in MATLAB.

3. LITERATURE REVIEW

The compensation theory, plant configuration and the mathematical derivations of design approaches, loop parameters and open loop of the controllers mentioned in this paper fully follow the literature provided in [1]. The controller transfer function for first-order compensation can be written as

$$D(z) = \frac{K_d(z-z_0)}{z-z_p} \tag{1}$$

Here, z_0 and z_p represent the zero and pole positions, respectively. The controller's bilinear or trapezoidal transformation from the discrete z-plane to the continuous w-plane (warped s-plane) implies $D(w) = D(z), z = \frac{1+(T/2)w}{1-(T/2)w}$ and $\mathrm{D(w)} = \mathrm{a}_0 \frac{1+(\mathrm{w}/\omega_{\mathrm{w0}})}{1+(\mathrm{w}/\omega_{\mathrm{wp}})}$, Here $\omega_{\omega 0}$ and $\omega_{\omega p}$ denotes the zero and pole positions in the w-plane, and a_0 denotes the compensator dc gain. The bilinear approximation states that:

$$w = \frac{2}{T}\frac{z-1}{z+1} \tag{2}$$

From the equations (1)-(4), in the z-plane the controller can be realized as

$$D(z) = a_0 \frac{\omega_{wp}(\omega_{w0}+2/T)}{\omega_{w0}(\omega_{wp}+2/T)} \frac{z-\left(\frac{2/T-\omega_{w0}}{2/T+\omega_{w0}}\right)}{z-\left(\frac{2/T-\omega_{wp}}{2/T+\omega_{wp}}\right)} \tag{3}$$

The equation (1) yields to

$$K_d = a_0 \frac{\omega_{wp}(\omega_{w0}+2/T)}{\omega_{w0}(\omega_{wp}+2/T)} \tag{4}$$

$$z_0 = \frac{2/T-\omega_{w0}}{2/T+\omega_{w0}} \tag{5}$$

$$z_p = \frac{2/T-\omega_{wp}}{2/T+\omega_{wp}} \tag{6}$$

4. BLOCK DIAGRAM EXPLANATION

A closed-loop model for digital control systems and applications of digital controllers to speed drives has been shown in the above diagram. Thus, consists of a sampler, digital controller block, D/A block which is a zero-order hold (ZOH), a power amplifier gain, a servomotor represented by a s-domain transfer function, gears represented by a gain value and a feedback sensor block. In the case of a closed-loop feedback system, the D(z) digital controller system is implemented. The controller uses algebraic algorithms such as filters and compensatory controls to correct or regulate the controlled system's behavior. The zero-order hold is a practical mathematical model of signal reconstruction using a digital-to-analog converter (ZOH). This can be illustrated by you take a and convert it to a continuous-time signal, at a set time, it stores each sample value and does not allow changes. The amplitude or power of a signal input to output port can be increased by connecting it to an amplifier whose gain is set to a particular level [9].

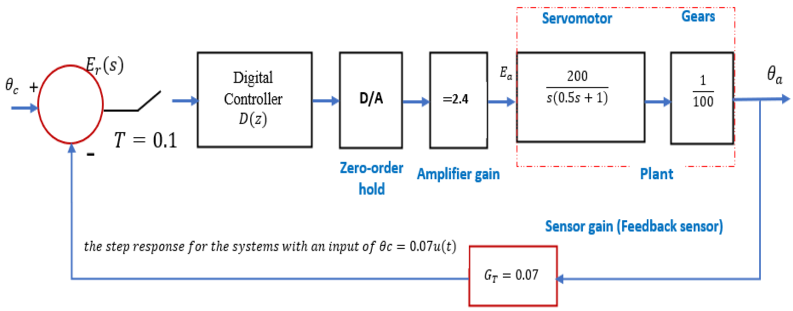

Figure 1. Robot arm joint control system block diagram

In order for a servomotor to transform the control signal from the controller into the rotational angular displacement or angular velocity of the motor output shaft, implies it has a servomotor. To power the arms of the robot, Servo motors are used. Gears are used to transfer motion. By finding the torque and speed of the output gear, you can find the torque and speed of the input gear. The uncompensated plant is presented by a s-domain transfer function. The sampler initiates A/D conversion and zero-order hold implements D/A conversion. For performance evaluation, steady-state error, percent overshoot, rise time and settling time are measured for each controller. Here the given sensor feedback gain, GT= 0.07. The sensor input is θ_a In degrees and the output is in volts.

5. PLANT

The control system of the robot arm has been shown in Fig. 1. This system has shown the sampling time, $T = 0.1s$, the power amplifier increase, K = 2.4 and the sensor feedback gain, H_k= 0.07. The system phase margin with, $D(z)$ = 1. The ZOH-TF can be defined as

$$G_{HO}(s) = \frac{1-e^{-sT}}{s} \tag{7}$$

The plant TF in continuous time

$$G_p(s) = \frac{9.6}{s^2+2s} \tag{8}$$

The sensor gain feedback TF is used in a continuous-time plant

$$G_c(s) = G_p(s) \times H_k = \frac{0.672}{s^2+2s} \tag{9}$$

Where the TF is transfer function.

The sensor gain feedback TF that operates in discrete time is known as a discrete-time plant

$$G_d \frac{0.00028289 \ (s+3.39e04)}{(s+1.524)\ (s+0.4406)} \tag{10}$$

Fig. 2. Introduces $D(z) = 1$ system bode diagram, Pm, for the uncompensated system is $79.6\ deg$ with a gain margin $Gm = 35.8\ dB$.

5.1 DESIGN OF PHASE LAG CONTROLLER

Design a phase-lag controller with a dc gain of 10 that yields a system phase margin

$$G_{hf}(dB) = 20\log\frac{a_0\omega_{wp}}{\omega_{w0}} \tag{11}$$

The controller in this paper is built for 39.7842 degrees. For this design, the Pm and the cross-over or Pm frequency have been chosen as $\omega_{wc} = 1.1291\text{rads}^{-1}$.

$$\omega_{w0} = 0.1\omega_{wc} \tag{12}$$

and

$$\omega_{wp} = \frac{\omega_{w0}}{a_0|G_d(j\omega_{wc})|} \tag{13}$$

The TF of the controller is

$$D_{lag}(z) = \frac{0.01167\ (z-0.7105)}{(z-0.9919)} \tag{14}$$

Figure 5 shows the phase-lag controller. The compensated plant Pm, $Pm = 39.7842\ deg$ at $0.0925\ rad/s$, can be seen on the bode plot. $Gm = 29.6\ dB$ at $0.575\ rad/s$. The gain and phase margin values are unknown in the marginalized bode plot of the controller, and hence these are determined to be infinite. The gain and phase margin values are unknown in the Bode plot of the controller, and hence these are found to be infinite where the Pm is the phase margin.

5.2 DESIGN OF PHASE LEAD CONTROLLER

The phase-lead controller, $\mathrm{a}_0 = 10$ and maximum phase shift, θ_m occurs at a frequency $\omega_{wm} = \sqrt{\omega_{w0}\omega_{wp}}$. The controller in this paper is equipped for 39.8827 degrees for this design, the Pm and cross over or Pm frequency have been chosen as $2.2950\ rad/s$. a phase-lead design controller with a dc gain of 10 that yields a system phase margin 40 deg.

$$D(j\omega_{wc})G_d(j\omega_{wc}) = 1\angle(180 + \phi_{pm}) \tag{15}$$

Here ϕ_{pm} pm is the desired Pm and

$$D(w) = a_0\frac{1+w/(a_0/a_1)}{1+w/(b_1)^{-1}} \tag{16}$$

Where $\omega_{w0} = \mathrm{a}_0/a_1$ and $\omega_{wp} = 1/b_1$. The angle can be described as.

$$\theta_r = \angle D(j\omega_{wc}) = 180 + \phi_{pm} - \angle G_d(j\omega_{wc}) \tag{17}$$

The controller design requires

$$|D(j\omega_{wc})| = \frac{1}{|G_d(j\omega_{wc})|} \tag{18}$$

from the equation (16)-(18), it can be evaluated that

$$a_1 = \frac{1 - a_0|G_d(j\omega_{wc})|\cos\theta_r}{\omega_{wc}|G_d(j\omega_{wc})|\sin\theta_r} \tag{19}$$

and

$$b_1 = \frac{\cos\theta_r - a_0|G_d(j\omega_{wc})|}{\omega_{wc}\sin\theta_r} \tag{20}$$

Because of the phase lead characteristic, $\theta_r > 0$ and in the design procedure ω_{wc} has been constrained by the following requirements

$$\begin{aligned} &\angle G_d(j\omega_{wc}) < 180 + \phi_{pm}; |D(j\omega_{wc})| > a_0 \\ &|G_d(j\omega_{wc})| < \frac{1}{a_0}; b_1 > 0 \\ &\cos\theta_c > a_0|G_d(j\omega_{wc})| \end{aligned} \tag{21}$$

The transfer function of the controller is

$$D(z) = \frac{10.424*(z-0.9832)}{(z-0.9618)} \tag{22}$$

From the bode plot, it can be observed that the compensated plant Pm, $P_m =$ 39.8827 deg. At 2.29 rad/s and the gain margin, $G_m = 16.2\ dB$ at 6.57 rad/s. From the bode plot of controller figure, in fact, it is evident that the gain and Pm values are undefined and thereby these are found to be infinite.

5.3 DESIGN OF PI CONTROLLER

PI controller means Proportional Integral controller it is composite of proportional and integral controller. They are in cascade with each other, as we see in fig.

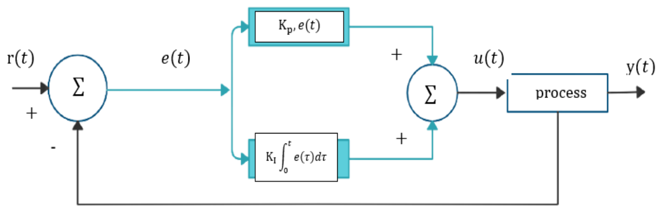

Figure 2. THE DESIGN OF PI CONTROLLER

The TF of the controller can be expressed as

$$D(w) = K_P + \frac{K_I}{w} = K_I\frac{1 + w/\omega_{w0}}{w} \tag{23}$$

Where $\omega_{w0} = K_I/K_P$. However, the discrete TF of a PI controller can be expressed as

$$D(z) = K_P + K_I \frac{T}{2}\frac{z+1}{z-1} \tag{24}$$

PI controller design that yields a system phase margin with 40 deg

$$D(j\omega_{wc})G_d(j\omega_{wc}) = 1\angle(-180 + \phi_{pm}) \tag{25}$$

Let A = $|\ G_d(j\omega_{wc}\ |$, The Kp proportional gain and K_I integral gain can be expressed as

$$Kp = \frac{\cos\theta_r}{|\ G_d(j\omega_{\omega_c}\ |}$$

$$K_I = \frac{\omega_{wc}\sin\theta_r}{|G_d(j\omega_{\omega c})\ |}$$

The TF of the controller is

$$D(z) = \frac{1.4575\ (z-0.9648)}{(z-1)} \tag{26}$$

From the bode plot, this is worth noting as that the compensated plant Pm, $P_m = 40.0182$ deg. At 0.553 rad/s and the gain margin, $G_m = 30.9\ dB$ at 5.61 rad/s. From the bode plot of controller figure, it can be observed that the gain and Pm values are undefined and thereby these are found to be infinite.

5.4 DESIGN OF PD CONTROLLER

PD controller means proportional derivative Controller so it has both, the proportional controller and derivative controller in cascade, so we have to add both, as we see in fig.

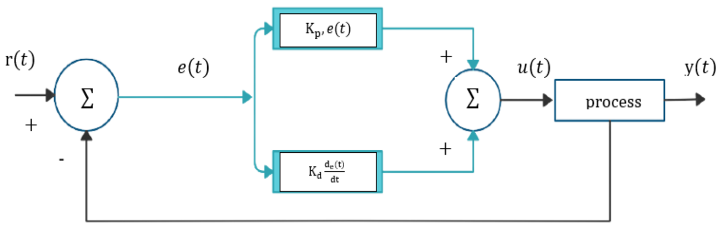

Figure 3. THE DESIGN OF PD CONTROLLER

Let w_1 the Gain crossover frequency of the system with cascade PD controller, A_1 the $|G_1(j\omega)|$ at ω_1. The PI controller transfer function is

$$D(\omega) = k_p + k_D w \tag{27}$$

Moreover, we can change the transfer function from w-plane to z -transform using the bilinear transformation. In Bilinear transformation, ω is replaced by $\frac{2}{T}\left(\frac{z-1}{z+1}\right)$, where $T =$ sampling time.

the discrete TF of a PI controller is

$$D(z) = kp + k_D \frac{2}{T}\left(\frac{z-1}{z+1}\right) \tag{28}$$

controller design that yields a system phase margin with 40 deg

$$-k_d w_1^2 + k_i + jkpw_1 = \frac{\omega_1}{A_1}\sin\theta + j\frac{\omega_1}{A_1}\cos\theta \tag{29}$$

The derivative gain and proportional gain can be expressed as

$$k_d = \frac{\sin\theta}{\omega, A_1}$$

$$\therefore k_{\mathrm{d}} = \frac{\sin\theta}{\omega_1 |G(j\omega_1)|} \tag{30}$$

$$k_p = \frac{\cos\theta}{A_1}$$

$$\therefore k_p = \frac{\cos\theta}{|G(j\omega_1)|} \tag{31}$$

5.5 DESIGN OF PID CONTROLLER

PID controller proportional Integral Derivative controller Consists of proportional, integral, and Derivative controller all connected in the cascade form, as we see in fig.

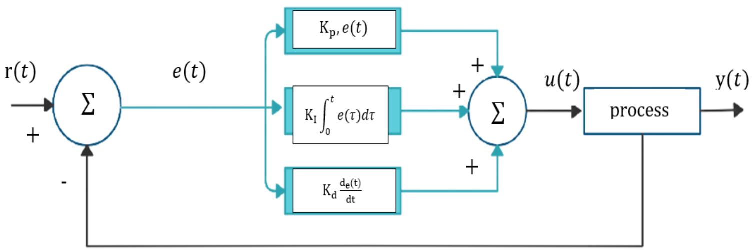

Figure 4. THE DESIGN OF PID CONTROLLER

$$D(w) = K_P + \frac{K_I}{w} + K_D w \tag{32}$$

Moreover, we can change the transfer function from w-plane to z – transform by using the bilinear transformation. In Bilinear transformation ω is replaced by $\frac{2}{T}\left(\frac{z-1}{z+1}\right)$, where $T =$ sampling time.

The PID controller's discrete TF can be expressed as

$$D(z) = K_P + K_I \frac{T}{2}\frac{z+1}{z-1} + K_D \frac{z-1}{Tz} \tag{33}$$

controller design that yields a system phase margin with 40 deg

$$\left[K_P + \frac{K_D \omega_{wc}^2 (2/T)}{(2/T)^2 + \omega_{wc}^2}\right] + j\left[\frac{K_D \omega_{wc} (2/T)^2}{(2/T)^2 + \omega_{wc}^2} - \frac{K_I}{\omega_{wc}}\right] = K_R + jK_C$$

The K_P proportional gain, K_D derivative gain and K_I integral gain can be expressed as the controller transfer function, which can be expressed as

$$\therefore K_P + \frac{K_D \omega_{wc}^2 (2/T)}{(2/T)^2 + \omega_{wc}^2} = \frac{\cos\theta_r}{|G_d(j\omega_{wc})|} \tag{34}$$

$$\therefore \frac{K_D \omega_{wc} (2/T)^2}{(2/T)^2 + \omega_{wc}^2} - \frac{K_I}{\omega_{wc}} = \frac{\sin\theta_r}{|G_d(j\omega_{wc})|} \tag{35}$$

The gain margin is = $20\,dB$ at 6.99 rad/s, and the Pm is = 38.1 degrees by the PID controller at 1.85 rad/s. The gain and phase margin values are unknown in the marginalized bode plot of the controller, and hence these are determined to be infinite.

5.6 CONTROLLERS' BODE PLOT

The curves and the table below are for all the controllers discussed in the previous sections.

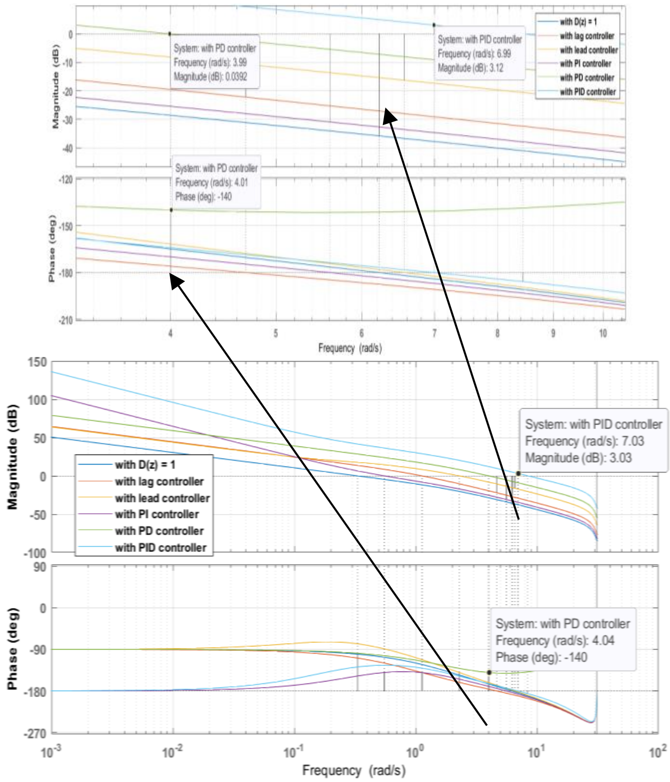

Figure 5. Controllers' Bode plot of the open loop

Table 1. Controllers' Bode plot characteristics

Characteristics	Pm with D(z) = 1	Lag	Lead	PI	PD	PID
Gain Margin	61.5755 1.7929e+04	12.8749 6.7538e+0	6.49351.7 014e+03	09.97021. 8455e+03	Inf	0 9.9702 1.8455e+03
GM Frequency	6.2240 31.4159	4.6917 31.4159	6.5659 31.4159	0 6.9890 31.4159	Inf	0 6.9890 31.4159
Phase Margin	79.6399	39.7842	39.8827	38.1362	40.0	38.1362
PM Frequency	0.3315	1.1291	2.2950	1.8486	4.003 5	1.8486
Delay Margin	41.9333	6.1499	3.0331	3.6006	1.743 8	3.6006
DM Frequency	0.3315	1.1291	2.2950	1.8486	4.003 5	1.8486
Stable	1	1	1	1	1	1

6. STEP RESPONSE CHARACTERISTICS

Design problem explained in this paper has assumed an input of θ_c = 0:07u(t). The controller scaled step response of the closed-loop system for the design is presented in Figure 6. For the step response overshoot, ├ ξ↓⇒M_p%(%OS))↑. From figure 6 and table 2, the PID controller is the best because it has less steady state error than other controllers. For PID steady-state error ∝1/k_p , OS ∝1/k_d , Rise Time ∝1/k_p , ∝1/k_i , Settling Time ∝1/k_d . Kp,Kd, and Ki can be described as the proportional, derivative, and integral parameters. The closed-loop controls system is affected by all three of these parameters. In addition to those factors, the slow rising, slow settling, and long. Overshoot, as well as the steady state error, are also affected. A lag compensator shifts the Bode magnitude plot down at mid and high frequencies with its attenuation property. Highlights for specification on steady-state error, the low frequency gain is changed. The proportional-integral controller is equivalent to a control system that produces an output, this calls attention to which is the result of adding outputs from the proportional and integral controllers. PID is used in systems where proportional, integral, and derivative controllers are used to compute an output. Implies It's also there to reduce steady state error and improve stability. Reveals that when used in conjunction with a proportional and a derivative controller, the proportional derivative controller generates an output, which is the product of the proportional and derivative controllers. If PD is being used, noise may be suppressed in the higher frequencies.

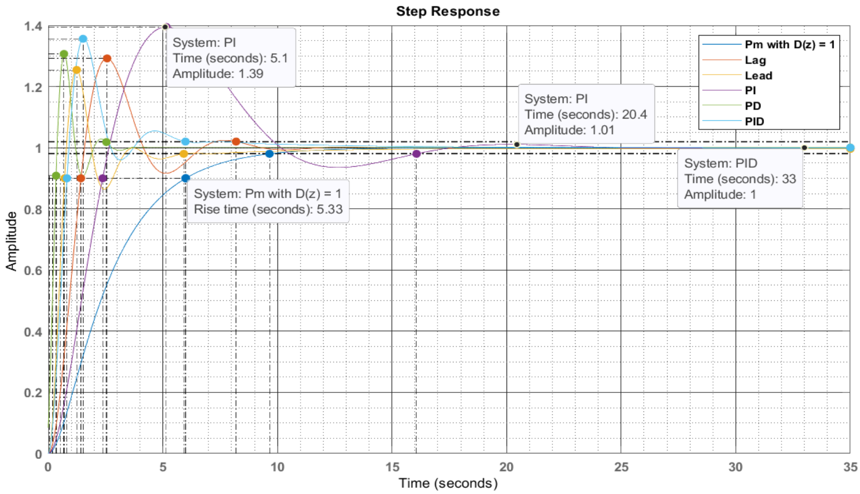

Figure 6. Controllers' step response of the closed loop

Table 2. Controllers' step response characteristics

Characteristics	Pm with D(z) = 1	Lag	Lead	PI	PD	PID
Rise Time:	5.3278	1.0700	0.5359	1.8526	0.2940	0.6182
Settling Time	9.6546	8.1969	5.9127	16.0705	2.5379	5.9852
Settling Min	0.9020	0.9004	0.8641	0.9053	0.9068	0.9321
Settling Max	0.9986	1.2919	1.2543	1.3949	1.3064	1.3560
Overshoot	0	29.1881	25.4273	39.4865	30.6421	35.6044
Undershoot	0	0	0	0	0	0
Peak	0.9986	1.2919	1.2543	1.3949	1.3064	1.3560
Peak Time	15.6573	2.5692	1.2423	5.1509	0.6846	1.5198

7. CONCLUSION

This paper examines the performance and design assessment of five simple digital controllers, including lag, lead, PI, PD, and PID controllers, which are used for a physical robot arm joint plant. C-O frequency is a crucial design specification to compensate the plant. Implies design a system controller with a dc gain of 10 that yields a system phase. The design methodologies have been investigated in both discrete z-domain time approaches and warped s-domain or w-plane time frames. The controllers have been simulated on MATLAB and bode plots with open loop and closed loop step response curves have been analyzed for comparative margin Pm 40 deg. Premises. The suggests tells us such design is crucial as its specifications are applicable in different practical control systems.

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IMPROVING CAPABILITIES OF EMG SIGNALS WITH PREDICTION ALGORITHMS[1*]

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ABSTRACT

In this study, long-term performance signals were measured; to minimize the changes in the characteristics of the signals due to long term performance of amputated arm patients, it is aimed to improve the read signals by using machine learning algorithms. In our study, the data obtained from the measurements we made through the Armband device of the right arms of seven people were used. While the data were obtained, the hand was turned into a fist, and this movement continued until fatigue occurred in the muscle. Naive Bayes, Generalized Linear Model, Logistic Regression, Fast Large Margin, Deep Learning, Decision Tree, Random Forest, and Gradient Boosted Trees algorithms are used to process signals, and 16796 models are created. Data were analyzed based on Accuracy, Classification Error, Area Under Curve, Precision, Recall, F Measure and Specificity. The algorithms that yield the best results were determined in each variable, and the results were shared. This study was orally presented in 10th International Conference on Image Processing, Wavelet and Applications, IWW2019.

Keywords: *EMG Signals, Machine Learning Algorithms, Signal Processing, Signal Efficiency, MYO Armband.*

1. INTRODUCTION

The use of prosthetic limbs has been applied to millions of people since the 1970s [6]. The prosthesis limbs developed due to limb losses due to various reasons allow people to hold onto life. Today, studies in this field are continuing increasingly. Wiener has proposed the idea of using prosthetic arms using Electromyogram (EMG) signals for real-time motion. These signals were used as a control mechanism for the prosthetic limb systems. Boston Arm(MIT) and the Utah artificial arm are some examples [8].

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In this study, we worked with EMG signals. The use of electromyographic (EMG) signals from skeletal muscle advantages of being both convenient and natural [1]. That means EMG signals are directly correlated with the contraction and relaxation of muscle fibers [7]. We're using MYO Armband to detect EMG signals. Our purpose is to maximize signal detection when long term muscle movements happened. When muscles are tired due to long term usage, characteristic of the signal has been changing. When the signal changes, it might affect the working of the mechanism. So with the help of machine learning algorithms, we tried to increase the success of the muscle signal process. This way, with enough data and properly applied machine learning techniques, system will work as intended even if the signal starts to change and the model will predict the correct movement so do the work as its intended. To achieve this, we have used MYO Armband on seven volunteers and get right arm muscle data. After collecting the tired muscle data, first of all different subject's data were compiled within a single dataset. When the dataset is completed, the data were cleaned with some preprocessing steps. These include removing the repeating rows, getting rid of low variance values, high correlated values, applying normalization and principal component analysis. The main reason for using these methods is to correctly predict the required values while minimizing training time, increasing the accuracy of the classification models and so increasing the results of the prediction for the research. When the preprocessing is done, this data is directly used as an input on the eight different machine learning algorithms. Results have been shared on the Results and Discussion part. The importance of our study is to share the results of different machine learning algorithms that worked with our dataset.

2. MATERIALS AND METHODS

In this study, muscle signal measurements were performed with MYO Armband produced by Thalmic Labs. MYO Armband is a wristband with 8 EMG electrodes, three axis accelerometer, three axis gyroscope and three axis magnetic force measurement. This wrist strap can also show the orientation of the arm in 3-dimensional space. The orientation data from the wristband is transmitted to the computer via wireless communication (Bluetooth). After the data is processed with the software prepared in Python programming language, it is sent to the industrial robot in real-time via TCP / IP communication [3].

Dataset collected by MYO Armband are processed and used by machine learning algorithms which are Random Forest, Deep Learning, Gradient Boosted Trees, Decision Tree, Naïve Bayes, Logistic Regression, Generalized Linear Model, and Fast Large Margin. These algorithms are explained in next titles. The reason these algorithms are picked, because the data we are working on requires classification to make the prediction. Although some of the algorithms also works on regression, the main idea is to classifications these data properly and preparing the prediction models based on this accurate classification.

2.1. NAÏVE BAYES

Naive Bayes is a machine learning algorithm used for classifications and has been proven to be effective in areas such as email spam filtering and document categorization [9]. This algorithm is preferred for efficiency, low variance, increased learning, direct estimation of probability, robustness in data corruption, and robustness in incomplete data [10]. The efficiency of the calculation is important because the performance of the algorithm, especially for big data in modeling and estimation, makes the difference in terms of time, cost and stability, as well as the reliability of the results obtained [2].

2.2. GENERALIZED LINEAR MODEL

The generalized linear model is the algorithm where the usual linear model is generalized [11]. The linear model says that the sum of the model and data is equal to the data. Anova, Ancova and regression analysis have emerged from this model. It is different from usual model in two main aspects, for example, where multiple regression is somewhat a different case: It only contains information about the ranks. Secondly, dependency variable values are estimated from the combination of estimates of the linear variable which is linked to dependency variable by a link function.

2.3. LOGISTIC REGRESSION

Logistic Regression is a statistical management that has one or more arguments and is used to determine a result. The analysis of an existing data set yields two possible results and is used in linear classification problems. Logistic regression contains binary 1 or 0 encoded data.

For a logistic regression analysis in which the machine will find out whether the person is a hyperthyroid or not, the result is negative if the result is 1 and the result is not hyperthyroid. From this example, it can explain the purpose of logistic regression as follows; to find the most suitable model for defining the suitable connection between a group of sovereign variables related to the dependency variable having two-way characteristics.

2.4. FAST LARGE MARGIN

Idea of the fast large margin is to apply a speedy margin learner to a SVM based on a learning plan [4]. Although similar to those presented by conventional SVM or logistic regression applications, this linear classifier can work on a dataset containing millions of samples and attributes. It has been preferred due to its ability to work with large scale data.

2.5. DEEP LEARNING

Deep learning is developed from artificial neural networks and is a widely used algorithm for machine learning. Main idea is to extract automatically the necessary classification for low and high level features. Deep learning models often adopt hierarchical structures to interconnect layers. Having this feature can be more powerful in the feature presentation of deep learning models than shallow machine learning models. While the performance of traditional machine learning methods is often based on users' experiences, deep learning approaches are based on data.

2.6. DECISION TREES

This algorithm has been used for many years as a prediction, classification and rule determination algorithm. The ID3 algorithm has come a long way in finding information. Advantage of the decision tree is being intuitive and easy to understand. The decision tree is not only easy to classify and predict, but it is also very easy to understand the course of development, classification and forecasting. However, the variable value is a continuous and gradual change in many industrial controls and optimizations, and in most cases it is not necessary to control the exact scope, but to classify for the decision, not to produce the exact predictive value.

2.7. RANDOM FOREST

When communities of decision trees work together, it is known as Random Forest. Each tree in the Random Forest estimates one class, and the class with the most votes becomes the prediction of the model. This algorithm works well where there are classes and lots of data because the better the estimation according to the working principle, the higher the estimation level. Of course, the lower the correlation in the data, the more accurate the predictions will be. Some of these trees may be true and some of them may be wrong, but as the algorithm iterations continue, these trees will move forward and get closer to the result.

2.8. GRADIENT BOOSTED TREE

This algorithm is known for the ability of being able to work with both the Regression and Classification issues [5]. When considered as a tree, it can be said that it stores only scalar values in its leaves. Multiple scalar deciduous trees should be used to address vector regression or multiclass classification problems. The reason for its use is that the data obtained from the trees that have been mis-sampled is used to prevent errors in subsequent trees. So this algorithm learns from its mistakes and tries not to repeat these steps. It is a useful algorithm in terms of this feature and it can produce very good results with sufficient iterations in case of estimation.

3. RESULTS AND DISCUSSION

As explained in the previous chapters of our study, EMG signals measured from seven different individuals with Vocational School Armband were used in Random Forest, Deep Learning, Gradient Boosted Trees, Decision Tree, Naïve Bayes, Logistic Regression, Generalized Linear Model, Fast Large Margin algorithms and 16796 models were created and Receiver Operating Characteristic (ROC) curve is shared in Figure 1.

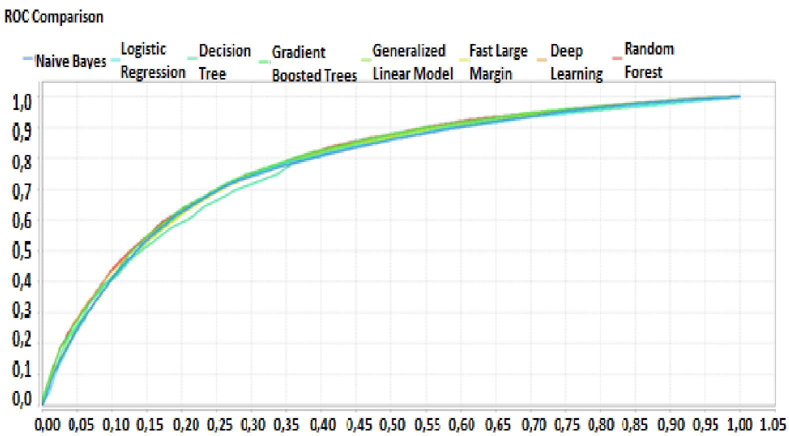

Figure 1: Mechanical model equivalent to the raised water tank

The equations for the Housner (Epstein, 1976) approximations for hydrodynamic pressure are set below [7].

3.1. ACCURACY BASED RESULTS

Accuracy defines the distance between the actual value and the measured value.

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

- True Positive (TP): is where the signal is strong and our model correctly predicts as strong signal
- True Negative (TN) is where the signal is weak and our model correctly predicts as weak signal
- False Positive (FP): is where the signal is strong and our model predicts as weak signal
- False Negative (FN): is where the signal is weak and our model predicts as strong signal

After all algorithms worked with our dataset, accuracy based results shared in Figure 2 and Table1.

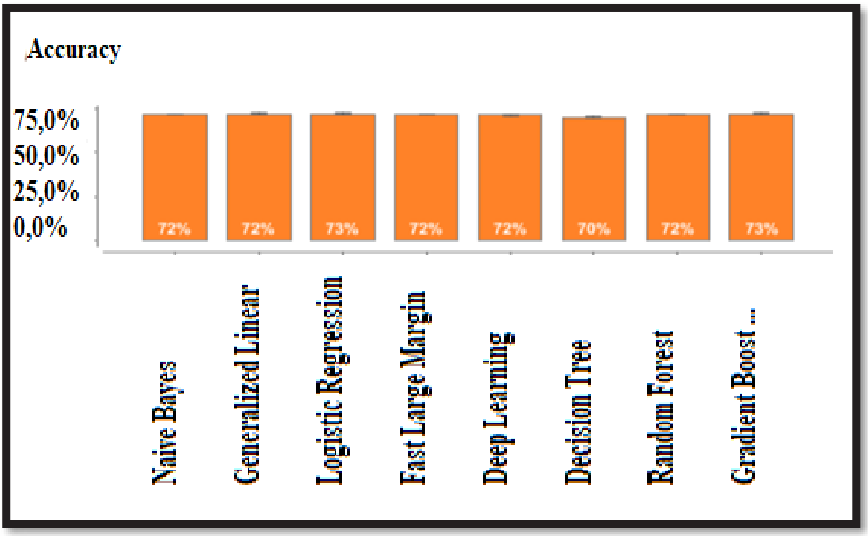

Figure 1. Accuracy based success rates of all algorithms.

Table 1. Accuracy based results of all algorithms.

Model	Accuracy	Standard Deviation	Gains	Total Time	Training Time (1,000 Rows)	Scoring Time (1,000 Rows)
Naïve Bayes	0,7230	0,000974	25382,0	699452,0	1,3	54,1
Generalized Linear Model	0,7239	0,003031	25586,0	696467,0	5,5	73,0
Logistic Regression	0,7255	0,001514	25686,0	514505,0	4,7	56,3
Fast Large Margin	0,7193	0,001400	24998,0	92,6654,0	50,8	56,1
Deep Learning	0,7165	0,001658	24716,0	1115023,0	104,9	106,7
Decision Tree	0,7033	0,002573	23096,0	523277,0	2,0	85,7
Random Forest	0,7212	0,004561	10284,0	1024953,0	11,0	251,4
Gradient Boosted Trees	0,7257	0,005856	10472,0	936112,0	119,5	148,6

3.2. PRECISION BASED RESULTS

Precision defines the distance between the measured values.

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

After all algorithms worked with our dataset, precision based results shared in Figure 3 and Table2.

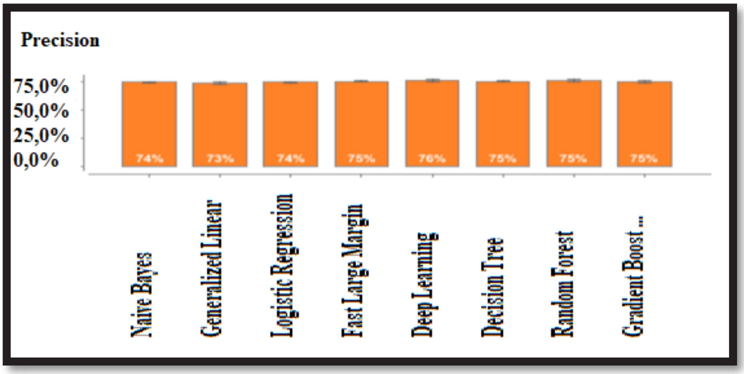

Figure 2. Precision based success rates of all algorithms.

Table 2. Precision based results of all algorithms.

Model	Precision	Standard Deviation	Gains	Total Time	Training Time (1,000 Rows)	Scoring Time (1,000 Rows)
Naïve Bayes	0,740990	0,007916	25382,0	699452,0	1,3	54,1
Generalized Linear Model	0,732197	0,008251	25586,0	696467,0	5,5	73,0
Logistic Regression	0,741457	0,004204	25686,0	514505,0	4,7	56,3
Fast Large Margin	0,748666	0,003733	24998,0	926654,0	50,8	56,1
Deep Learning	0,758971	0,008881	24716,0	1115023,0	104,9	106,7
Decision Tree	0,749864	0,005209	23096,0	523277,0	2,0	85,7
Random Forest	0,753676	0,013546	10284,0	1024953,0	11,0	251,4
Gradient Boosted Trees	0,747325	0,014196	10472,0	936112,0	119,5	148,6

3.3. RECALL BASED RESULTS

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

After all algorithms worked with our dataset, recall based results shared in Figure 4 and Table 3.

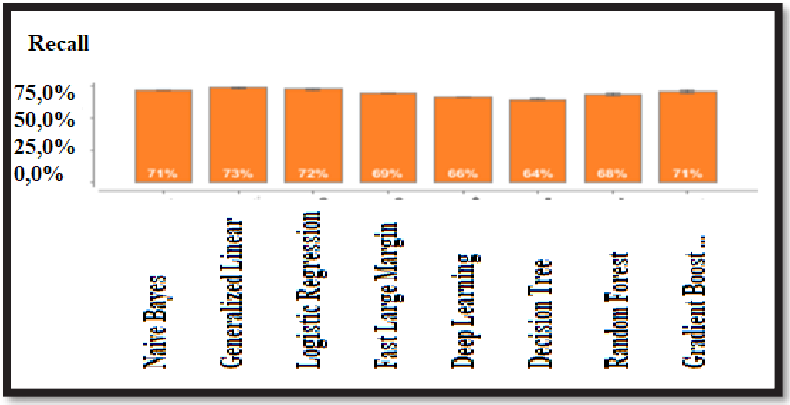

Figure 3. Recall based success rates of all algorithms.

Table 3. Recall based results of all algorithms.

Model	Recall	Standard Deviation	Gains	Total Time	Training Time (1,000 Rows)	Scoring Time (1,000 Rows)
Naïve Bayes	0,712751	0,002113	25382,0	699452,0	1,3	54,1
Generalized Linear Model	0,733414	0,004357	25586,0	696467,0	5,5	73,0
Logistic Regression	0,723134	0,002924	25686,0	514505,0	4,7	56,3
Fast Large Margin	0,690873	0,001569	24998,0	926654,0	50,8	56,1
Deep Learning	0,660657	0,003019	24716,0	1115023,0	104,9	106,7
Decision Tree	0,642487	0,003214	23096,0	523277,0	2,0	85,7
Random Forest	0,680806	0,008022	10284,0	1024953,0	11,0	251,4
Gradient Boosted Trees	0,705492	0,008991	10472,0	936112,0	119,5	148,6

3.4. CLASSIFICATION ERROR BASED RESULTS

$$Classification\ Error = \frac{(FP+FN)}{(TP+FP+FN+TN)} \quad (4)$$

After all algorithms worked with our dataset, classification error-based results shared in Figure 5 and Table 4.

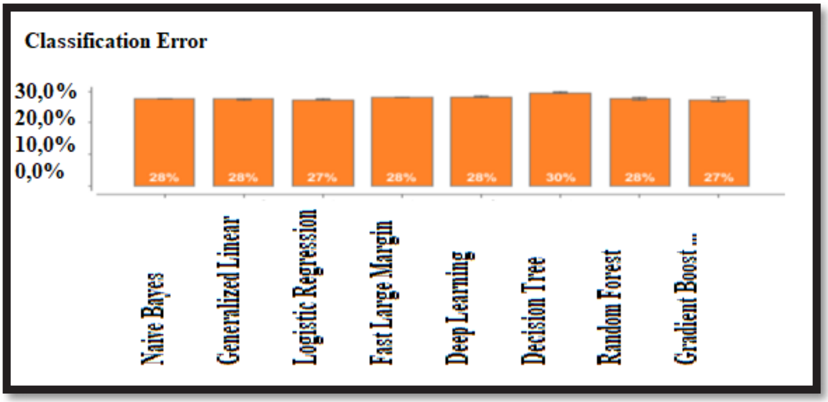

Figure 5. Classification Error based success rates of all algorithms.

Table 4. Classification Error based results of all algorithms.

Model	Classification Error	Standard Deviation	Gains	Total Time	Training Time (1,000 Rows)	Scoring Time (1,000 Rows)
Naïve Bayes	0,276901	0,000974	25382,0	699452,0	1,3	54,1
Generalized Linear Model	0,276054	0,003031	25586,0	696467,0	5,5	73,0
Logistic Regression	0,274434	0,001514	25686,0	514505,0	4,7	56,3
Fast Large Margin	0,280686	0,001400	24998,0	926654,0	50,8	56,1
Deep Learning	0,283473	0,001658	24716,0	1115023,0	104,9	106,7
Decision Tree	0,296647	0,002573	23096,0	523277,0	2,0	85,7
Random Forest	0,278770	0,004561	10284,0	1024953,0	11,0	251,4
Gradient Boosted Trees	0,274289	0,005856	10472,0	936112,0	119,5	148,6

3.5. SPECIFICITY BASED RESULTS

$$Specificity = \frac{(TN)}{(TN+FP)} \tag{5}$$

After all algorithms worked with our dataset, specificity-based results shared in Figure 6 and Table 5.

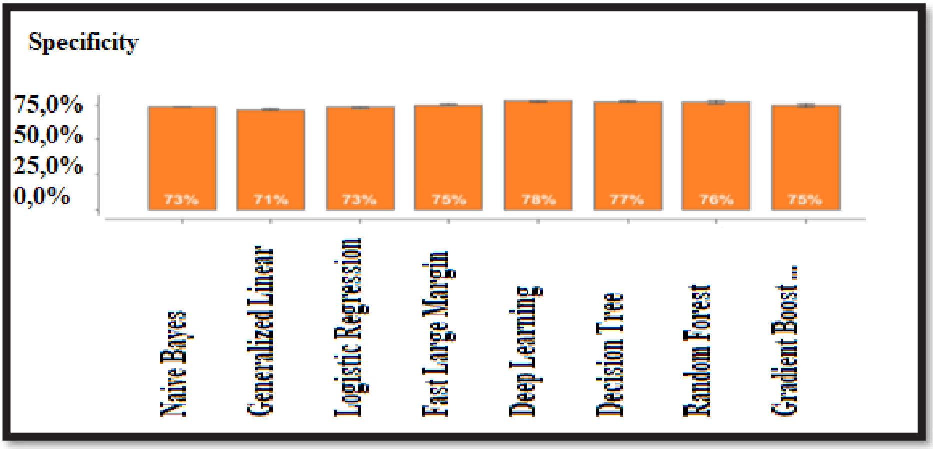

Figure 6. Specificity based success rates of all algorithms.

Table 5. Specificity based results of all algorithms.

Model	Specificity	Standard Deviation	Gains	Total Time	Training Time (1,000 Rows)	Scoring Time (1,000 Rows)
Naïve Bayes	0,734166	0,003673	25382,0	699452,0	1,3	54,1
Generalized Linear Model	0,713779	0,002292	25586,0	696467,0	5,5	73,0
Logistic Regression	0,728154	0,003146	25686,0	514505,0	4,7	56,3
Fast Large Margin	0,749947	0,003163	24998,0	926654,0	50,8	56,1
Deep Learning	0,776169	0,003125	24716,0	1115023,0	104,9	106,7
Decision Tree	0,768939	0,004299	23096,0	523277,0	2,0	85,7
Random Forest	0,764204	0,011877	10284,0	1024953,0	11,0	251,4
Gradient Boosted Trees	0,747265	0,011986	10472,0	936112,0	119,5	148,6

3.6. F MEASURE BASED RESULTS

$$F\ Measure = \frac{(2*\mathrm{TP})}{(2*\mathrm{TP}+\mathrm{FP}+\mathrm{FN})} \quad (6)$$

After all algorithms worked with our dataset, F Measure based results shared in Figure 7 and Table 6.

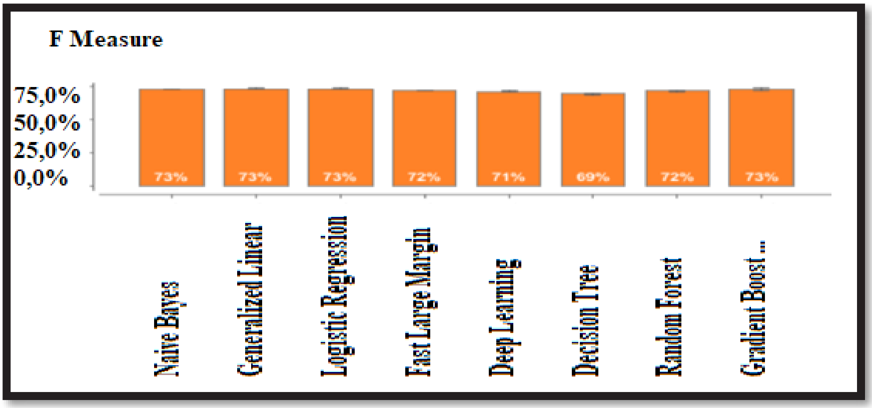

Figure 7. F Measure based success rates of all algorithms.

Table 6. F Measure based results of all algorithms.

Model	F Measure	Standard Deviation	Gains	Total Time	Training Time (1,000 Rows)	Scoring Time (1,000 Rows)
Naïve Bayes	0,726577	0,003765	25382,0	699452,0	1,3	54,1
Generalized Linear Model	0,732800	0,006241	25586,0	696467,0	5,5	73,0
Logistic Regression	0,732178	0,003199	25686,0	514505,0	4,7	56,3
Fast Large Margin	0,718608	0,002392	24998,0	926654,0	50,8	56,1
Deep Learning	0,706395	0,005015	24716,0	1115023,0	104,9	106,7
Decision Tree	0,692032	0,003805	23096,0	523277,0	2,0	85,7
Random Forest	0,715304	0,006225	10284,0	1024953,0	11,0	251,4
Gradient Boosted Trees	0,725726	0,007947	10472,0	936112,0	119,5	148,6

3.7. AREA UNDER CURVE (AUC) BASED RESULTS

ROC (Receiver-Operating-Characteristic-Curve) is a graph that calculates the correct positivity on the vertical axis and the false positivity on the horizontal axis, calculated for different threshold values. Area Under Curve is used as a benchmark for superiority of tests. After all algorithms worked with our dataset, Area Under Curve based results shared in Figure 8 and Table 7.

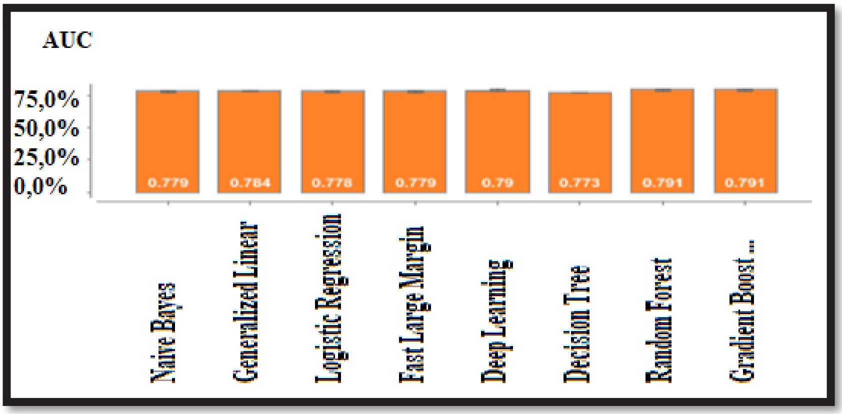

Figure 8. AUC based success rates of all algorithms.

Table 7. AUC based results of all algorithms.

Model	AUC	Standard Deviation	Gains	Total Time	Training Time (1,000 Rows)	Scoring Time (1,000 Rows)
Naïve Bayes	0,779166	0,002422	25382,0	699452,0	1,3	54,1
Generalized Linear Model	0,783586	0,002128	25586,0	696467,0	5,5	73,0
Logistic Regression	0,778040	0,001512	25686,0	514505,0	4,7	56,3
Fast Large Margin	0,779310	0,002495	24998,0	926654,0	50,8	56,1
Deep Learning	0,789668	0,002204	24716,0	1115023,0	104,9	106,7
Decision Tree	0,773046	0,001483	23096,0	523277,0	2,0	85,7
Random Forest	0,791139	0,004807	10284,0	1024953,0	11,0	251,4
Gradient Boosted Trees	0,790987	0,004761	10472,0	936112,0	119,5	148,6

4. CONCLUSION

Much artificial intelligence and machine learning methods are being tried to strengthen the signals obtained nowadays. In this study, eight different machine learning algorithms have been tried on the same dataset, and the success rates have been shared. The results obtained in our study are essential in order to predict which machine learning algorithm works with a higher success rate when the data obtained through MYO Armband. The studies to be carried out in this field are of great importance, primarily because they affect the amputee people.

The results obtained in our study can be expressed as follows: Logistic Regression stands out with a success rate of 72.55%. Although the Gradient Boosted Trees algorithm gives almost the same results, it fails when the Training Time and Scoring Time data are examined. When precision-based results are examined, Deep Learning algorithm has come to the forefront with a success rate of 75.89%. When recall based results are examined, the Generalized Linear Model has come to the forefront with a success rate of 73.34%. When sensitivity-based results are examined, the Generalized Linear Model with 73.34% success rate came to the forefront. When the Classification Error based results are examined, Gradient Boosted Trees came to the forefront with a rate of 27.42%. When the results are analyzed based on Specificity, Deep Learning algorithm came to the fore with 77.61%. When F Measure based results are examined, the Generalized Linear Model was successful with a success rate of 73.28%. Finally, when AUC-Based analysis was performed, Random Forest algorithm was used with a success rate of 79.11%.

ACKNOWLEDGEMENT

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Research Article

ON THE SPECTRUM OF A NEW CLASS OF GRAPHS[1*]

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ABSTRACT

The pineapple graph K_n^t is a graph of the form K_n (complete graph of order n) with $'t'$ pendant edge attached to any one vertex of K_n. In this paper, we determined the adjacency Laplacian and signless Laplacian spectrum of pineapple graphs. Here we investigate some graph invariants like the number of spanning trees, Kirchhoff index and Laplacian-energy-like invariants of these graphs.

Keywords: *Pineapple graph, Spectrum, Spanning tree, Kirchhoff index, Laplacian-energy-like invariant.*

AMS Subject Classification (2010) : *05C50*

1. INTRODUCTION

All graphs explained in this paper are undirected, without parallel edges and loops. Let $G = G(V, E)$ be a graph with vertex set $V(G) = \{v_1, v_2, \ldots, v_n\}$ and edge set $E(G)$. The adjacency matrix, $A(G) = (a_{ij})_{n\times n}$, is an $n \times n$ symmetric matrix with rows and columns are indexed by vertices of G where $a_{ij} = 1$ if the vertices v_i and v_j are adjacent in G, 0 elsewhere. The characteristic polynomial of A is of the form $f_G(A{:}\,x) = det(xI_n - A)$ where I_n is the identity matrix of order n. The roots of $f_G(A{:}\,x) = 0$ constitute the eigenvalues of G.

Let d_i be the diagonal degree of the vertex v_i in G and $D(G) = diag(d_1, d_2, \cdots d_n)$ be the diagonal matrix of G. The Laplacian matrix and signless Laplacian matrix of the graph G are defined as $L(G) = D(G) - A(G)$ and $Q(G) = D(G) + A(G)$ respectively. The eigenvalues of A,L and Q are respectively called the A-spectrum, L-spectrum and Q-spectrum of the graph G. Some new graphs are defined and their spectrum are calculated in [3, 6, 7, 8].

In this paper, we are interested in finding the Laplacian and signless Laplacian spectrum

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of the pineapple graphs. Also, as an application,we investigated the Kirchhoff index, the number of spanning trees and Laplacian-energy-like invariants of the pineapple graphs.

The arrangement of the paper in section wise as follows. Section 2, describes the necessary preliminaries. In section 3, we determine the Laplacian and signless Laplacian spectrum of pineapple graphs and some applications such as the number of spanning trees, Kirchhoff index and Laplacian-energy-like invariants of the graphs.

2. PRELIMINARIES

Definition 2.1 *A pineapple graph is a graph of the form K_n with t pendant edge attached to any one vertices of the complete graph K_n. We denote this graph by K_n^t.*

As we know K_n^t has $(n+t)$ vertices and $\binom{n}{2}+t$ edges. Also, we assume that $n \geq 3$ and $t \geq 1$.

Theorem 2.2 *[5, 9] The spectrum of the pineapple graph K_n^t with $(n+t)$ vertices consists of,*

- *(i)* -1, *repeated* $(n-2)$ *times*
- *(ii)* 0, *repeated* $(t-1)$ *times*
- *(iii)* *Three roots of the cubic* $x^3-(n-2)x^2-(n+t-1)x-(n-2)t=0$.

Proof. Let $G = K_n^t$ be a pineapple graphs on $(n+t)$ vertices. The adjacency matrix of G is,

$$A = \begin{bmatrix} 0 & J_{1\times(n-1)}^T & J_{1\times t}^T \\ J_{(n-1)\times 1} & J_{1\times(n-1)} - I_n & 0_{n\times t} \\ J_{t\times 1} & 0_{t\times(n-1)} & I_t \end{bmatrix},$$

where J is the all one matrix of appropriate order and I_n is the identity matrix of order n.

It can be proved that the characteristic polynomial of G is,

$$f_G(A{:}\,x) = x^{t-1}(x+1)^{p-2}(x^3 - x^2(n-2) - (n+t-1)x + t(n-2)).$$

Example : The following graph represents a particular example of pineapple graph.

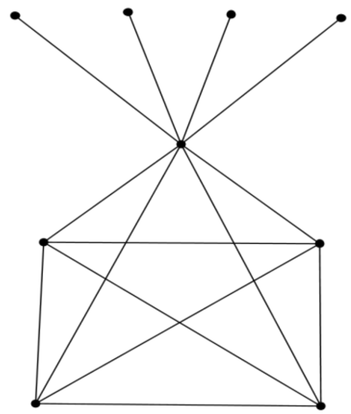

Figure 1: Pineapple graph K_5^4

3. LAPLACIAN SPECTRUM OF PINEAPPLE GRAPH

In this section, we determine the Laplacian and signless Laplacian spectrum of pineapple graphs.

Theorem 3.1 *Let K_n^t be a pineapple graph with $(n+t)$ vertices. Then L- spectrum of K_n^t consists of,*

(i) 0 ;
(ii) $n+p$;
(iii) 1, repeated t times;
(iv) n, repeated $(n-2)$ times.

Proof. Let t pendant vertices x_j, $j=1,2,\dots,t$ is attached to the vertex v_1 of the pineapple graph. The degree of the vertices of K_n^t are

$d(v_1)=n-1+t$,

$d(v_i)=n-1,\ i=2,\dots,n$ and $d(x_j)=1,\ j=1,2,\dots,t$.

The diagonal degree matrix of the pineapple graph is,

$$D(K_n^t)=\begin{bmatrix} n+t-1 & 0 & 0 \\ 0 & (n-1)I_{n-1} & 0 \\ 0 & 0 & I_t \end{bmatrix}.$$

The Laplacian matrix of K_n^t is,

$$L=D-A$$

$$= \begin{bmatrix} n+t-1 & -J^T_{1\times(n-1)} & -J^T_{1\times t} \\ -J_{(n-1)\times 1} & nI_{n-1}-J_{n-1} & 0_{n\times t} \\ -J_{t\times 1} & 0_{t\times(n-1)} & I_t \end{bmatrix},$$

Let 1_n denote the eigenvector corresponding to the eigenvalue $(n-1)$ of G, then $A.1_n = (n-1)1_n$.
Let $(\alpha, \beta 1_{n-1}, \gamma 1_t)$ be a non zero vector.

$$(n+t-1)\alpha - (n-1)\beta - t\gamma = x\alpha \tag{3.1}$$

$$-\alpha + \beta + 0.\gamma = x\beta \tag{3.2}$$

$$-\alpha + 0.\beta + \gamma = x\gamma \tag{3.3}$$

From equation (3.2), we get $\beta = \frac{-\alpha}{x-1}$.

From equation (3.3), we arrive at $\gamma = \frac{-\alpha}{x-1}$.
Substitute these values in (3.1), we get

$$(n+t-1)\alpha + \frac{(n-1)\alpha}{x-1} + \frac{p\alpha}{x-1} = x\alpha.$$

Since $\alpha \neq 0$ we arrive at,

$$(n+t-1)(x-1) + n - 1 + t = x(x-1)$$
$$nx - n + tx - t - x + 1 + n - 1 + t = x(x-1)$$
$$nx + tx = x^2$$
$$x^2 - (n+t)x = 0$$
$$x = 0, n+t.$$

Consider $U = \begin{pmatrix} 0 \\ 0 \\ X \end{pmatrix}$, where X is a $t \times 1$ vector.

$$LU = \begin{bmatrix} n+t-1 & -J^T_{1\times(n-1)} & -J^T_{1\times t} \\ -J_{(n-1)\times 1} & nI_{n-1}-J_{n-1} & 0_{n\times t} \\ -J_{t\times 1} & 0_{t\times(n-1)} & I_t \end{bmatrix} \begin{pmatrix} 0 \\ 0 \\ X \end{pmatrix}$$

$$= \begin{pmatrix} -J^T X \\ 0 \\ I_t X \end{pmatrix}$$

$$= \begin{pmatrix} 0 \\ 0 \\ X \end{pmatrix} = U.$$

Hence $\mu = 1$ is an eigenvalue corresponding to U, which repeats t times.
Consider $V = \begin{pmatrix} 0 \\ Y \\ 0 \end{pmatrix}$, where Y is a $(n-1) \times 1$ vector,

$$LV = \begin{pmatrix} -J^T Y \\ (nI - J)Y \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ nY \\ 0 \end{pmatrix} = nV.$$

Hence $\mu = n$ is an eigenvalue corresponding to V, which repeats $(n-1)$ times.
Thus the theorem is proved.

3.1 THE NUMBER OF SPANNING TREES

Spanning tree of a graph is a subgraph of it which is also a tree. The number of spanning tree of a graph G is denoted by $t(G)$. If G is a connected graph with n vertices and the Laplacian spectrum $0 = \mu_1(G) \le \mu_2(G) \cdots \le \mu_n(G)$ then [1] the number of spanning trees,

$$t(G) = \frac{\mu_2(G)\mu_3(G)\cdots\mu_n(G)}{n}. \tag{3.4}$$

Theorem 3.2 *Let $G = K_n^p$ be a pineapple graph with $(n+p)$ vertices. Then, $t(G) = t(K_n)$.*

Proof. Referring the notations used in Theorem 3.1.

The Laplacian spectrum consists of 1 repeated p times and n repeated $(n-2)$ times together with 0 and $(n+p)$.

Substituting these result in the equation (3.4) we get,

$$t(G) = \frac{\mu_2(G)\mu_3(G)\cdots\mu_n(G)}{n}$$

$$= \frac{1}{(n+p)}[(n+p).n^{n-2}]$$

$$= n^{n-2}.$$

We know that for a complete graph of order n, the number of spanning tree, $t(K_n) = n^{n-2}$.

Hence $t(G) = t(K_n)$.

3.2 KIRCHHOFF INDEX

Randić and *Klein* in [2] introduced a new notion named *resistance distance*, based on electric resistance in a network corresponding to a graph. Here the resistance distance between any two adjacent vertices is chosen as 1 ohm. By means of the Kirchhoff laws, the electric resistance is calculated and is called *kirchhoff index*. For a graph G with n $(n \ge 2)$ vertices the Kirchhoff index, $Kf(G)$, is defined as,

$$Kf(G) = n\sum_{i=2}^{n} \frac{1}{\mu_i}. \tag{3.5}$$

Theorem 3.3 *Let* $G = K_n^p$ *be a pineapple graph with* $(n+p)$ *vertices. Then,*

$$Kf(G) = 1 + \frac{(n+p)(np+n-2)}{n}.$$

Proof. We know that for a pineapple graph, the Laplacian spectrum consists of 0, $n+p$, 1 repeated p times and n repeated $(n-2)$ times by referring 3.1. Substituting these result in the equation (3.5) we get,

$$Kf(G) = n\sum_{i=2}^{n} \frac{1}{\mu_i}$$

$$= (n+p)\left[\frac{1}{n+p} + p + \frac{n-2}{n}\right]$$

$$= 1 + p(n+p) + \frac{(n+p)(n-2)}{n}$$

$$= 1 + \frac{(n+p)(np+n-2)}{n}.$$

3.3 LAPLACIAN-ENERGY-LIKE INVARIANT

A new graph invariant based on Laplacian spectrum called, Laplacian-energy-like invariant was defined by B. Liu and Liu in [4]. The Laplacian-energy-like invariant (LEL) of a graph G with n vertices is defined as,

$$LEL(G) = \sum_{i=2}^{n} \sqrt{\mu_i} \ . \tag{3.6}$$

Theorem 3.4 *Let* $G = K_n^p$ *be a pineapple graph with* $(n+p)$ *vertices. Then Laplace-energy-like invariant,* $LEL(G) = p + (n-2)\sqrt{n} + \sqrt{n+p}$.

Proof. Using the Theorem 3.1,

$$LEL(G) = \sum_{i=2}^{n} \sqrt{\mu_i}$$

$$= \sqrt{n+p} + p + (n-2)\sqrt{n}$$

$$= p + (n-2)\sqrt{n} + \sqrt{n+p}.$$

3.4 SIGNLESS LAPLACIAN SPECTRUM OF PINEAPPLE GRAPH

Here we find the signless Laplacian spectrum (Q-spectrum) of pineapple graphs.

Theorem 3.5 *Let* K_n^t *be a pineapple graph with* $n+t$ *vertices. Then* Q*-spectrum of* K_n^t *consists of,*

(i) 1, repeated $(t-1)$ times ;
(ii) $(n-2)$, repeated $(n-2)$ times;

(iii) Three roots of the cubic,

$$x^3 - (3n + p - 3)x + (n + p)(2n - 3)x - 2(n - 1)(n - 2) = 0.$$

Proof. The degree of the vertices of K_n^t are $d(v_1) = n - 1 + t,\ d(v_i) = n - 1,\ i = 2, \dots, n$ and $d(x_j) = 1,\ j = 1, 2, \dots, t$.
The diagonal degree matrix of the pineapple graph is, The signless Laplace matrix of K_n^t is,

$$Q = D - A$$

$$= \begin{bmatrix} n + t + 1 & J^T & J^T \\ J & (n-2)I + J_{n-1} & 0 \\ J & 0 & I_t \end{bmatrix},$$

We have the Q-spectrum of the complete graph K_n is $(n - 2)$, repeated $(n - 1)$ times and
$(2n - 2)$, repeated 1 time.

Consider $U = \begin{pmatrix} 0 \\ 0 \\ X \end{pmatrix}$, where X is a $t \times 1$ vector.

$$QU = \begin{bmatrix} n + t + 1 & J^T & J^T \\ J & (n-2)I + J_{n-1} & 0 \\ J & 0 & I_t \end{bmatrix} \begin{pmatrix} 0 \\ 0 \\ X \end{pmatrix}$$

$$= \begin{pmatrix} JX \\ 0 \\ I_t X \end{pmatrix}$$

$$= \begin{pmatrix} 0 \\ 0 \\ X \end{pmatrix} = U.$$

Hence $\nu = 1$ is an eigenvalue corresponding to U, which repeated $(t - 1)$ times.

Consider $V = \begin{pmatrix} 0 \\ Y \\ 0 \end{pmatrix}$, where Y is a $(n - 1) \times 1$ vector,

$$QV = \begin{pmatrix} JY \\ \big((n-2)I + J\big)Y \\ 0 \end{pmatrix}$$

$$= \begin{pmatrix} 0 \\ (n-2)Y \\ 0 \end{pmatrix} = (n - 2)V.$$

Hence $\nu = n - 2$ is an eigenvalue corresponding to V which repeated $(n-1) - 1 = n - 2$ times.
So there are $n - 2 + t - 1 = n + t - 3$ eigenvectors of Q.
The remaining four eigenvectors of Q are of the form $(\alpha, \beta 1_{n-1}, \gamma 1_t)$ for some $(\alpha, \beta, \gamma) \neq 0$.
Let x be an eigenvalue of Q corresponding to $(\alpha, \beta 1_{n-1}, \gamma 1_t)^T$ we get a system of equation,

$$(n + t - 1)\alpha - (n-1)\beta + t\gamma = x\alpha \tag{3.7}$$

$$\alpha + (n - 2 + n - 1)\beta + 0.\gamma = x\beta \tag{3.8}$$

$$\alpha + 0.\beta + \gamma = x\gamma \tag{3.9}$$

From equation (3.8), we get $\alpha = x - 2n + 3\beta$, then we get $\beta = \frac{\alpha}{x-2n+3}$.
From equation (3.9), we arrive at $\alpha = x - 1\gamma$, which implies $\gamma = \frac{\alpha}{x-1}$.
If $\alpha = 0$ then $\beta = \gamma = 0$. So assume $\alpha = 0$.
Substitute the value of β and γ in equation (3.7) we get,

$$(n + t - 1) + \frac{(n-1)\alpha}{x-2n+3} + \frac{t\alpha}{x-1} = x\alpha.$$

$$(n + t - 1)(x - 2n + 3)(x - 1) + (n - 1)9x - 1) + t(x - 2n + 3) \\ = x(x - 1)(x - 2n + 3).$$

On simplifying we get,

$$x^3 - (3n + t - 3)x^2 + (2n^2 + 2nt - 3n - 3t)x - 2(n^2 - 3n + 2) = 0.$$

From these arguments, all the spectral values are calculated.

4. CONCLUSION

Determining and analysing the spectrum of graphs is an important and exciting research topic in Mathematics and in theoretical Computer Science. Several graph spectra are introduced by researchers to get deep information about a graph. The main idea of spectral graph theory is to exploit the relation between graphs and matrices. This is possible with the help of eigenvalues and eigenvectors of some graph matrices. In addition to this, we determined such spectrum of pineapple graphs. Also, we investigate some graph invariants like the number of spanning trees, Kirchhoff index and Laplacian-energy-like invariants of such graphs.

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