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A Decision Support System for Multi-Objective Porcelain Container Loading Problem Based on Genetic Algorithm

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Abstract

The multi-objective genetic algorithm approach for solving the Porcelain Container Loading Problem (PCLP) has a vital role in the global logistics industry. In this paper, a logistical problem with one constrained container loading problem that has to be filled with a set of boxes has been the focus. This study addresses a real-life problem that exports departments in the international porcelain industry face. Our objective is to maximize product profitability and delivery priority. Since the CLP is known as an NP-hard problem, the Genetic Algorithm (GA) approach is proposed to solve the problem based on these objective functions. The parameters of the GA affect the obtained results. We made tuning by using an experimental design in order to determine the appropriate parameters. The main contribution of the study is to present a new decision support system taking into account the objectives of the delivery time and profit rate priority of the manufacturer in the porcelain sector. Thus, loading according to the company's priority and distribution in the shortest distance has been successfully achieved. The results show the efficiency of the proposed decision support system, which solves the CLP with up to 12 different products in boxes of different volumes.

Keywords: Decision support system for porcelain industry, container loading problem, experimental design, multi-objective problem.

1. INTRODUCTION

In a competitive worldwide market, studies regarding the decision support system offering solutions and suggestions for Container Loading Problem (CLP) and Routing Problem (RP) in industrial and commercial decision-making processes are pretty critical [1]. The goal of the CLP is to put a set of orthogonal boxes to a limited capacity area called containers [2]. Containers are delivered with the optimal routes from depots to several cities or customers by considering some constraints [3]. When the literature is examined, CLPs are classified into two main groups [4, 5]. Studies in the first group are based on the minimization problem, where the storage space is sufficient to load all the boxes. The objective function is to minimize the number of containers required to load all available boxes. In the studies of the second group, the issue is the problem of output maximization. It is not possible to load all the boxes for a limited volume of container area. Therefore, the goal is to choose a box subset that maximizes the volume or value associated with the load.

The CLP is a type of knapsack problem formulated as considering limited container capacity, being one of the fundamental problems in combinatorial optimization and CLP is classified under the category of NP-hard problem [6-8]. It has crucially significant applications in the packaging and transportation industries. This study focuses on road transportation in the porcelain industry, mainly consisting of single container loading. For loading, a set of rectangular boxes of known dimensions is used in a limited container. This paper presents a decision support system based on the multi-objective genetic algorithm (GA) approach to assist decision-makers in generating an optimized solution for the Porcelain Container Loading Problem (PCLP). The objective of the proposed approach is to maximize the profit of the product loaded and the priority of delivery to enhance customer satisfaction.

As a result of this study, a decision support system based on the multi-objective GA approach for solving the CLP was developed for manufacturers in the porcelain sector, taking into account the priority of delivery time and profit rate. Loading according to the company's priority and distribution in the shortest distance has been successfully achieved. Sensitivity analysis was performed considering the different objective weights of each objective. Thus, it is ensured to perform the loading process with a container occupancy rate of 98.19% for the appropriate weight combination of the objectives. After loading the container, the container was

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routed considering the shortest distance among all distribution centers.

The paper is organized as follows: Section-2 provides a brief overview of PLCP-related work for the loading and routing process. Section-3 presents an overall definition of the problem. In Section-4, the problem is defined by applying a bi-objective mathematical model. In Section-5, a MOGA-based approach is proposed. Section-6 indicates the proposed DSS with an example based on a real-life problem in the porcelain industry. Section-7 presents sensitivity analysis performed by considering the different weights of objective functions. Finally, Section-8 provides the conclusion and suggestions for the future.

2. CONTAINER LOADING PROBLEM

Container loading contains the cutting and packing problem, which is an NP-hard problem. Wäscher et al. [5] proposed the typology for cutting and packing problems, classifying the problems according to dimensionality, the assortment of large or small items, the kind of assignment and the shape of small items [12]. Whether the assortment is strongly heterogeneous (many species) or weak heterogeneous (several species) is usually related to the variety and number of large and small items. The studies on assignment problems in the literature focus on two main objectives. The first group of studies, the number of containers not being enough to cover the entire load, aims to increase the number of loads to the maximum level, while the second group of studies aims to minimize the cost of containers when there are enough containers [12-14]. Bortfeldt and Wäscher [15] suggested a classification of container loading problems for real-world constraints. They mention distinctions between: container-related constraints (weight limits, weight distribution); item-related constraints (loading priorities, orientation, stacking); cargo-related constraints (complete shipments, allocation); positioning constraints; and load-related constraints (stability, complexity). The solution suggestions for container loading problems are to place the dimensions of n boxes with height, length and width information in a certain container. Following the settlement comes the objective to minimize the space in the container and maximize the container volume [16]. Zhao et al. [17] examined the container loading problems in 14 different sub-categories, depending on the type of container and cargo, yet it was stated that the main purpose was to fill the container as fully as possible according to the constraints.

Decision support systems (DSSs) assist decision-makers in decision-making processes related to the problems that may be rapidly changing and not easily specified in advance result reporting, operation management, process evaluation, etc. Especially in the last decade, DSS has been preferred because it has made the decision-making process more manageable. Thus, the design of the DSS interface is crucial for decision-makers. Many container loading studies are based on decision support systems in the literature [18-24].

The algorithm in the DSS is mainly based on mathematical modelling and metaheuristic methods. The framework of DSS is constructed considering objective functions and constraints in mathematical modelling. In CPL, a mathematical model has also been developed for container capacity utilization and departure times of loaded vehicles [25].

In this study, a user-friendly DSS based on a multi-objective Genetic Algorithm (GA) approach was proposed in the search for a solution to the capacity management problem in the container terminal, aiming at presenting a better service level to the customers in the porcelain sector. This DSS based on metaheuristic algorithm considers two objective functions: simultaneously maximizing product profitability and delivery priority. There are many studies about the container loading problem during the past decade, as shown in Table 1. It has been limited research, including both multi-objective function and DSS. To the best of our knowledge, such a case study applied to the porcelain sector has not been done before. It is thought that DSS will contribute to container loading problems, particularly in the porcelain sector.

Although the CLP has widely been studied in the literature as seen in Table 1, there is not any investigation on a study applied to the porcelain sector as it is done in this study. Production priorities in the porcelain industry are constantly changing due to profitability, customer satisfaction and storage constraints. Depending on these situations, the order of shipment transactions varies. For this reason, there is a need for decision support systems for container loading operations, and solution proposals containing decision support systems should be optimized with artificial intelligence-based algorithms. With the use of the container loading and vehicle routing software suggested in our study, it is predicted that time savings, ease of inspection, effective planning and profitability will increase in the loading and delivery processes in the porcelain sector and other sectors.

3. PROBLEM DEFINITION

In this study, a decision support system is proposed for the problems of loading and shipping goods for "Kütahya Porselen Industry Incorporated", one of the world's largest porcelain manufacturers. The company presents both modern and exclusive designs to its consumers in the international arena. There are kitchenware products such as dinner sets, cup sets, bowls, mug sets, etc. Special decorative porcelain products such as handmade vases, paintings, etc. based on customer demands. However, unique decorative porcelain products are shipped to the customer using special cargo companies instead of containers and boxes with different volumes. These boxes are placed on pallets in the packing department. The pallets are lifted via a forklift and placed in the container. As seen in Figure 1, in the porcelain industry (01), products (02) that will be delivered are sent to the storage area (04) after the packing process (03). The loading (06), considering the delivery time (05) of the products, are routed (08) by taking into account the shortest route between the depots to be distributed (07).

Table 1. The summary of the related research

Ref.	Scope of the Research	Solution Method	Number of Objective Functions			DSS
			Single	Bi	Multi	
[3]	Air cargo operations	Literature Review				
[4]	Integrating pricing and capacity decisions in car rental	MM		√		√
[5]	Automating the planning of container loading for Atlas Copco	GA		√		√
[6]	Logistics Problems in Smart-City Environments	Unbalanced version of the Hungarian algorithm & Hybrid GA	√			√
[7]	A capacity management problem at a container terminal	Tabu Search Algorithm	√			√
[8]	The stowage of maritime containers in inland shipping	MM & Hybrid VNS and Greedy Search	√			√
[9]	Integrated container handling in a transhipment hub	Queuing model & Simulation			√	√
[9]	The air cargo load planning problem	Literature Review				
[10]	Internal and external transportation	MM & GA	√			
[11]	Container Stacking Problem	A GRASP-based metaheuristic		√		√
[12]	Container Stacking Problem	Reward-based Stacking Algorithm			√	
[13]	Intelligent agent system for efficient logistics transport	Integrated NSGA-II & SA	√			
[14]	Cargo transportation by truck	Physics simulation tool & Multiple regression analysis	√			√
[15]	Priority-based container loading problem	Hybrid GA & FLC	√			
[16]	Planning the route of container ships	A fuzzy genetic approach			√	
[17]	3-D container loading problem	Biased random-key GA			√	
[18]	Output maximization container loading problem	Stochastic dynamic programming		√		

Abbreviations: DSS: Decision Support System, MM: Mathematical Model, VNS: Variable Neighborhood Search, FLC: Fuzzy logic controller, NSGA-II: Non-dominated Genetic Algorithm II, SA: Simulated Annealing

Figure 1. Flowchart of container loading & routing in the porcelain industry

In this study, the container loading problem was studied by considering the container capacity constraint with two factors to be maximized simultaneously: the priority delivery date and the profitability of each product. The container capacity was set as the volume of the container. This volume is the 20ft container size in the company. For the objective function value calculation of the priority delivery date, products are ranked in ascending order according to the lead time of each product. Then, the coefficient value is assigned from a large value to small value. This calculation provides a high priority to products of which delivery due date is near or delayed. Thus, it is aimed to ensure customer satisfaction.

The other objective function is value computation, and it is required to load the products having high-profit margins per product. The weighted sum scalarization method was used to convert into a single objective. Since the weights of each objective function affect the obtained results, the sensitivity analysis was carried out based on the different weights of the objectives. Depending on the objectives and constraints, the routing is designed by considering the distances from the depot to the cities after the container is loaded. The following assumptions are taken into consideration.

(1) Loading is made based on the volume of the boxes.
(2) All the loads in the boxes are considered to be consisting of porcelain dinner sets (the items in the set can be packed separately).
(3) The volumes of the pallets used for the calculations are neglected.

In this research, the operational decision support system software based on the multi-objective genetic algorithm approach was used to solve the container loading problem. The multi-objective GA approach based on DSS for PCLP system architecture is shown in Figure 2.

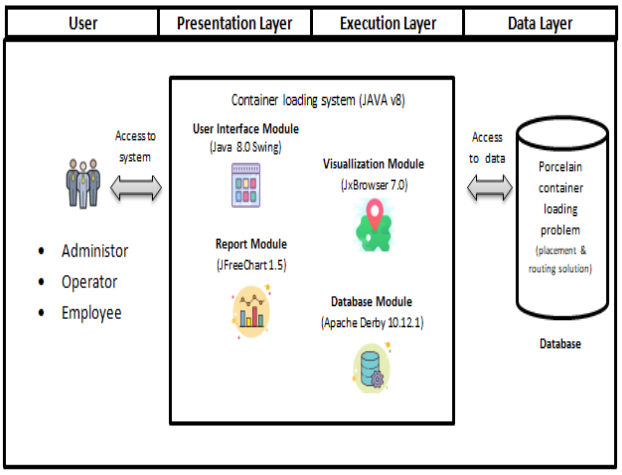

Figure 2. The multi-objective GA approach based on DSS for PCLP System Architecture

4. BI-OBJECTIVE MATHEMATICAL MODEL

Many studies propose mathematical programming, heuristic and metaheuristic approaches to solve container loading problems [27]. In this study, firstly, the problem is defined using a bi-objective mathematical model, and then, a multi-objective metaheuristic approach is presented for solving the PCLP.

The bi-objective mathematical model of the PCLP needs optimization of the priority delivery date and the profitability of each product simultaneously subject to the following constraints:

Indices:
i: Product index i=1,2,…,n

Parameters:
q_i: The profit rate of product *i*
t_i: The priority value of the product *i* by the delivery time
v: Volume of the container

Decision variables
x_i: The quantity of the product *i* loaded into the container
y_i: 1, if the product *i* is loaded into the container and 0 otherwise

$$Max\left\{\sum_{i=1}^{n} q_i x_i y_i\right\} \text{ and} \quad (1)$$

$$Max\left\{\sum_{i=1}^{n} t_i x_i y_i\right\} \quad (2)$$

Subject to:

$$\sum_{i=1}^{n} w_i x_i y_i \le v \quad (3)$$

$$y_i \in \{0,1\} \,\&\, x_i \ge 0 \quad (4)$$

Eq. (1) maximizes the product profitability, while Eq. (2) maximizes a high-profit margin per product. Eq. (3) provides the container capacity constraint. Eq. (4) defines both positive and binary variables. The objective functions are converted into a single objective through Eq. (5).

$$Max\left\{w_1\sum_{i=1}^{n} q_i x_i y_i + w_2\sum_{i=1}^{n} t_i x_i y_i\right\} \quad (5)$$

Subject to:

Equations 3-4 are all satisfied.

w_1 and w_2 represent the significance weights of the objective function. $w_1+w_2=1$ and $w_1, w_2 \ge 0$ should be provided.

5. PROPOSED MULTI-OBJECTIVE GENETIC ALGORITHM

Traditional approaches solve multi-objective problems, including dynamic programming, random methodologies, and gradient approaches, whereas modern heuristic methods include cognitive paradigms such as artificial neural networks, simulated annealing, and Lagrange approaches. Some of these methods are used to find (approximately) optimal solutions, but convergence times can be longer than estimated. For this reason, the multi-objective GA approach is implemented based on the principles of natural biological evaluation, and (approximately) optimal solutions are obtained [30]. Since container loading problems are called NP-hard problems [6-8] in the literature, we proposed a metaheuristic algorithm to solve these problems. In our study, the genetic algorithm begins with the initial population, and then the fitness values are computed considering the maximization of product profitability and delivery time. After calculating the fitness values, the selection, crossover, and mutation operator are applied to each solution. The multi-objective genetic algorithm is run until the termination criteria are satisfied. Thus, the best solution is obtained at the end of the algorithm.

Algorithm 1 illustrates the solution of the multi-objective GA approach for the PCLP. The following sections depict the components of the multi-objective GA design in detail.

Algorithm 1 Pseudo-code of the proposed algorithm

Randomly generate an initial population
Compute the fitness of each individual
while termination criteria are not satisfied, **do**
  Choose parents from the population ← (population, tour size)
  Perform crossover to produce offspring← (one-point crossover, parents)
  Perform mutations ← (bit-flip random, offspring)
  Calculate the fitness of each individual
  Replace the parents with the corresponding offspring in a new generation
end while
  Return the best solution

5.1. Chromosome representation

In this section, a chromosome is designed to represent the solution to our problem. As a sample, a set of 12 different

products is used. The chromosome representation consists of five vectors ($v_i(t)$, i=1, 2, …, 5; t=1, 2, …, 12) as follows:

(1) $v_1(t)$, whether the product is loaded in the t position,
(2) $v_2(t)$, how many amounts the loaded product is in the t position,
(3) $v_3(t)$, the volume of the box of the loaded product in the t position,
(4) $v_4(t)$, the delivery priority of the loaded product in the t position,
(5) $v_5(t)$, the profit of the loaded product in the t position.

v_1 consists of the 0 or 1 values and is randomly assigned to the t position. The value 1 means that the product is loaded and otherwise not loaded. In vector v_2, the amount of that product is determined. For this calculation, a randomly generated value between at least half of that amount and the available amount of that product is used for each position. The available value is set as the demand value of the customers. The volume of each product set is defined in vector v_3. A priority value is assigned a coefficient value according to the proximity of the delivery date in the vector v_4. In this computation, products are ranked in ascending order according to the lead time of each product. Coefficient value is assigned to small value from large value. If two or more products have the same delivery date, the same priority value can be assigned (as seen in the 3rd and 11th positions in Figure 3).

In the case of products with delayed delivery, a value with the highest priority is assigned as a coefficient value. The vector v_5 shows the profit margin per product. The solution representation includes the vectors v_1 and v_2, while the others are the supported data constructors. The chromosome representation containing these vectors is shown in Figure 3. As a sample, Figure 3 shows that the second product is loaded because a value in the second position is 1 in the vector v_1. In the vector v_2, 292 items are loaded from the second product. It is computed as 292x3000 cm3 because the volume of each of the second products is 3000cm3.

Position: t	1	2	3	4	5	6	7	8	9	10	11	12
$v_1(t)$	0	1	1	1	1	1	0	1	1	1	1	0
$v_2(t)$	199	292	96	106	461	1085	374	180	1579	838	1499	7
$v_3(t)$	1000	3000	250	4050	1520	1500	3500	4505	5000	3000	6700	7500
$v_4(t)$	1	5	8	9	7	10	2	6	3	4	8	11
$v_5(t)$	1	2	5	4	3	2	4	7	6	4	3	7

Figure 3. DSS based on the multi-objective GA approach for PCLP Architecture

5.2. Evaluation of fitness function

There are many studies on the performance of genetic algorithms and traditional methods in the literature. However, most of these do not include enough information about the fitness function used by the genetic algorithm, whereas the fitness function affects the entire performance of the model [17]. The larger the fitness function value (for the maximization problems), the better the performance of the chromosome. After calculating the objective values for the priority delivery date and the profitability of each product, the weighted-sum scalarization method (WSM) is used to convert into a single objective. WSM proposed by Miettinen [18] is the most popular scalarization method for Pareto efficient solutions using Eq. (5).

Population initialization is vital for evolutionary algorithms as it can affect the speed of convergence and the quality of the result [19]. In this study, random population initialization is used to generate better solutions.

5.3. Genetic operators

Genetic operators are essential for the diversification of the population. Operators of mutation, elitism, selection, and crossover are adapted to provide a feasible solution to the research problem.

Crossover operator; the crossover operator enables generating better chromosomes through gene exchange. In the crossover example in Figure 4, the crossover point is randomly selected between 1 and the length of the chromosome l. In the two paired sequences, the sections after this cross-section are replaced, and two new offsprings are obtained.

Mutation operator; the main purpose of the mutation is to keep the population diverse. The bit-flip mutation operator is utilized to optimize functions over binary strings in this study. If the generated value between 0 and 1 is smaller than the mutation rate, the allele of the gene is changed from 0 to 1 or 1 to 0. This process is implemented for each gene between 1 and the length of the chromosome l.
Selection operator; employing a good selection operator ensures the probability of the survival of the best individuals. There are many standard selection operators in the literature, such as roulette wheel selection, rank-based selection, tournament selection, and seed selection. At this stage, tournament selection is used because of better convergence and computational complexity [20].

Elitism; this operator ascertains that the fittest chromosomes preserve from one generation to the following and guarantees that their characteristics cannot be lost after crossover and mutation operations [21].

5.4. Setting the parameters of the multi-objective GA

Since the multi-objective GA parameters impact the results, a full factorial experimental design is used to determine the appropriate parameters. Parameter tuning of a genetic algorithm can significantly affect the performance of the algorithm [31]. The steps for the application are presented as follows:

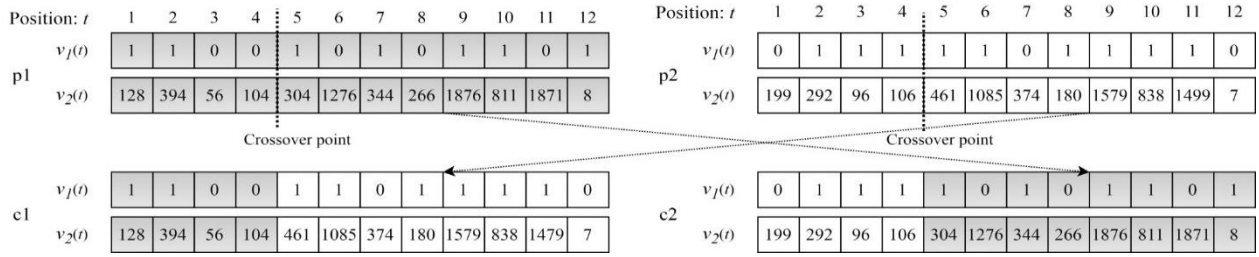

Figure 4. Chromosome representation of the proposed model

Step 1: Determination of the appropriate parameters in the multi-objective GA approach, 12 different product data were taken from the company's delivery process in the porcelain industry.

Step 2: Population size, crossover rate, mutation rate, and tournament size are selected as the main factor. Factors and levels are given in Table 2.

Table 2. Factors and levels for the multi-objective GA approach

Factors	Level 1	Level 2	Level 3
Population size	30	50	70
Crossover rate	0.6	0.8	1.0
Mutation rate	0.05	0.10	0.15
Tournament size	3	5	7

Step 3: To investigate the factors' effectiveness, 81 (3 × 3 × 3 × 3) different experiments were conducted. In addition, the result of each experiment is determined based on independently 31 runs to provide the accuracy of the solutions. Thus, the number of experiments required for this problem was computed as 2511 (81 × 31). Based on the convergence graph given in Figure 5, the stop criterion was determined as 1000.

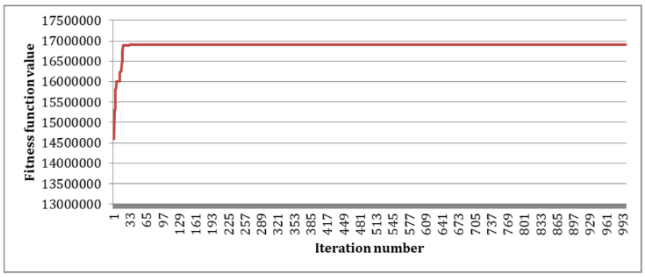

Figure 5. The graph of the convergence

Step 4: The variance analysis was performed by using Minitab 18 software. The main effect plot of this problem is shown in Figure 6. As a result of the variance analysis, Population size (Pop size), Crossover rate (Cross_rate), Mutation rate (Mut_rate), and Tournament size (Tour size) are obtained as 70, 1.0, 0.1, and 3, respectively. In this section, the weights of objective functions are considered as w1=0.5 and w2=0.5.

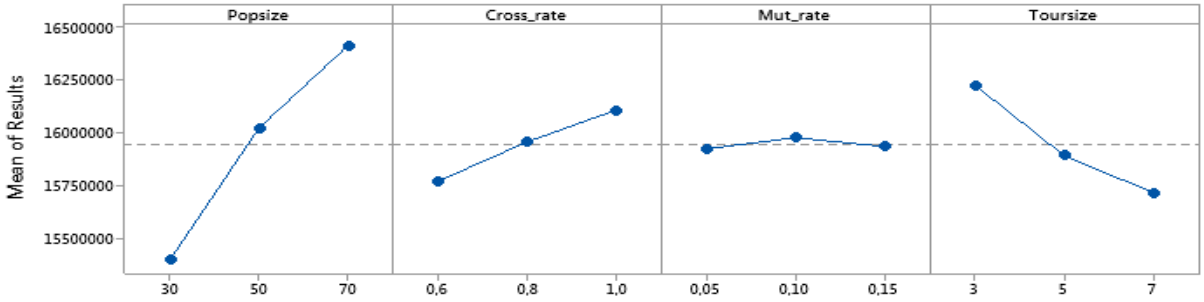

Figure 6. Main Effects Plot for w1=0.5, w2=0.

6. EVALUATION OF THE PROPOSED DECISION SUPPORT SYSTEM

The conceptual design and improvement of a Decision Support System (DSS) for the strategic design are essential for managing operative activities in a porcelain industry system. This section indicates the use of the proposed DSS via a real-life problem in the porcelain industry put forth here as an example. A two-stage DSS was suggested in this research. The container loading process is implemented using the multi-objective GA approach with suitable parameters in the first stage. Then, the container is routed to the determined cities. To illustrate how the DSS is used, the example of 12 different products is presented. Dealers mainly demand these products among product categories produced in the porcelain factory. In this sample, the products are distributed to dealers in 10 different cities in different regions throughout Turkey. The steps for solving the problem in DSS software are as follows:

Step 1: In the first stage, the data belonging to each product, such as barcode number, material number, material name, delivery date, quantity, destination city, and depot, as shown in Figure 7, are entered.

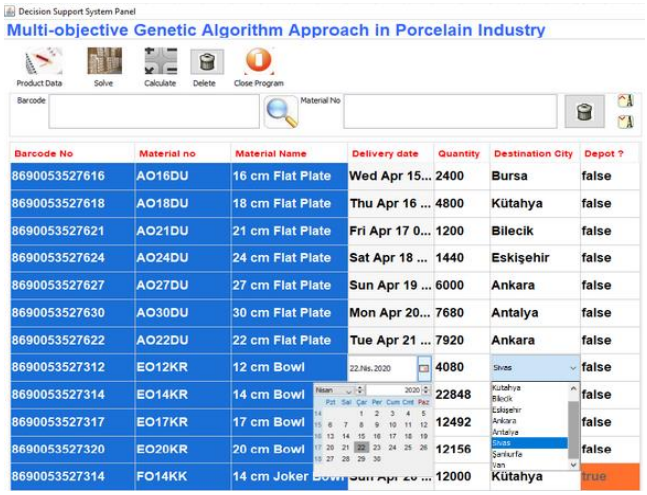

Figure 7. Data entry screen

Step 2: The list of destination cities is included in the combo box. The destination city of each product is selected from the combo box. Since it has to be one depot, it should be marked as one of the destination cities listed as a depot. Therefore, that city on the depot column is selected as true (see Figure 8).

Figure 8. Depot city selection

Step 3: As seen in Figure 9, all parameters of the genetic algorithm are entered.

Figure 9. Sensitivity analysis based on objective weights

Step 4: The type of container is determined among the related choices (see Figure 10).

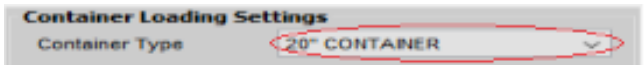

Figure 10. Container loading setting

Step 5: In the container loading process, the weight data are processed in the relevant areas of the software. These values show the weights of objective functions: product profitability and delivery priority (see Figure 11).

Figure 11. Weights of objectives

Step 6: The route is constructed by Dijkstra's algorithm to find the shortest path among the cities. After this solution process is completed, the routing is created. Along with the traffic information of the created route, the Google map is displayed to the decision-maker (see Figure 11).

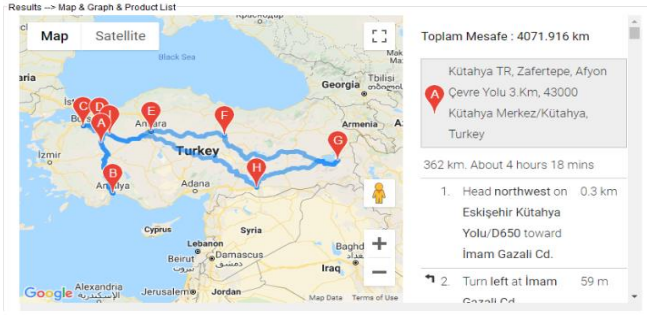

Figure 12. Display of the determined route

Step 7: After the DSS is run, the selected products, the amount of that product, and the routing are obtained. These results are presented to the decision-maker. This report provides the decision-maker with assistance for the management of operative activities and processes.

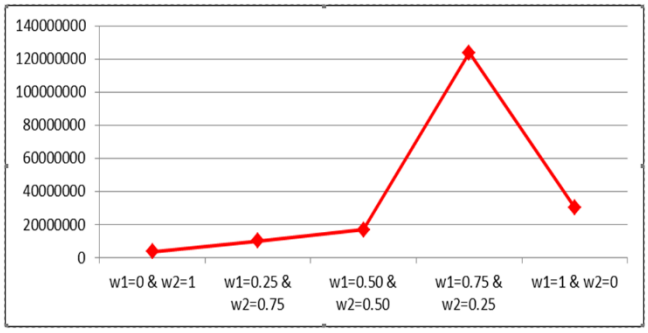

Figure 13. Sensitivity analysis based on objective weights

The screen output based on the sample problem is presented in Figure 13. Thus, the factory management decides to load and route the container according to the obtained results. As illustrated in Figure 13, the maximum fitness value is obtained at w1=0.75 and w2=0.25.

7. CONCLUSIONS AND FUTURE WORK

This research examined the Porcelain Container Loading Problem (PCLP) in Kütahya Porselen Industry Incorporated. Due to the NP-hardness of our model, a multi-objective genetic algorithm (GA) approach was proposed in order to load the container, considering two objective functions such as maximization of both product profitability and delivery priority simultaneously. The decision support system (DSS) software based on the multi-objective GA approach was developed to obtain prompt and high-quality solutions for the PCLP. This software was coded in the JAVA programming language. With the help of the software, decision-makers do not need to know any methods to obtain the results. The parameters of the multi-objective GA affect

the obtained results. Therefore, in order to determine the appropriate parameters, we conduct tuning by using an experimental design. Sensitivity analysis was executed to test the effects of the objectives' weights on the obtained results. This problem needs to be solved for future research to be compared with the results obtained from other methods. The different objective functions and constraints are added to the model.

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Prediction of Demand for Red Blood Cells Using Artificial Intelligence Methods

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Abstract

Blood is a vital product with limited resources, available only from volunteers. For this reason, the blood components to be sent from the blood bank to the transfusion centers (hospitals) should be accurately predicted. There are many variables that affect the demand prediction. In this study, fifteen different qualitative and quantitative variables were determined. Artificial intelligence (AI) methods are used because the prediction has nonlinear, complex and uncertain relationships and thus it is also difficult to mathematically express on relationship in between input and output variables. AI methods have the feature of predicting the information that is not given or that may occur in the future by learning the past data. In the study, AI methods such as Decision Tree (DT), Support Vector Machine (SVM), Artificial Neural Network (ANN) and Deep Learning (DL) were applied to blood bank providing blood supply to public and private hospitals operating in four provinces. The data obtained from the prediction results of AI methods were compared with performance criteria (MAPE, MSE, MAE RMSE and R^2) and values of overprediction, underprediction, minimum and maximum deviation. The weekly average over predictions are calculated as 9.69, 5.29, 8.45, and 15.65 and weekly average underpredictions as 17.57, 3.03, 3.94, and 14.69 for DT, SVM, ANN, and DL methods, respectively. SVM method was determined as giving the best prediction values. Therefore, it is envisaged that the blood component demand prediction can be calculated using the SVM method.

Keywords: Demand prediction, decision tree, support vector machine, artificial neural network, deep learning.

1. INTRODUCTION

Blood transfusion is an important part of contemporary medicine. 85 million blood transfusions are carried out annually across the globe, which translates to three blood transfusions per second approximately [1,2]. Therefore, sustainable blood donation provided is important. However, measures implemented due to epidemics such as COVID-19 and people's reluctance to go to donation centers reduce blood donation, but the need continues. In addition, although the need for blood increases in disasters such as earthquakes, floods and mass fires, donations decrease in the disaster area. In this case, the most important problem is making the demand prediction correctly. For this reason, blood banks must be sent enough blood components to the hospitals and the disposal of blood components must be prevented due to the expiration date.

Some difficulties on prediction of blood need:

- Blood is an urgent and vital need,
- Demand quantity is uncertain,
- Demand time is uncertain,
- Donation quantity is uncertain,
- Donation time is uncertain,
- Preparation of blood components is time-consuming and the processing time of the blood taken is uncertain because it is affected by external factors,
- Short storage period,
- Storage area requires special conditions,
- High storage cost,
- Different blood groups depending on the blood grouping system,
- It is the necessity of meeting some blood component needs from fresh blood, not from old blood due to special circumstances. For example, the blood component to be given to a premature baby should be selected from the blood of the appropriate donor.

Prediction models can reduce mistakes when deciding about how much blood to donate and produce, making possible better accuracy of product supply from a perspective of time and amount needed. Moreover, predicting reduces a part of uncertainty, so decision-makers establish more realistic production plans. Predicting and stock management methods achieve improving blood inventory management efficiency.

The number of blood component to be demanded from blood banks is usually predicted using quantitative methods in the literature [3,4]. The methods mostly predict based on similar

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quantitative variables such as age, blood group and gender. But, the number of blood component demand is heavily influenced by the outside world and is constantly changing. The quantitative prediction methods are not sufficient since the uncertainty is too high, the parameter values affecting the inventory cannot be known precisely and demand can be predicted within the framework of probabilities. It is not possible to manually process and analyze real, large, complex, and contradictory data. In this study, the prediction of red blood cells (RBCs) demand has nonlinear, complex, and ambiguous relationships. Also, expressing the relationship between input and output variables is difficult with a mathematical equation. For this reason, AI prediction methods are used to predict information that is not given to it by learning historical data or that may occur in the future. Several studies have focused on using AI methods to predict blood component demand in the literature. Decision tree [5], support vector machines [6-8], artificial neural network [9-11], and deep learning [12-14] methods are frequently used in prediction models.

In the study, it is aimed is to determine the suitable variables and determine the AI method that predicts the optimum demand and minimizes overstock and shortage. It is aimed to make predictions by taking into account the variables that have not been taken into account in the literature that will affect the prediction. The inputs of the models dealing with the blood demand constitute variables related to human biology such as age, blood group, gender in the literature. However, blood component demand is a dynamic process that is affected by the external environment. Therefore, fifteen different variables such as the number of operations, the population of provinces, and temperature are determined in the study, unlike other studies. In the literature, no study has examined the external variables that affect RBCs demand. Then it is explored which AI method predicts the optimum demand using determined variables. Predictions of the determined AI methods were compared on a weekly, unit, and average basis. As a result of the comparisons, it was determined that the most appropriate prediction method was the support vector machine.

This paper was organized as follows. Material and methods were explained in section 2. The application was described and applied to the data set obtained from a blood bank in Turkey in section 3. In section 4, the overstock and shortage results in the blood bank inventory were compared. In final section 5, the conclusion was summarized.

2. MATERIAL AND METHODS

2.1. Material

Red blood cells (RBCs) which are a life-saving component are used to treat emergency patients [15] and also it has the highest demand among blood components (Table 1).

According to Table 1, 74449 units of RBCs were requested from the blood bank from June 2019 to June 2020. Therefore, the sample size of the data group to be used in prediction methods was predicted to be at least 382 with a 95% confidence level [16]. To better represent the sample size of the population, this study was carried out with 5 transfusion centers, which includes 45000 of the RBCs demand.

Table 1. The number of blood components requested from blood bank (from June 2019 to June 2020)

	RBCs	FF	PS	TOTAL
Amount(units)	74449	33333	15443	123225
Percentage(%)	60.417	27.051	12.532	100

FF: Fresh frozen plasma, PS: Platelet suspension, TOTAL: Total blood component amount

2.2. Methods

AI methods such as decision tree, support vector machine, artificial neural network and deep learning are applied to blood bank providing blood supply to public and private hospitals operating in four provinces.

2.2.1. Decision tree method

Decision tree (DT) is one of the most popular machine learning methods because it is the ability to generate understandable knowledge structures, and handle symbolic and numeric input variables, provisioning a clear indication of which attributes are most important for prediction or classification. It has also a low computational cost when the model is being applied to predict or classify new cases.

DT method brings data with similar criteria to the same class or predicts by applying a set of decision rules to a data set containing many criteria. The most important step is deciding which criteria and how to divide all nodes starting from the root nodes [17]. Therefore, split criteria such as entropy, Gini index, and information gain are calculated.

Entropy is a split criterion of uncertainty that deals with the occurrence of events. It takes values between 0 and 1. If the entropy value approaches 0, the uncertainty decreases, and if the entropy value approaches 1, the uncertainty increases (Eq.1).

$$H = -\sum p\,(x)\ \log\ p\,(x) \tag{1}$$

where H is entropy and p(x) is the frequentist probability of a variable or a class ‘x’ in the dataset.

In addition, the Gini index is used to determine the contribution values of the variables in the branches (Eq. 2). The Gini index varies between 0 and 1, where 0 denotes that all variables belong to a certain class and 1 denotes that the variables are randomly distributed across various classes.

$$Gini\ index = \frac{f\,(C_i,\ T)}{|T|} \tag{2}$$

where T is the training set, C_i is i^{th} class.

Information gain (IG) is used to determine which attribute gives the maximum information about a class (Eq. 3). In the DT method, branching is started with the variable with maximum information gain in the data set and the method

aims to reduce the level of IG from the root node to the leave nodes.

$$IG\ (S,D) = H\ (S) - \sum_{V \in D} \frac{|V|}{|S|} H\ (V) \quad (3)$$

where S is the original data set, D is a split part of the data set and V is a subset of S.

2.2.2. Support vector machine method

Support vector machines (SVM), is developed by Vapnik and Chervonekis in the late 1960s, are the most popular, robust, and widely used AI method that works according to structural risk minimization [18,19]. Structural risk minimization means getting a low error rate on unseen data set (outside training data set) [20]. In contrast to the experimental risk minimization used in traditional machine learning methods, structural risk minimization overcomes multiple training data requirements, local minimums, low convergence rate, and overfitting problems [21].

Today, SVM and other learning-based-kernel algorithms show better results than ANN and other intelligent or statistical models, on the most popular benchmark problems [22]. SVM does not rely so heavily on heuristics and has a more flexible structure [23]. Besides, it is very powerful in realizing complex and nonlinear predictions.

The main purpose of the SVM method is to select the plane or hyperplane that will make the smallest classification or prediction error when encountering unknown or reserved data for testing, but it is impossible to draw the linear hyperplane in nonlinear SVM. In other words, it is not possible to separate complex data with a flat plane. To find the best boundary between nonlinear classes, data is transferred from the original input space to a higher dimensional space using the mapping function (Φ) (Eq. 4) [24].

$$x \in R^d \rightarrow (x)\ \Phi \in R^f \quad (4)$$

However, it is often difficult to obtain the mapping function. Therefore, for non-linear classification problems, kernel function-based SVM is used instead of the mapping function. Kernel function maps training input data of input space R^d onto a higher dimensional feature space H using transformation operator Φ. After this, an optimal separating hyperplane is used to separate the two classes of the two-class pattern classification problem [20].

Kernel functions frequently used in the literature are shown in Eqs. 5-8. C is kernel value, d is polynomial degree and γ is a hyperparameter of the radial basis function (RBF) kernel which is also called gamma parameter and it defines the spread of the kernel.

LF $\quad C(x_i\ , x_j) = x_i^T\ x_j \quad (5)$

PF $\quad C(x_i\ , x_j) = (x_i x_j)^d \quad (6)$

SF $\quad C(x_i\ , x_j) = \tanh k\ x_i x_j - \delta \quad (7)$

RBF $\quad C(x_i\ , x_j) = \exp\left(-\gamma \left\|x_i - x_j\right\|^2\right) \quad \gamma \geq 0 \quad (8)$

LF: Linear function PF: Polynomial function SF: Sigmoid function RBF: Radial basis function

2.2.3. Artificial neural network method

Artificial neural network (ANN) is an information processing system inspired by biological neural networks, whose main task is to predict the output set corresponding to the data set displayed as input. ANN method is one of the widely used machine learning methods recently [9].

ANN method bases normalized input data, makes generalization, and collects information during the training phase. In the testing phase, it predicts the normalized output that it has never seen before or that may occur in the future.

The normalization increases processing speed and accuracy. The "Min-Max Normalization" method is frequently used in the literature as the normalization method (Eq. 9).

$$X^{\iota} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (9)$$

where X_{min} is the minimum value of dataset, X_{max} is the maximum value of dataset, and X is the actual data.

The training performance varies based on optimization methods. The most popular optimization methods are variants of gradient-based back-propagation algorithms. Levenberg-Marquardt (LM) is the most used algorithm which is used as back-propagation algorithms. In addition, the performance of ANN depends on different criteria such as number of the hidden layer, number of the neurons in hidden layer, transfer function, and number of iteration. Some of the advantages of ANN are being tolerant of errors, adapting to environmental changes, working with incomplete information, and making decisions under uncertainty. Therefore, it can be used in stochastic situations such as nonlinear, complex, and uncertain relationships.

2.2.4. Deep learning method

Deep learning (DL) method is an AI method that uses a multi-layered (deep) architecture to match the relationships between inputs or observed features and the result. It has been used in many fields of science, business, and administration, as it is very good at discovering complex structures in high-dimensional data [25]. There is some advantage of using DL method according to machine learning. It is able to calculate in one layer instead of many layers, to discover even the parameters you need to define in machine learning, and to determine better parameters. The disadvantage of DL is that there is a risk of over-compliance problems [26].

2.2.5. Statistical performance criteria

The statistical performance criteria such as mean absolute percentage error (MAPE), mean square error (MSE), mean absolute error (MAE), root mean squared error (RMSE), and coefficient of determination (R^2) are used to compare the prediction results of methods (Eqs.10-14).

$$MAPE(\%) = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{|T_i - P_i|}{T_i}\right] x\ 100 \quad (10)$$

$$MSE = 1/N\sum_{i=1}^{N}(T_i - P_i)^2 \quad (11)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|T_i - P_i| \quad (12)$$

$$RMSE = \sqrt{1/N\sum_{i=1}^{N}(T_i - P_i)^2} \quad (13)$$

$$R^2 = \left[\frac{\sum_{i=1}^{N}((T_i - \bar{T})(P_i - \bar{P}))}{\sqrt{\sum_{i=1}^{N}(T_i - \bar{T})^2 \sum_{i=1}^{N}(P_i - \bar{P})}}\right] \quad (14)$$

where T_i is i[th] actual data, $\bar{T}$ is the mean of actual data, P_i is the i[th] predicted output data and $\bar{P}$ is the mean of i[th] predicted output data in the dataset.

3. AN APPLICATION

The application consists of three phases. The first phase deals with determining the variables, the second phase deals with predicting the blood component demands, and the last phase deals with calculating the overstock and shortage in the blood bank inventory.

3.1. Determining variables

Fifteen independent variables that affect the blood demand were determined by using the brainstorming method with the doctors working in the blood bank (Table 2). As a result of the limited searches, the determined variables in this study were not seen in the literature.

Table 2. Variables affecting the amount of RBCs demanded

Notation	Variables
V_1	The demand for RBCs which couldn't provide by the blood bank in the last period (unit/week)
V_2	The demand for RBCs of BTC in the last period (unit)
V_3	The number of bed available in BTC (number)
V_4	The initiation of new treatment practices (number)
V_5	The total number of medical examination in BTC (number/week)
V_6	The total number of medical examination in the emergency room in BTC (number/week)
V_7	The number of inpatient in BTC (number/week)
V_8	The bed occupancy rate in BTC (number/week)
V_9	The type of BTC (AI, AII, B, C, D)
V_{10}	The number of surgery in BTC (number/week)
V_{11}	The province/district population where the BTC is located (number)
V_{12}	The number of public holidays (number/week)
V_{13}	The number of organ transplantation (number/week)
V_{14}	The number of immigrant (person/year)
V_{15}	The value of temperature (°C)

BTC: Blood transfusion center

3.1.1. Predicting the number of RBCs demand

A data set was created for AI methods. The data set consisted of a 520 (5 transfusion centers x 104 weeks) x 15 (variables affecting the number of RBCs demand) size matrix. In the AI methods, the variables affecting the RBCs demand were determined as the input variable (Table 2). On the other hand, the weekly RBCs demand requested by the transfusion center from the blood bank was determined as the output variable (Table 3). In all AI methods, 364 units (520 x 0.70 = 364) were separated for training, 94 units (520 x 0.18 = 94) were separated for validation, and 62 units (520 x 0.12 = 62) were separated for testing.

Table 3. Data set used in AI methods

Observation Unit (week)	TC	Variables affecting the number of RBCs demanded								
		V_1	V_2	V_3	.	.	.	.	V_{14}	V_{15}
1st observation unit	H_1 1st week	78	257	3363					2082	-7.1
2nd observation unit	H_1 2nd week	60	288	3363					2082	4.1
3rd observation unit	H_1 3rd week	144	472	3363					2082	4.7
.	.									
.	.									
.	.									
518th observation unit	H_5 518th week	19	209	1817					370	8.4
519th observation unit	H_5 519th week	10	232	1817					370	3
520th observation unit	H_5 520th week	11	223	1817					370	4.4

H_1: 1st transfusion center H_5: 5th transfusion center TC:Transfusion center

3.1.2. Decision tree method

In the DT method, the data set in Table 3 created for AI methods was used. In order to determine the optimum maximum tree depth, different values from 2 to 25 were tried and the value giving the lowest error rate was determined as 10 (Table 4).

Table 4. Determination of optimum parameters in DC method

Maximum tree depth	Lowest error
2	21.7
4	16.8
7	11.8
10	10.5
15	10.5
25	10.5

The first 3 and the last 3 predicted values obtained using DT method are given in Table 7.

3.1.3. Support vector machine method

Different levels were determined for the gamma parameter and kernel value of SVM method. Gamma parameter levels were determined as 0.000, 0.001, 0.010, 0.100, 1,000 and 10.00, C parameter levels were determined as 10, 100 and 1000. The optimum parameter levels were determined as 0.010 for the gamma parameter and 1000 for the C parameter with a 4.6% error rate (Table 5). Besides, the total number of support vectors used in the prediction was found to be 218.

Table 5. Optimum parameters of the SVM method

Gamma	Error rate		
	C		
	10	100	1000
0.000	29	27	16.6
0.001	27	16.9	10.5
0.010	19	10.1	4.6
0.100	16.2	6.7	27.6
1.000	23.6	14.5	13.7
10.00	28.1	27.1	28.3

The first 3 and the last 3 predicted values using SVM method are given in Table 7.

3.1.4. Artificial neural network method

In the ANN model, variables which affect the demand for RBCs was determined as input and the optimum number of RBCs was determined as output. Therefore, in the ANN model, a 15-input and 1-output feed-forward model was used to predict the optimum number of RBCs.

The data set was normalized to make more efficient of training data and shortened training period, using Eq. 9. Then, the dataset was divided three such as in other AI prediction methods

Multi-layer perceptron (MLP), which is effective in determining demand problems, was used in prediction [27]. Besides, the Levenberg-Marquardt algorithm, which is determined as the fastest algorithm in the MLP model, was preferred [28]. The number of hidden layers was also taken as 1 in the model because it has been demonstrated in practice that having more than one hidden layer slows down learning [29].

The other parameters were determined using trial and error method (Table 6).

Table 6. ANN parameters

Parameter	
Training algorithms	BR
Learning functions	Learngdm
Transfer function in the middle layer	Tansig
Number of neurons	20
Transfer function in the output layer	Tansig
Maximum error	10
Number of iterations	1000

BR: Bayesian Regularization

The R^2 value of the training, validation, testing, and all data set obtained by the ANN method is given in Figure 1. According to the figure, the rate of predicting the number of RBCs demand was calculated as 98.60%.

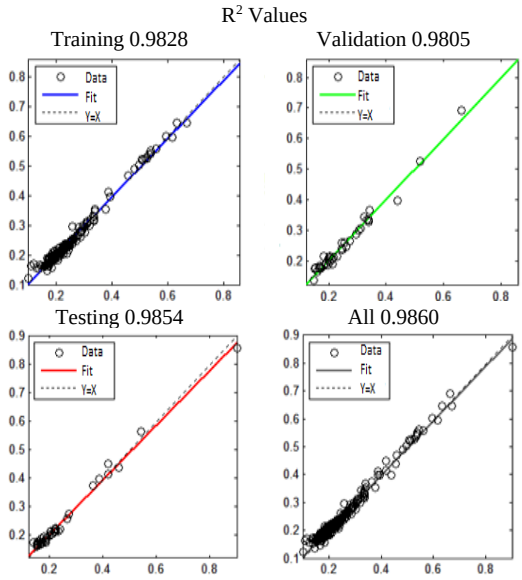

Figure 1. Results of ANN

3.1.5. Deep learning method

In the DL method, firstly, training, and testing data were normalized. The rectified linear unit (ReLU) function was used as the activation function.

The first 3 and the last 3 predicted values obtained by using the deep learning model are given in Table 7.

4. RESULTS AND DISCUSSIONS

To compare the prediction accuracy of the AI methods, five statistical performance criteria, including MSE, RMSE, MAPE, MAE, and R^2 were used. SVM predicted the closest value to the actual number of RBCs demand because it also has minimum prediction errors and largest R^2 value.

Table 7. Real and predicted by AI methods the number of RBCs

Week	Real RBCs demand (unit)	Predicted RBCs demand (unit)			
		DT	SVM	ANN	DL
1	144	148	148	149	163
2	194	187	194	194	173
3	184	187	184	184	157
.	.	.	.	.	.
.	.	.	.	.	.
60	164	159	169	172	161
61	232	232	231	231	218
62	223	220	223	223	210
MSE		687.79	36.983	97.076	419.44
RMSE		26.226	6.0814	9.8527	20.480
MAPE		4.8044	1.3831	2.0254	8.1671
MAE		13.037	3.2411	4.7481	15.403
R^2		0.9960	**0.9990**	0.9860	0.9770

In the blood banks, only the number of RBCs that can be requested should be sent to the transfusion centers, and underprediction/overprediction should be avoided. In Figures 2 - 5, 62-week (y axis) testing data set values were examined. In the figures, negative values (x axis) indicate unmet demand for RBCs, while positive values (x axis) indicate the number of RBCs sent in excess of demand. It had been determined that both the minimum deviation and the maximum deviation had the best value in the SVM method.

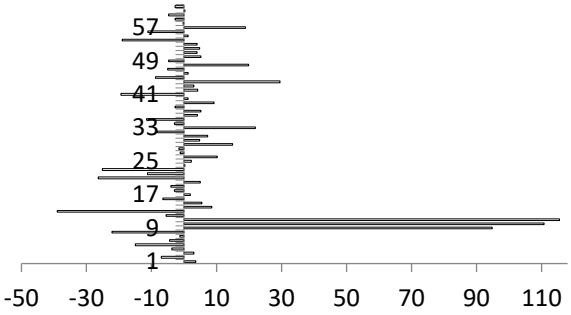

Figure 2. The deviation in unit of RBCs predicted and requested using the DT method

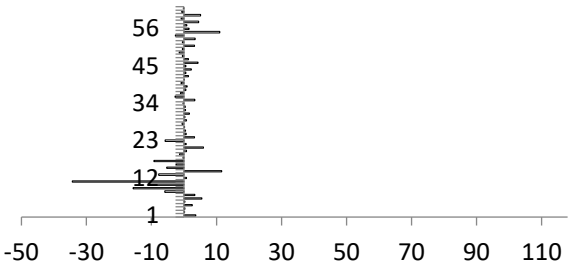

Figure 3. The deviation in unit of RBCs predicted and requested using the SVM method

When AI prediction methods were examined, 20 observation units of RBCs were underpredicted in the ANN method. However, in the SVM method, 24 observation units and 111 total units of RBCs were underpredicted. Similarly, in the SVM method, only 88 units of RBCs were overpredicted, although the 38-week observation unit was overpredicted (Table 8). If these values were averaged on a weekly observation unit basis; in SVM, there was an overprediction of 5.29 units and an underprediction of 3.03 units. Therefore, the SVM method should be preferred for prediction.

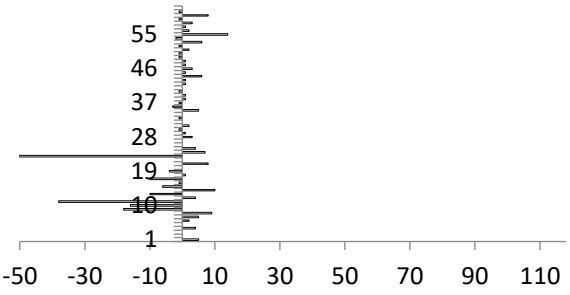

Figure 4. The deviation in unit of RBCs predicted and requested using the ANN method

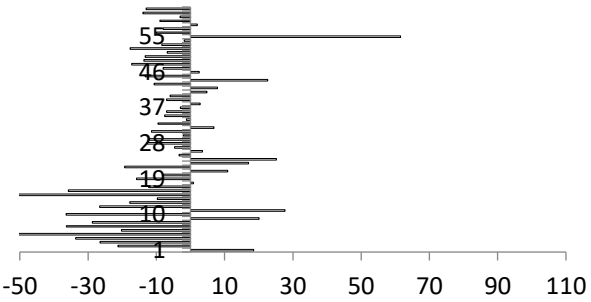

Figure 5. The deviation in unit of RBCs predicted and requested using the DL method

Table 8. Comparing the results of the methods

	Prediction methods			
	DT	SVM	ANN	DL
Underprediction (week)	30	24	20	46
Overprediction (week)	32	38	31	16
Underprediction (unit)	281	111	169	720
Overprediction (unit)	527	88	122	235
Overprediction (Avarage)	9.69	5.29	8.45	15.65
Underprediction (Avarage)	17.57	3.03	3.94	14.69
Maximum deviation	116	12	14	62
Minimum deviation	-39	-34	-44	-50

5. CONCLUSIONS

The transfusion of blood components to sick or injured persons is vital. In addition, the number of blood donations and the time of blood donation are completely variable. But, the blood components in stock should be transferred to the patient or the injured person in the required transfusion center at the required time, in the desired amount, and in the appropriate manner.

This study aimed to predict the blood component demand accurately that will occur in the next period by considering the variables that may affect the blood component demand.

The variables that affect the number of blood components to be demanded were determined differently from other study

in literature. Then, AI methods were used to predict the number of demands by using these variables. Although quantitative prediction methods had been widely used on the demand predicting in the blood bank, there had been limited use on ANN and there was no study focusing on the other AI methods such as support vector machine and decision tree.

The proposed model was designed to reduce the demand prediction deviation of fresh frozen plasma and platelet suspension, which are other blood components. Therefore, the model has the ability to use different blood components. In addition, it can be applied to different blood centers. Even if the data changes, the model will be able to determine the demand prediction model that will minimize the deviation.

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Investigation of the effect of demagnetization fault at Line Start AF-PMSM with FEM

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Abstract

In motors containing magnets, irreversible demagnetization failure is one of the factors that negatively affect motor performance. In this study, the traditional Axial Flux Permanent Magnet Synchronous Motor (AF-PMSM) rotor structure was changed and the structure that gained the feature of starting from the line was used. Line Start AF-PMSM with 5.5 kW shaft power has 4 poles and each pole consists of 5 magnets. Demagnetization failure was obtained by the flux values of the magnets in any pole are drawn to zero and virtual demagnetization failure is created at certain rates (20%, 40% and 60%). With FEM, the data of the healthy and faulty motor were obtained. The data are then presented comparatively. Obtained data showed that demagnetization fault in Line Start AF-PMSM negatively affects motor performance, and the results are given in detail in the article. The original aspect of the study is that the demagnetization fault in Line Start AF-PMSM was investigated for the first time with FEM.

Keywords: Line start, Axial Flux PMSM, Demagnetization fault, FEM

1. INTRODUCTION

Permanent Magnet Synchronous Motor (PMSM) has advantages such as high power-to-weight ratio, high torque-inertia ratio and high efficiency and power factor compared to other motors [1,2]. Therefore, it has been widely used in industry recently, especially in servo systems. PMSMs are produced in different structures. The Axial Flux Permanent Magnet Synchronous Motor (AF-PMSM) structure is one of them. The main advantages of this type of motors are high efficiency, power density, torque density, adjustable and planar air gap, and shape compatibility with working areas[3]. One of the disadvantages of these motors is that they cannot start directly from the network. To overcome this, either high-capability drivers or a change in rotor architecture are needed. With the short-circuit cage to be added to the rotor, they can start directly from the line.

As the usage of PMSMs increases, faults in these motors are encountered more frequently. One of these faults is the demagnetization fault. Demagnetization fault is examined in two basic groups as reversible and irreversible demagnetization fault. Reversible demagnetization failure is explained by the state of restoring the material properties when the motor cools down unless the motor is raised above a certain level in operating condition [4]. Irreversible demagnetization failure is expressed as the situation in which the property losses in the materials cannot be recovered due to different reasons in the operation of the motor.

In PMSMs, demagnetization failure occurs due to reasons such as high temperature, stator faults or inverter-induced short circuit currents, high stator currents, structural parameters, corrosion, magnet life or damage to the magnet. The sources of these failures can be classified as thermal causes, mechanical stress, or environmental factors [5,6]. The main reason for these faults is mostly armature reaction [7].

For this reason, magnets damaged by demagnetization failure will cause the motor to draw more current to obtain the magnetic flux needed, and therefore cause the temperature to increase further. This temperature increase will cause an increase in demagnetization failure [8–10].
Recently, with the more frequent use of electric motors containing rare-earth-elements, the demagnetization failure that occurs in these motors has started to attract more attention of researchers. There are studies on issues such as the causes of the demagnetization fault and its effects on motor performance, and the prevention of damage to other

* Corresponding Author

components of the machine by detecting potential damages. In addition to the basic parameters such as current and voltage values of the motor, magnetic flux, frequency, torque ripple, and other parameters of the motor are also considered in these studies to protect motor components [11].

In this study, demagnetization fault that may occur in Line Start AF-PMSM was investigated with FEM. Demagnetization fault was created by setting the magnetic flux value provided by some of the 5 identical magnets in 1 pole to zero. Motor parameters were examined with the FEM for healthy and faulty cases and the results were given comparatively.

2. LINE START AF-PMSM

Conventional PMSM motors are produced in different topologies. AF-PMSM is one of these topologies. Research/studies on AF-PMSMs have been increasing in recent years. This situation is caused by advantages such as efficiency in unit volume, higher torque, and power density than other radial flux motors, shape advantages, adjustable air gap [12,13]. Another advantage of the AF-PMSM is that it can be produced in different topologies [14].

Since AF-PMSMs contain magnets, additional hardware/processes are needed to be able to start from the line. High-skilled drivers are among them. Another method is the changes made in the motor architecture. With the short-circuit bars added to the rotors, it is provided to start directly from the line. While these short-circuit bars produce the starting torque until it reaches the synchronous speed, they provide the opportunity to be synchronized again in case of pulled out of synchronism. In this way, the AF-PMSM operates as an asynchronous motor in transient state and as a synchronous motor in steady state. In Figure 1, there is a photograph of the short-circuit bar attached to the AF-PMSM.

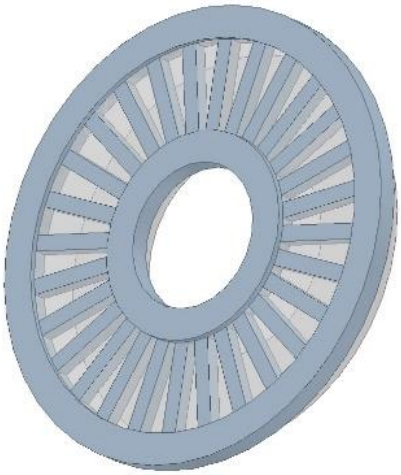

Figure 1. Short-circuit bar added to the rotor of the AF-PMSM

In this study, 3-phase 4-pole 5.5kW AF-PMSM was used. Since the rotor structure of the motor used is hybrid, it can start directly from the line. The characteristics and parameters of AF-PMSM are given in Table 1.

Table 1. AF-PMSM parameters

Motor parameters	values
Rated voltage (V)	380
Nominal Torque (Nm)	35
Outer/Inner diameter of stator (mm)	248/132
Outer/Inner diameter of rotor with cage (mm)	268/112
Air gap length (mm)	1
Rotor Speed (rpm)	1500
Number of stator/rotor slot	36/28
Stator axial length (mm)	58
Number of stator/rotor slot	36/28
Number of one phase winding (turns)	38
Number of magnets (piece)	20
Magnet thickness/ length (mm)	4/58
Stator material	JFE_20JNEH1500
Core loss coefficient of Stator	
Kh (W/m^3)	176.316
Kc (W/m^3)	0.102337
Ke (W/m^3)	2.72383
Permanent magnet material	N45SH
Squirrel Cage material	Aluminum
Rotor material	Steel 1010

The rotor of the AF-PMSM consists of 4 poles. Since it is a 4-pole structure, there are 2 N and 2 S group magnets. Each magnet group consists of 5 identical magnets. The magnets are mounted on the rotor surface. The magnets used are NdFeB magnets with N45SH code.

3. FINITE ELEMENT MODELING

FEM is a solution developed against various engineering problems. In the electrical machine design process, FEM is an effective method to reveal the effects of materials such as core, winding, short-circuit cage, magnet on the motor performance [15]. Ansys software is one of the package programs used to solve these problems. ANSYS Electromagnetics Suite 17.0 software was used in this study. The demagnetization failure of Line Start AF-PMSM was investigated on the full model in 3D environment for 3 main reasons. First, 3D FEM analyzes have higher accuracy than 2D and RMxprt methods. The second reason is that correct results cannot be obtained in 2D resolutions in nonlinear axial flux topology. Since the time parameter is an important factor in FEM analysis, analyzes can be made by taking references such as motor 1/2, 1/3, 1/4, etc. symmetrically in such analyzes. The last reason for the 3D and full model study is the investigation of the demagnetization failure occurring in one of the rotor poles in this study. Because in partial analysis, local faults will give results as if they are spread throughout the motor.

The accuracy of the results obtained in the analysis methods with FEM is directly related to the mesh process to be used. The more nodes used, the higher the accuracy of the result. However, since each node used will prolong the analysis

process, the optimum number of node is selected. The mesh process created varies according to the condition of the motor part. TAU mesh method was used in the analysis. In the ANSYS software, meshing is defined by the number of regions that appear. As a result of the mesh process, 13856 zones were created on the stator, 7000 zones on the rotor, and 3600 zones on the magnets.

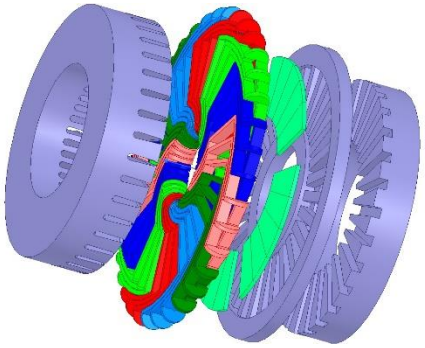

Figure 2. Full model of the AF-PMSM at FEM

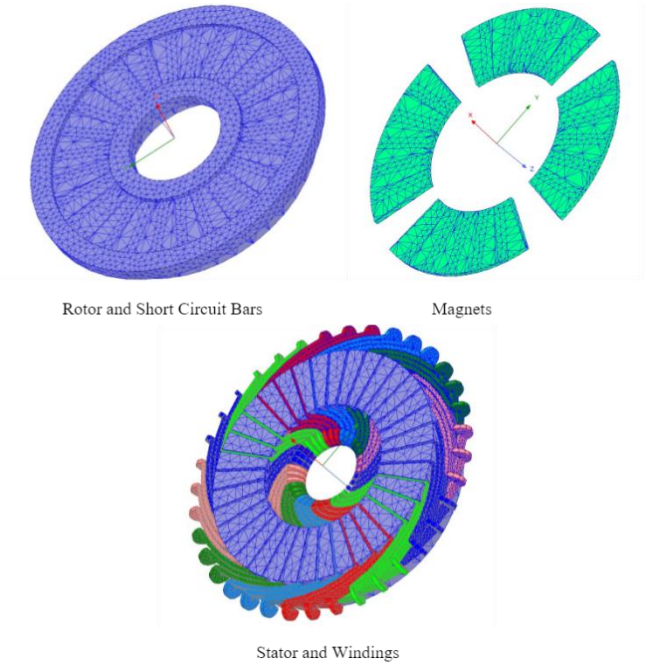

Figure 3. Regions formed as a result of meshing applied on AF-PMSM parts

In Figure 2 and Figure 3, the complete model created in the Maxwell software and the images of the regions formed as a result of the applied mesh process are shown. In Figure 4, the generated demagnetization faults are given. The creation of demagnetization in magnets was carried out by pulling the magnetic property of the N45SH material to zero in the material library. In this way, there will be no change in the weight parameter of the material used and its effect on the moment of inertia, which is important for electric motors, will remain constant in all magnets.

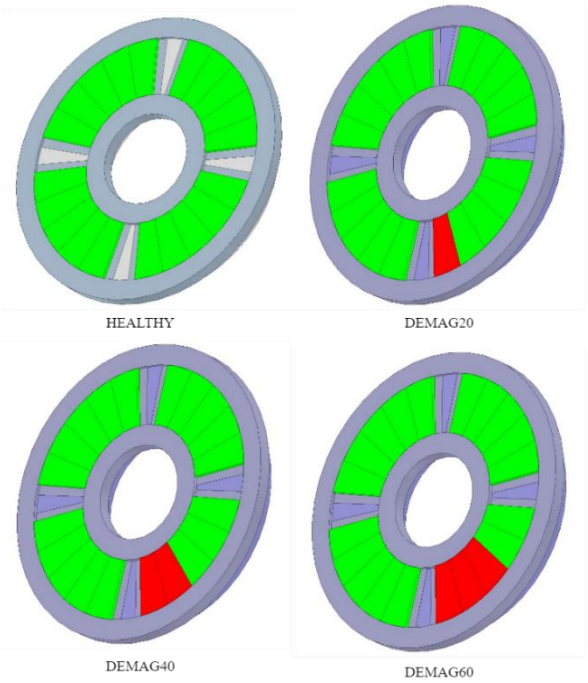

Figure 4. The generated demagnetization faults

4. RESULTS AND DISCUSSION

In different fault conditions, the motor was operated for 1.5s with 0.001s time intervals under dynamic operating conditions and parameters such as 3-phase stator current, electromagnetic torque, speed, efficiency, and power factor of the motor were obtained. In Figure 5 and Figure 6, there are phase current graphs of healthy and faulty motors that were dynamically operated for 1.5 seconds at a speed of 1500 rpm at 35 Nm nominal load with FEM in ANSYS Maxwell.

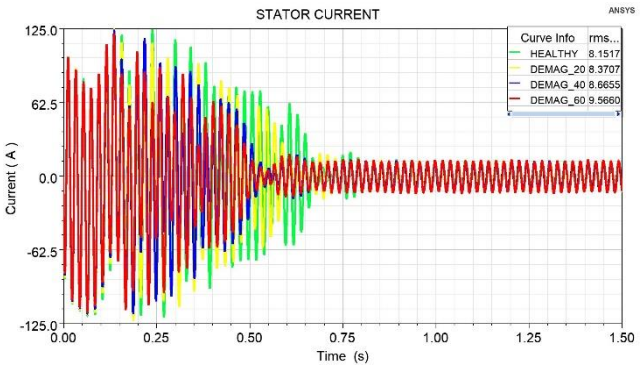

Figure 5. Stator one phase current curves of healthy and faulty motors

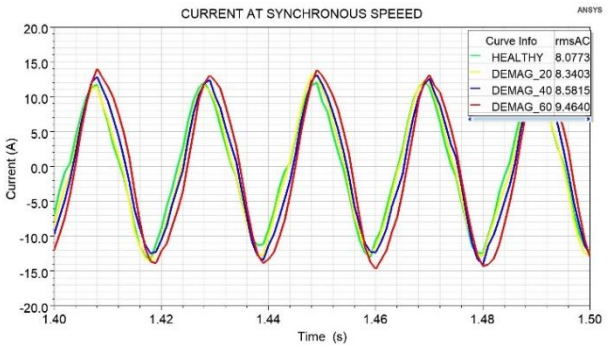

Figure 6. Stator one phase current curves of healthy and faulty motors (0.1s)

As a result of the analyzes made with FEM in the graphics, the one phase current rms value was obtained as 8.15 A while the healthy motor was running at nominal load at synchronous speed, and the one phase currents were obtained as 8.37 A, 8.61 A and 9.57 A for 20%, 40% and 60% faulty cases, respectively. When the waveforms are examined in detail, it is observed that as the failure rate increases, the maximum value of the current amplitude increases in the current waveform and there are very small shifts in the period.

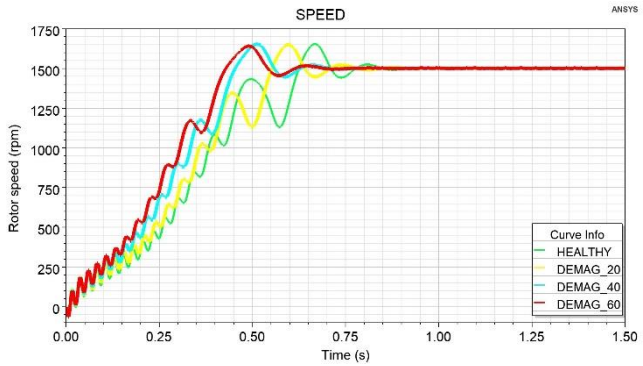

Figure 7. Speed curves of healthy and faulty motors

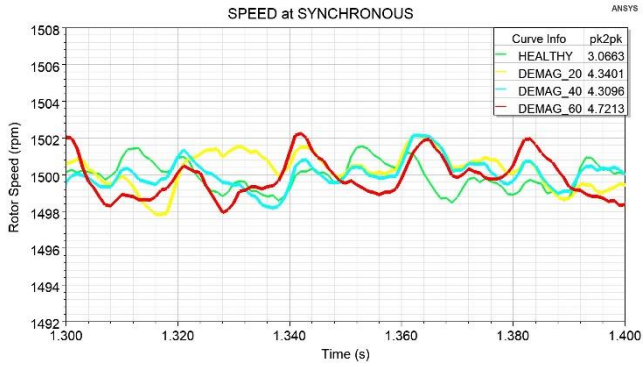

Figure 8. Speed curves of healthy and faulty motors (0.1s)

In Figure 7, the speed-time change graph during the starting of the rotor is seen. In Figure 8, the fluctuations in the rotor speed at synchronous speed are seen. It reaches the nominal speed in a time approximately 1.0 second in the analysis of healthy and faulty motors with FEM. It is observed that the motor can reach synchronous speed at full load for all cases. However, as the demagnetization rate increases, the synchronization time becomes shorter, and a decrease is observed in the collapses due to magnets in the acceleration curve. This can be explained by the decrease in the flux provided by the magnets due to the demagnetization failure. It is also observed that the demagnetization failure does not make a change in the acceleration curve at the maximum speed reached. When Figure 8 is examined, it is observed that the fluctuation in speed increases with the increase of demagnetization fault.

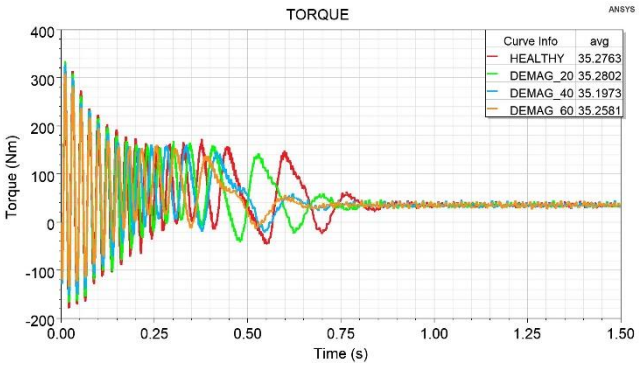

Figure 9. Torque curves of healthy and faulty motors

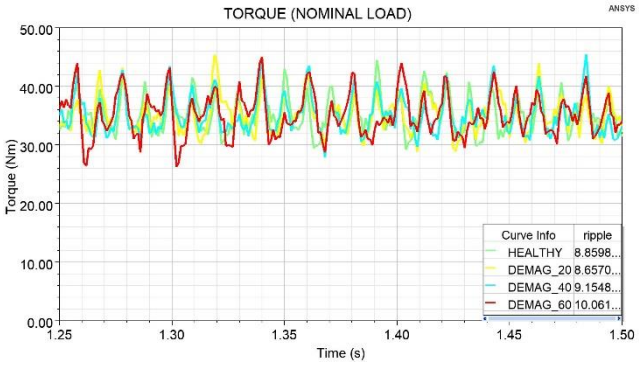

Figure 10. Torque curves of healthy and faulty motors (0.25s)

Figure 9 shows the torque curve of the Line Started AF-PMSM during starting. Electromagnetic torque is higher than load torque for both healthy and faulty states until the motor reaches synchronous speed. At the same time, there is a large ripple in electromagnetic torque initially for all situations. The reason for this situation can be said as the reaction of the rotational inertia of the system. Average torque values are positive although there are negative peaks until the electromagnetic torque equals the load torque. In other words, the prototype motor accelerates with positive average torque. The motor reaches the nominal torque value for healthy and faulty situations. The ripple in the torque curve in synchronous operation for these values are given in detail in Figure 10. As the failure rate increases, the torque ripple value occurring at the nominal load value increases.

In motor design, one of the factors affecting motor performance is the magnetic flux densities of the materials. The saturation in the motor magnetic materials affects the iron losses in the material and thus the efficiency. The flux densities occurring in the stator and rotor yokes and teeth are also important. In Figure 11 and Figure 12, the magnetic flux density distributions on the stator and rotor, in Figure 13 flux density distributions on magnets are given.

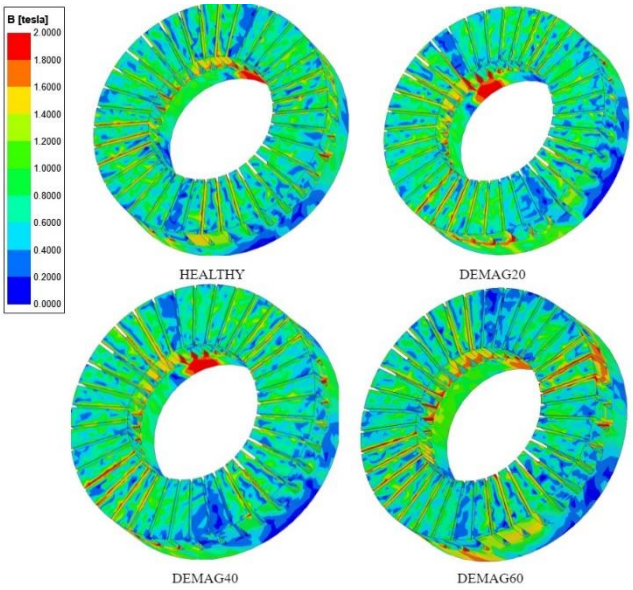

Figure 11. Magnetic flux density distributions occurring in the stator

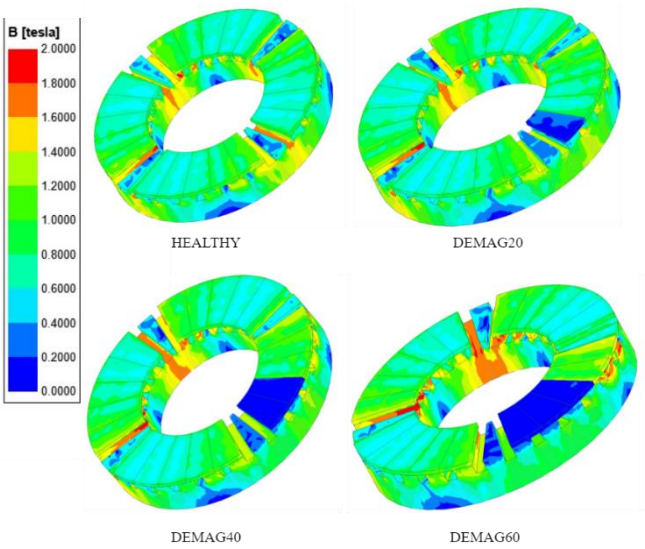

Figure 12. Magnetic flux density distributions occurring at rotor

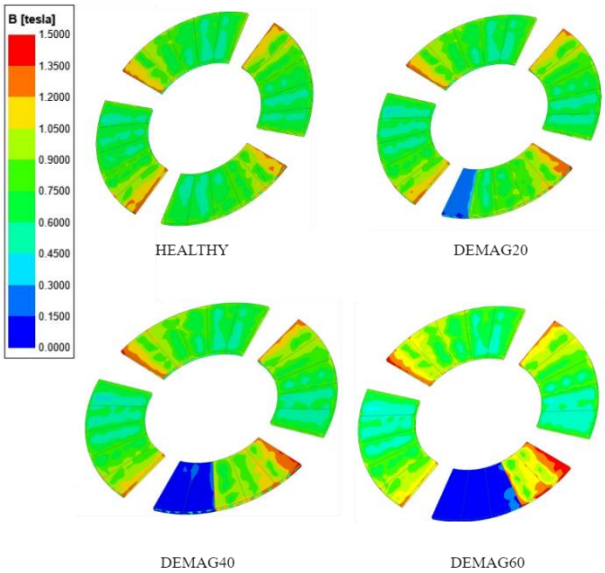

Figure 13. Magnetic flux density distributions occurring at magnets

Core losses and magnetization EMF vary directly with the flux density in the teeth, high flux density at these points is undesirable. The flux density in the teeth should not exceed 1.5 T [16]. When the figures are examined, it is seen that the flux distributions in the stator do not change much, but there is a concentration in a certain region with the increase of demagnetization failure. From the flux distributions in the magnets, it is clearly seen that there is an irregularity in the flux distribution due to the demagnetization fault. It shows that higher flux density occurs in healthy magnets in the demagnetized pole, and in this case, healthy magnets may be damaged thermally in long-term operation. While the maximum flux values in the magnets are 1.68 T in a healthy motor, this value reaches 1.83T in a motor with 60% demagnetization failure. This will cause other magnets to demagnetize with temperature in long-term use.

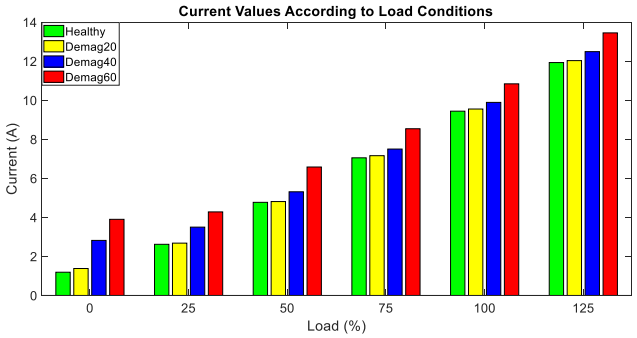

Figure 14. Stator current values under different load conditions

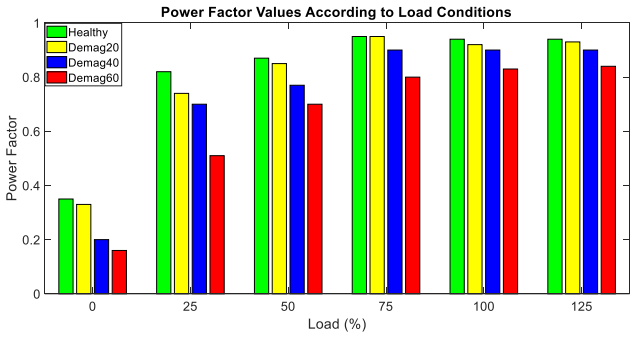

Figure 15. Power factor values under different load conditions

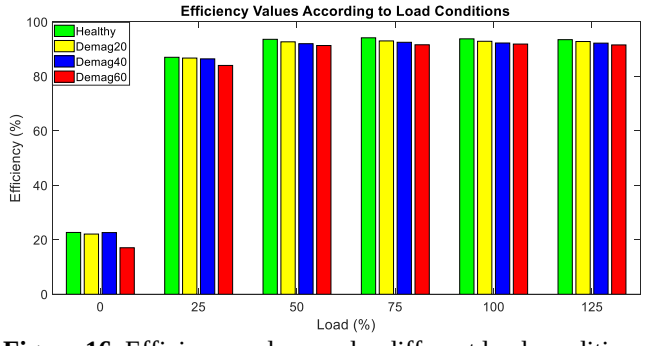

Figure 16. Efficiency values under different load conditions

In magnetic analysis, 20%, 40% and 60% demagnetization failures were created at one pole of the motor, and the results obtained under different load conditions were compared with the data obtained from the healthy motor. The data obtained from the faulty motors show that the fault causes changes in the motor current, power coefficient and efficiency parameters. Since Kh, Kc and Kp values of Steel 1010 steel used in the rotor are not defined in the software used, rotor core losses are not taken into account. As can be seen in Figure 14, it has been observed that the stator current of the motor increases according to the fault rate. Although the increase in the phase current is not obvious when the demagnetization interval is low, this difference is clearly observed when the demagnetization rate of a pole reaches 60%. When Figure 14 -16 is examined, the motor current increases with the increase in the demagnetization fault rate. As the motor current increases, the losses in the motor also increase. In terms of motor efficiency, while the healthy motor runs with 93.79% efficiency at full load, as the ratio of failure increases, the motor runs with approximately 2-3% lower efficiency at the same load (nominal load). In addition, the increase in torque ripple is caused by uneven magnetic pull force and distortions in holding torque. According to the results obtained, it was observed that the demagnetization failure adversely affected the motor performance.

5. CONCLUSION

In this study, the effect of demagnetization fault on Line Start AF-PMSM was investigated with FEM. AF-PMSM, that line start feature has been gained by changing the rotor architecture, has a 4-pole 5.5 kW shaft power and is in a single sided structure. One pole of the line start AF-PMSM consists of 5 identical magnets. Demagnetization fault rates of 20%, 40% and 60% are generated in one pole. The results obtained by operating each faulty condition at different loads were compared with the healthy motor. The results showed that demagnetization failure negatively affected the motor parameters. Magnets meet the flux required for excitation in AF-PMSM. With demagnetization failure, the flux provided by the magnets decreases and the motor accordingly draws more current from the network. However, thermal losses increase, power factor decreases, so a decrease in efficiency is observed. It also had negative effects on the speed parameter. The fluctuation at the synchronous speed has increased. While it did not have any negative effect on starting speed due to line start, it caused an increase in starting current. With the demagnetization fault, a 14.4% increase in current, 11.70% in power factor and 2% decrease in efficiency were observed at nominal load. The original aspect of this study is the investigation of demagnetization failure in Line Start AF-PMSM for the first time with FEM.

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Calculation Of The Optimum Number Of Unmanned Air Vehicles Required For Surveillance Missions

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Abstract

The aim of this study is to determine minimum quantity of unmanned aerial vehicles (UAVs) that should be used in an area where an aerial reconnaissance/observation activity will be carried out. In order to make this kind of calculation, firstly, the energy consumption of a UAV while flying with a constant speed was examined and then % energy level consumed by the UAV while passing each meter was obtained approximately. In this study, by considering the length of the trajectory which a UAV will navigate, required % energy level of a UAV to complete a single tour is calculated. If it is determined that one UAV can not complete its assigned trajectory, the number of UAVs are increased until each UAV complete its trajectory. In this study, the vehicle routing problem approach was used to calculate the UAV trajectories. Genetic algorithm method that is one of the metaheuristic optimization methods, was used obtain the solution of the vehicle routing problem (VRP). The developed algorithm has been run in Matlab environment. By changing the parameters of crossing rate and the population number in the genetic algorithm (GA) method, the lowest number of UAVs that is enough to carry out aerial observation over a target area and the shortest UAV trajectories were obtained. Results were presented in table form.

Keywords: unmanned aerial vehicles, vehicle routing problem, genetic algorithm

1. INTRODUCTION

Today, systems made with a single robot dominate robotic fields such as path planning and controller design. There are fewer studies on multiple robots and multi-target/task sharing [1]. Unmanned aerial vehicle (UAV) is an aircraft that can be controlled remotely [2]. With today's technology, unmanned aerial vehicles are widely preferred for many activities as stand-alone and robot clusters [3]. Unmanned aerial vehicles are used in many fields such as military, scientific research, imaging, fire fighting, camera shooting [4]. Vehicle routing problem (VRP) is based on calculating optimum routes that start from depots and include target waypoints [5, 6]. VRP has been used frequently in UAV trajectory planning in recent years [7, 8, 9].

In recent years, many studies have been carried out on VRP [10]. For example, a study was made to determine the shortest route for the waste collection truck in the city. In Matlab environment, ant colony optimization was developed and the shortest route was obtained [11]. In another study, a solution was sought with a genetic algorithm for the vehicle routing problem that emerged in line with the customer requests of the bread distribution company. The least costly route was determined [12]. In another study, the electric vehicle routing problem with time windows was discussed. A solution to the problem was sought with a combination of genetic algorithm and simulated annealing algorithms. It has been obtained that the developed algorithm gives better results than the genetic algorithm in terms of both optimum result and problem solving time [13].

In this study, the minimum number of unmanned aerial vehicles (UAVs) to be used in an area where aerial observation activity will be carried out is calculated with an approach based on UAV trajectory planning with VRP. A solution to the vehicle routing problem was sought in Matlab/Simulink environment with Genetic Algorithm (GA) [14, 15]. Genetic algorithm, which is a metaheuristic algorithm, has been used for many years to solve many engineering problems [16]. The genetic algorithm aims to give optimum results in less time. By changing the parameters of the genetic algorithm, the solution is prevented from repeating itself. The difference of this study from the studies in the literature is that it does not only include an algorithm that makes path planning, but is a study in which the required number of UAVs is determined with the method of genetic algorithms. Within the scope of the study, an algorithm that reaches the most accurate solution in the shortest time was developed by changing various parameters in the genetic algorithms method, and the optimum number

* Corresponding Author

of UAVs required for aerial observation in a region was determined.

By calculation of the optimum number of unmanned aerial vehicles required for observation activity in a region, the cost required for aerial observation activity can decrease, and control and tracking of unmanned vehicles will be easier. In addition, the number of personnel who will view the images to be transferred from unmanned vehicles will decrease in direct proportion to the decrease in the number of vehicles.

2. MATERIALS AND METHODS

2.1. Materials

In the experimental stages of this study, quadcopter type VTOL UAV was used. Figure 1 shows the UAV that was used in the experiments. The total weight of the UAV is 0.83 kg and the arm lengths of UAV are 22 cm from the body center to brushless DC motors. UAV has F450 type chassis, an external UBlox GPS+Compass module, an analog camera with transmitter. APM 2.6 was used as the flight control board of experimental UAV [17].

Figure 1. UAV that was used in experiments

Mission Planner program was used to monitor the flight data of the UAV used in this study. Mission Planner, an open source interface program, is widely used in the control of autonomous vehicles. It provides the instant location of unmanned vehicles on the world via Google Maps connection. In addition, the Mission Planner has been used to send some commands to unmanned vehicles via computer.

In order to make UAV that was used in this study fly about 5 minutes in windless weather conditions, a 2200 mAh, 11.1 Volt battery with a lithuim-polymer was preferred. The flight control card used in the UAV structure is the ArduPilot Mega 2.6. The control card includes barometer, accelerometer, 3-axis gyroscope.

2.2. Methods

In this study, first of all, the amount of energy consumed by a UAV per meter was obtained through experimental studies. Approximately the energy that a UAV will consume per main components of GA. The operation of the GA starts with determining an initial population randomly. The objective function is used to evaluate the members of the population. When all the members of the population have been evaluated, the lower rank chromosomes are removed and the remaining members are used for reproduction. In cross-over operation two members of the remaining population are randomly selected for gene exchange. The meter while moving at a constant speed has been obtained. Then, it was determined what percentage of the energy level of the UAV's battery would be consumed by making a tour in its trajectory obtained by the VRP path planning algorithm. In experimental studies, the UAV was moved at a speed of 4 m/sec horizontally. There is a 2200 mAh battery placed on the UAV. It has been determined that a UAV with a 2200 mAh battery consumes approximately 0.38% of its battery in 1 second if it travels at the speed of 4 m/sec. In this case, it has been determined that a UAV consumes approximately 0.095% of its battery in order to move 1 meter horizontally. It has been concluded that the UAV can travel approximately 1052 meters. This value was taken as 1000 meters in the calculation of the number of UAVs.

Energy level that each UAV will consume as a result of completing a tour in its trajectory represents the navigation cost. If the energy level of a UAV battery is greater than its trajectory cost, it means that a single UAV is sufficient for aerial observation activity. However, if the energy capacity of the UAV is insufficient for its trajectory, it will not be able to complete its trajectory. In this case, the number of UAVs is increased by one and the VRP algorithm is run again. This process continues until the proper UAV quantity for the area that will be observed is obtained. If the energy capacity of each UAV is higher than its trajectory cost, it is determined that the number of UAVs is sufficient to perform the observation activity.

In this study, the minimum number of unmanned aerial vehicles sufficient to carry out observation activity in a specified area was calculated. For this, the UAV trajectories must be created in a balanced manner. There are studies in the literature on obtaining balanced trajectories. In the literature, there are two objective functions, the first MinSum and the second MinMax, to produce balanced trajectories. MinMax aims to minimize the longest one of the UAV trajectories. Minsum aims to make the total length of the trajectories as minimum [18].

In this study, a single objective function containing these two objective functions was created. The purpose function created is given in Equation 1.

$$\text{Totalcost} = a * \text{lng\_trj} + b * \text{sum\_trj} \quad (1)$$

In Eq 1, Totalcost is the objective function, lng_trj denotes the longest trajectory and sum_trj denotes the total length of the trajectories. Coefficients of a and b were determined as 10 and 4 respectivelly by experimantal process explained in Results section.

The solution of the VRP model used in this study was carried out with the GA method in Matlab environment. Since Matlab has a rich library, it is preferred in codding stage in this study. The reason for choosing the GA method is that its structure is simple and it has been successfully used in solving VRP in the literature. GA flow chart is shown in Figure 2 and shows the general procedure of GA and the

last step of GA procedure is mutation and the mutation operator randomly mutates on a gene of a chromosome.

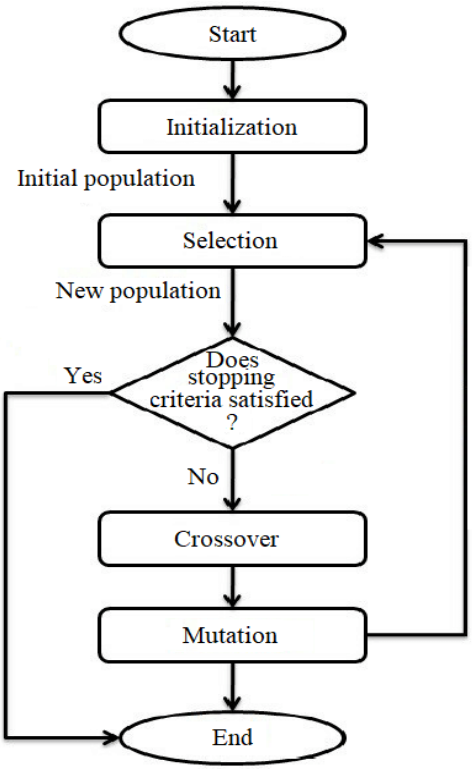

Figure 2. GA flow chart [19]

3. RESULTS

For the experiments in this study, 40x2 matrices containing the coordinates of the UAV visit points on the horizontal plane were produced in the Matlab environment. The randomly generated 40 visiting points are given in Figure 3. Tests were carried out by using 40 waypoints illustrated in Figure 3. In order to explain the contribution of the developed algorithm a sample test was illustrated by using 1,2,3,4,5 and 6 UAVs respectively for 40 waypoints. In Figure 4a, 2 UAV trajectories were given. In this situation, since the longest UAV trajectory was calculated as 1345 meters which is higher than UAV flight capacity, 2 UAVs are not enough to to carry out aerial observation over a target area. When the algorithm run with 3, 4 and 5 UAVs, it was observed that the longest UAV trajectory was calculated higher than UAV flight capacity. However, when 6 UAVs were used as shown in Figure 4b, the longest UAV trajectory was calculated as 939 meters which is lower than UAV flight capacity. This shows that the sample area can be observed by 6 UAVs at least.

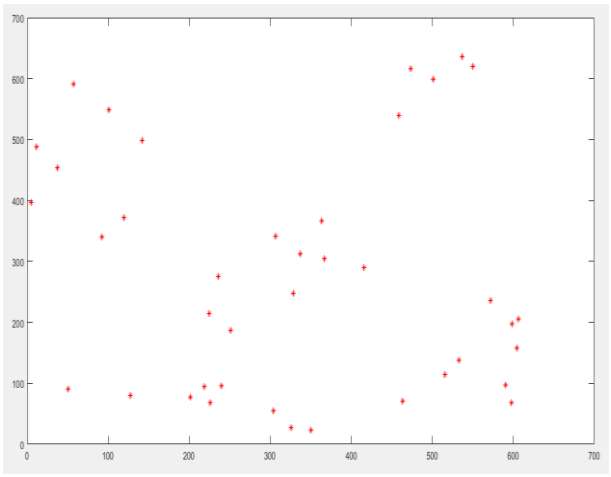

Figure 3. Randomly generated 40 waypoints

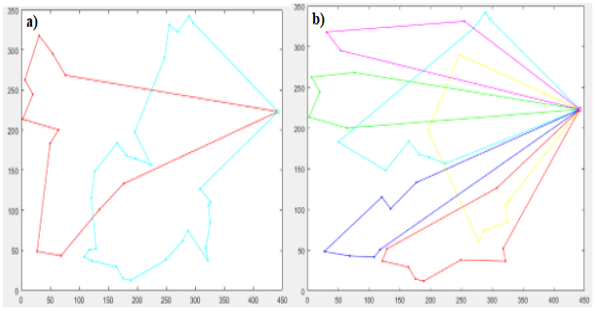

Figure 4. a) Trajectories for 2 UAVs b) Trajectories for 6 UAVs

In this study, the vehicle routing problem approach was used to calculate the UAV trajectories. By changing the parameters of crossing rate and the population number in the genetic algorithm (GA) method, the lowest number of UAVs that is enough to carry out aerial observation over a target area and the shortest UAV trajectories were obtained. Results were obtained by Tests that were carried out by using 40 waypoints illustrated in Figure 3 and as given in Table 1.

Table 1. Experiment table for 40 waypoints

Population size	Crossover rate	Iteration number	Longest trajectory length	Total length of all trajectories	UAV quantity
16	pmx(0.1)	4 438	955	4 490	5
16	pmx(0.5)	5 147	975	4 223	5
16	pmx(0.9)	4 437	954	5 179	6
48	pmx(0.1)	2 919	951.69	5 038.32	6
48	pmx(0.5)	3 719	994.05	4 675.54	5
48	pmx(0.9)	4 740	946.72	4 449.77	5
80	pmx(0.1)	1 044	972.10	4 537.58	5
80	pmx(0.5)	1 704	975.43	4 583.88	5
80	pmx(0.9)	3 890	985.71	4 261.95	5

4. DISCUSSION AND CONCLUSION

In literature there are lots of VRP approaches used in UAV routing [20]. Main subjects discussed in UAV based VRP studies can be grouped as: minimizing the sum of travel time among waypoints, minimizing the required UAV number and minimizing the total travel time of UAVs. The differences of this study from other studies in literature are including experimental data of battery consumption and including changing crossover ratio and population size parameters of GA procedure. It can be said that this study has a new approach within UAV based VRP studies.

In this study, an approach based on genetic algorithm method has been developed in Matlab environment to calculate the optimum number of drones required for air observation activities. In order to calculate the optimum number of UAVs, it is primarily aimed to create balanced orbits for UAVs. The closed-end vehicle routing problem is used to calculate the UAV trajectories. UAV trajectories start from the designated warehouse to carry out their activities and end in the same depot.

A solution to the scenario VRP was sought with a genetic algorithm. Partial planned crossover was chosen for crossover, which is one of the genetic algorithm parameters. In this study, the partial planned crossing rate was determined as 0.1, 0.5, 0.9 randomly. For the population size parameter, 16, 48 and 80 values were determined randomly. In this study, elitism method was used as the selection criteria. In this study, by changing the crossover ratio and population size input parameters, GA and closed-end VRP were solved and exit parameters such as number of iterations, total orbit length, longest orbit length and required number of UAVs were obtained.

The results of the experiments performed in Table 1, by selecting the coefficient a 10 in Equation 1, coefficient b 4, population size 16, 48, 80, and pmx crossing rate 0.1, 0.5, 0.9 and the number of visiting points 40, respectively, are as follows.

- It was determined that the number of iterations decreased while the population number was increasing and the crossing rate was constant. As a result, it has been determined that the number of populations should be increased if the solution time is an important criterion in the scenario problem.
- While the population number is increasing and the crossing rate is constant, it has been determined that there is no change in the length of the longest trajectory.
- While the population number is increasing and the crossing rate is constant, it has been determined that the total orbit length does not change.
- While the population number was increasing and the crossing rate was constant, it was determined that there was no change in the calculated number of UAVs.
- It was determined that the number of iterations increased when the population number was constant and the crossing rate was increasing.
- It was found that the longest orbit length increased when the population number was constant and the crossing rate was increasing.
- When the population number is constant and the crossing rate is increasing, it has been determined that there is no change in the total orbit length.
- When the population number was constant and the crossing rate was increasing, it was determined that there was no change in the calculated number of UAVs.

In this study, the optimum number of unmanned aerial vehicles required in a region for observation activity was calculated. As a result of the calculation of the optimum number of unmanned aerial vehicles, the cost required for observation activities in a region will be reduced and the control and tracking of unmanned vehicles will be easier. Since the number of vehicles is determined in the minimum number required, the number of personnel who will watch the images to be transferred from unmanned vehicles will be the least, which will reduce the cost.

Considering the changes caused by different parameter values in the results of the genetic algorithms method used in this study, it is possible that changing the selection criteria and testing various mutation operators will cause changes in the output parameters.

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LabVIEW and Embedded System based New IoT Solution for Industrial applications

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Abstract

The Internet of Things (IoT) is becoming increasingly popular around the world. Efficiency in terms of time and cost is ensured in all sectors, thanks to the internet of things technology. A novel IoT system design was created in this study to add Internet of Things technology to a new perspective. All clients can connect to the server using this IoT platform, regardless of their hardware or software capabilities, even if they are not capable of industrial communication. The platform brings flexibility and ease of use to IoT applications. Thanks to the platform's architecture, any device, whether inputs or outputs, can be easily added to an IoT network while it is running using the developed modules. The server software was created using the LabVIEW visual programming language and Raspberry Pi and MSP340F5529 embedded systems are used to develop hardware modules. To provide IoT data security, the TCP/IP protocol is used for data communication, and all data is encrypted using the AES (Advanced Encryption Standard) algorithm with a 128-bit key. A dynamic 1-N server-client IoT system has been implemented and tested with various analog, digital, and smart sensors, as well as smart devices. When the results are evaluated, it is found that industrial applications can be developed with the platform. Particularly in the case of transformation of industrial automation applications to IoT containing non-smart sensors and actuators, the developed platform can be preferred. In this case, the platform will bring opportunities to engineers in terms of cost and ease of development phase.

Keywords: IoT, AES, Plug-in Architecture, Labview, Raspberry Pi, Energia

1. INTRODUCTION

The Internet of Things (IoT) generally refers to the interconnection of different types of computers and devices to support various monitoring and control applications. A wide variety of innovative applications such as smart homes and smart cities are developed, as well as industrial applications, with the addition of digital communication features like sensors, actuators, subsystems, etc., which are expressed as objects. The concept of the Internet of Things, which emerged with the Industry 4.0 industrial revolution, which is also called the digital revolution, has started to spread around the world. Studies are carried out on remote control and monitoring applications in order to make automation lines autonomous. It is ensured that production is carried out more efficiently, quickly and without errors. This study focuses on Industry 4.0 and industrial applications of IoT technology. In various applications of industrial automation, monitoring and management systems, each of the sensors and actuators must have communication capability. Considering the transformation of existing systems, the renewal of all hardware is costly, and the transformation of the software requires time.
With the proposed method, it is aimed that many new clients, independent of hardware and software, can easily connect and adapt to the server without stopping the running server and making any changes to its software. For this purpose, an embedded system solution, a new communication method and general management software that will enable the IoT transformation of end objects has been developed. When studies in this field in are examined in the current literature, the ones listed below draw attention.

Chuan and Ruslan created a remote control and monitoring application to keep the materials in a medical warehouse at an appropriate temperature and humidity limits. In their study, they managed to keep the temperature and humidity data within the desired limits [1].

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Kaya et al. carried out a remote monitoring application to monitor the system in the automation lines of the cable production factory. Thus, they increased their productivity in production by monitoring the lines remotely [2].

Bolivar and Silva established a solar radiation monitoring system in their study. They measured the sun rays coming from the optical sensors by means of a microcontroller. They sent this value to the Raspberry Pi card and sent it to the server over the UDP communication protocol. The server saved the data both in the local database and in the cloud-based data storage system [3].

Jegan and Nimi performed measurements with improved performance on filtering techniques for processing the ECG signal and provided the opportunity to monitor these measurements in LabVIEW software over TCP/IP [4].

Hnidka and Rozehnal sent the sensor data they collected with NI DAQ cards to the GUI over Wi - fi. They monitored the strain gauge data from the LabVIEW software interface via TCP/IP protocol. They recorded the data collected in real time in TDMS format [5].

Shah and Mishra designed a customized IoT system that enables wireless sensing and monitoring for smart buildings In their study, they succeeded in collecting data such as light, humidity and temperature for building automation via RF [6].

Vujovic and Maksimovic, on the other hand, created a home automation system using the Raspberry Pi card in their study. They used each Raspberry Pi board as a sensor node within the scope of the Internet of Things. They collected data from different sensors and transferred them to the web environment. [7].

Swain et al. designed an autonomous vehicle that can reach areas that require security, without waking the enemy. They aimed to use this vehicle for operations such as bomb detection and destruction and threat diagnosis for security guards in border security zones or battlefields [8].

Gómez et al. aimed to develop an architecture based on the Internet of Things (IoT), which allows the use of sensors with the capacity to collect information about environmental variables and also allows easy integration with other relevant sensors [9].

Prada et al. proposed the use of MQTT protocol, a lightweight protocol for communication with resource-constrained devices, and a tool for easy integration of new devices into the system, especially for those who use web standards such as JavaScript for creating user-interactive interfaces in educational applications [10].

Oksanen et al. worked on adapting the industrial automation protocol OPC UA (Open Platform Communications Unified Architecture) technology to IoT systems for remote monitoring of mobile agricultural machinery. They successfully completed the telemetry application by keeping the end-to-end delay time detected over the internet connection below 250 msec [11].

In their study, Shah and Bharadi collected biometric data with the Raspberry Pi card they used as an IoT device and encrypted the data they collected using RSA and AES-256 crypto algorithms. They sent the encrypted biometric data to the Azure cloud system. Thus, they have succeeded in keeping biometric data securely in the cloud system by providing information security [12].

In their study, Raja Singh et al. realized intelligent monitoring of power quality events using cloud-based embedded IoT and real-time logging of their data to the Firebase database on the server. With this study, it is aimed to detect the fault in industrial power applications remotely and to intervene in a short time [13].

Vakaloudis et al. aimed to organize the tasks and skills needed to quickly and seamlessly deploy an IoT platform in an industrial environment. While doing this, they talked about the difficulties and restrictions to be tackled. They have done their work using their experience in deploying small and medium-sized IoT solutions in a variety of fields (agriculture, health, manufacturing, water and energy) and industrial and community environments. They explained the applications that included real-life adaptations of the structure they established [14].

IoT system in 1-N structure with easy add-on was realized thanks to multi-channel programming and special add-remove protocol. Using the created add-drop protocol format and TCP/IP protocol, the integration of any hardware and software-independent client to server is easily achieved. In theory, an unlimited number of clients can connect to the server and send their data to the server asynchronously within a specified time. An innovative IoT system with a fast, high performance and dynamic structure was created by writing the server software in the LabVIEW environment.

The remaining parts of the article are planned as follows. In the second part, the materials and software also hardware technologies used are explained, in the third part, the findings of the study are presented. In the discussion and conclusion section, practical results, limitations, pros and cons of the developed system has been presented also a comparison table has been added for a relevant study in the existing literature.

2. MATERIALS AND METHOD

In this study, the server interface software was written using LabVIEW visual programming language. Virtual client software has also been developed in the LabVIEW environment. Raspberry Pi 2 and MSP430 cards were used as an example for embedded system hardware client cards. The client software of the Raspberry Pi board was implemented using the LabVIEW for Raspberry Pi library. The client software of the MSP430 board was written in C-based software in the Energia development environment. Sensors used as examples in the system are LM35 temperature sensor, MZ80 infrared sensor, 4-channel relay and different colored LEDs. MariaDB platform is used in the database management system where the data is recorded. TCP/IP and special add-remove protocols are used for

communication between server and client. The e-mail system is written with the SMTP mail protocol.

2.1. System Software

LabVIEW is a visual programming language, that is faster in terms of software development time compared to other text-based languages. Thanks to the dynamic structure it offers, reproducible multi-channel copy function structures can be created. These duplicate functions are executed by calling them from the generated template VI. After the Template VI software is written, it is configured as "Pre-allocated Reentrant VI". This setting allocates a separate data space to template VI each time it is called. In other words, the data that these sub-functions keep in their memories are recorded in separate areas.

In LabVIEW, copies of template VI are called parallelly and asynchronously. The position of the template VI to be copied is converted into a reference. Template of VI dynamic aspect summoning is shown Figure 1. While the template VI is called dynamically, the first data is sent over the VI SERVER. The template VI reference that is opened is closed, eliminating unnecessary memory occupancy of this reference.

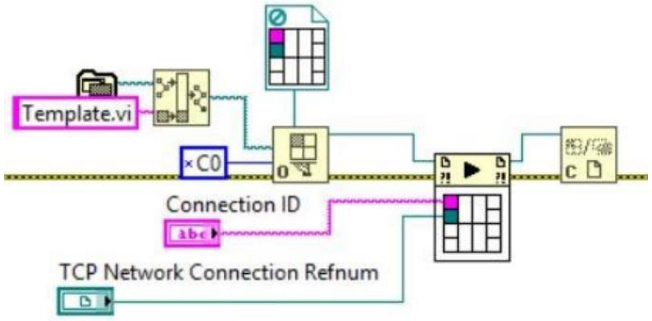

Figure 1. Template of VI dynamic aspect summoning

Template VI and the Producer/Consumer design template are used for the server. While user-interactive events are handled in the producer loop, the states of the events that occur in the consumer loop are processed. The cycle time of the event generating loop must be higher than the consuming loop. Queuing structures are used to create this design template and to provide inter-loop communication.

In this study, a queue-based Asynchronous Messaging structure (AMC) was used. Thanks to the AMC library, the server communicates asynchronously with all template VIs.

Messages created in producer loops are queued to be sent to consumer loops. In order to give priority to the message in the queue structure, which works with the first-in, first-out logic, the message sending function is adjusted. The consumer loop runs event states to process the messages it receives from the queue. Interprocess communication diagram is shown in Figure 2. Queues use queue names to communicate among themselves.

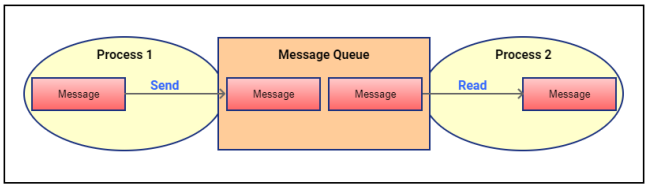

Figure 2. Interprocess communication diagram

LabVIEW for Raspberry Pi library is a tool that converts LabVIEW code to Python code both with and without an interface and transfers it to Raspberry Pi as an executable file. Thus, the software of the Raspberry Pi 2 embedded system board is written with the LabVIEW programming language without using the Python language.

The MSP430F5529 LP embedded system board was written in the Energia development environment. Energia is a development environment that can program Launchpad series such as MSP430 and 432, CC3100.
MariaDB is a relational database management system. A database management system is a system and software designed to create, use and modify databases and to meet all kinds of operating needs related to database systems. In this study, MariaDB database management system was used. Access to client data by HeidiSQL GUI is shown in Figure 3.

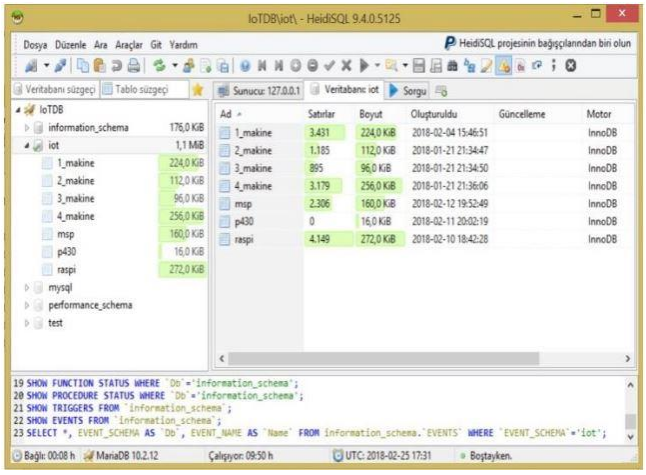

Figure 3. Access to client data by HeidiSQL GUI

Database Connectivity library is used in LabVIEW program. The database is accessed using this library. A separate table is automatically set up for each client connecting to the server. The name of this table consists of the machine name, and the columns consist of the data names. In addition to the data names, they are recorded at that date and time. When a client that was previously connected to the server reconnects to the system with the same name, it sends its data to the existing table. However, when it is connected with a new name, a different table is created and the new data is saved in this table.

Client data can be accessed from the server interface as well as from the HeidiSQL database client. HeidiSQL is a database client that is installed alongside MariaDB and supports database management system servers such as MySQL and SQL.

2.2. System Hardware

The Raspberry Pi 2 client is a credit card-sized single board minicomputer. It has a 900Mhz quad-core ARM Cortex-A7 CPU on it. Apart from the client, there are 4 USB ports, 1GB RAM, 40 GPIO pins, HDMI port, Ethernet port, audio output, camera connection interface, display interface, SD card slot and 3D graphics video core. Raspberry Pi client is connected to the server via Wi -fi through a plug-and-play USB Wi - fi adapter.

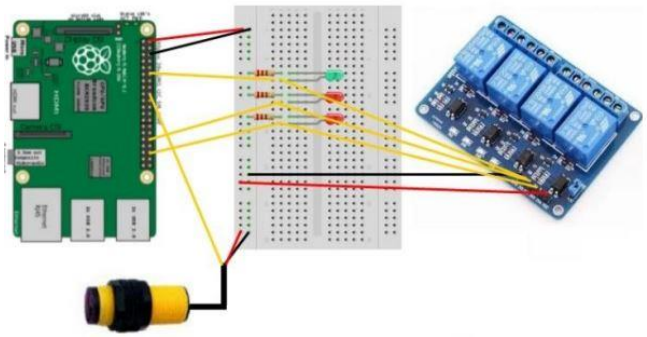

Figure 4. Sensor connections of Raspberry Pi device

Three digital outputs and one digital input are connected to the Raspberry Pi board. The digital outputs are 3 LEDs and 3 relays. The digital input is 1 MZ80 infrared sensor with 80 cm range. LED and relay outputs consist of the same pins. In addition, there is a random virtual data in the software of the RPI hardware to generate analog values between 0 and 10. Sensor connections of Raspberry Pi device is shown in Figure 4. The client card is prepared to send this data and digital input sensor data to the server every 300 milliseconds. Raspberry Pi client can be converted into an embedded system board that can be used in industry with additional cards.

The MSP430F5529 LP is an inexpensive and easy development kit for the MSP430F5529 USB microcontroller. MSP430F5529, a 16-bit MCU, has 128KB flash memory, 8KB RAM, 25MHz CPU speed, 12-bit A/D converter, 5 timers, onboard USB and many peripherals. The operating voltage of the device is between 1.8V-3.6V. There are 40 pins on the device.

Wi-fi add-on package is used to connect MSP430F5529 client wirelessly to a public network over the internet. Data is sent to the CC3100 add-on package via SPI. One LM35 temperature sensor and one LED are connected to this client. Sensor connections of MSP430F5529 LP device is shown in Figure 5.

2.3. System Communication Protocols

The protocol that provides data transmission between the server and the client is the TCP/IP protocol. This protocol includes both TCP and IP protocol. TCP/IP protocol consists of a 4-layer model. It consists of the application layer, transport layer, network layer and physical layer. The application layer contains applications that will process communication data. The transport layer determines how the data travels. The network layer is also known as the IP layer. Addresses are added to the packets and the data finds its destination. The physical layer determines the transmission path of the data.

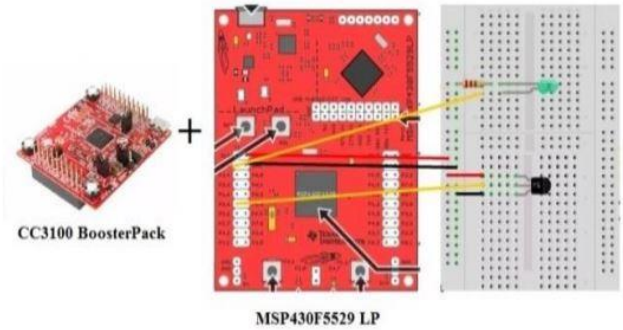

Figure 5. Sensor connections of MSP430F5529 LP device

TCP protocol splits the data coming from the upper layer into appropriate lengths. Gives a sequence number to the fragmented data. Allows reprocessing if parts are lost or sent damaged. It adds the header information to the packet to identify the tasks assigned to it. The IP layer, which is a lower layer, adds an IP header to the incoming packets and sends it to the receiver [15].

LabVIEW program, server-client software has been developed by using TCP/IP library in many software languages. In the server software, port 3584 is listened to at intervals of 100 milliseconds. The client software connects to the server with the connection function using the server's IP address and port 3584. TCP read and write functions also provide data exchange between server and client. In this study, while providing data communication, firstly the size of the data to be sent is calculated. The length data of a one-byte text is converted to text and added to the main data, and the total data is sent. The function that receives the data first reads the first byte of data and then determines the length of the data to be read. In the second reading, the main data is read and communication is provided. Server connection check, get initial text data is shown in Figure 6.

The server warns the users by e-mail system when an error occurs in any of the clients. This system is implemented through the SMTP (Simple Mail Transport Protocol) Simple Mail Transport protocol.

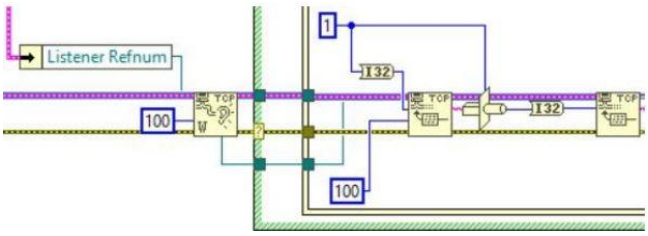

Figure 6. Server connection check, get initial text data

A special client add-remove protocol has been developed for new clients to connect to the server dynamically and asynchronously while the server is running and without making any changes to the server's software. Thanks to this protocol, any hardware created with client software suitable for the formats shown in the figure can be easily integrated

into the server. Thus, it is possible to add both hardware and software independent clients to the server at runtime.

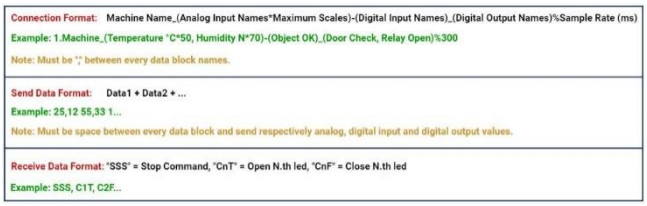

Figure 7. Application formats and examples for the client

The format that the client should send the first time it connects to the server is the connection format. In this format, the machine name, input-output names, scales, units and data collection time are entered. The data sending format is the format of the data that the client sends to the server during data collection. The data import format is the commands that go from the server to the client.

In the data import format “SSS” is the command to stop the client. “CnT” and “CnF” commands n. These are commands that specify the active or passive digital outputs. In the data sending format, a space must be placed between the data. In addition, the data must be sent in order of analog input, digital input and digital output. A comma must be placed between each data collection in the link format. The “%” sign should be used before the data collection time expression. “*” sign is used between scale data and data names. Detailed application formats and examples for the client is shown in Figure 7.

The firmware loop communicates via the TCP/IP protocol with the server TCP/IP connection operations consumer loop to establish the initial connection, and the template VI user interface consumer loop to send and receive data. If the server TCP/IP connection operations are the consumer loop, the server user interface communicates with the consumer loop and the template VI user interface communicates with the consumer loop. Inter-loop communication communicates over the AMC structure. The general communication diagram of the IoT system is set up in this way. Messaging and communication diagram of the system is shown in Figure 8.

2.4. Server software

The server software is written in LabVIEW programming language. TCP/IP listener is created after general reset settings when the server software is started. The server receives the initial data with the connection request from the clients. The initial information and connection reference are sent to the template VI, which will constantly communicate with the client. The client sends its data to the matching template VI at specified time intervals. The digital output of the current client has been checked over Template VI. If the client stops, the template VI is also closed and the server and client are disconnected. The client can also be stopped via the server and template VI.

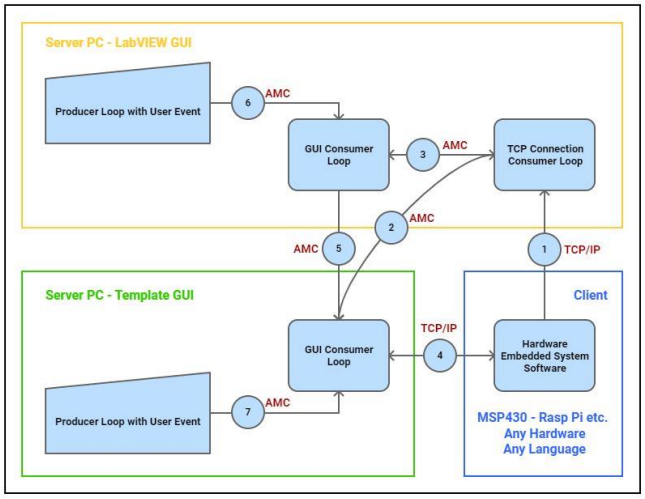

Figure 8. Messaging and communication diagram of the system

The server interface consists of two parts. The first part is where all clients are checked and general checks are made. The second section is the template VI interface section that opens specifically for each client. During data collection, data recording and instant data monitoring are performed from this interface, operations on historical data are carried out from the main server interface.

Clients connected to the server appear in the Connections selection bar. It is possible to operate on the client selected from this section. The client's template VI windows are hidden, shown, or terminated. Data from the database can be called to the table or output to excel.

More than one e-mail address can be registered in the system and e-mail can be sent. Warnings are presented in both written and visual form. Warning texts can be recorded. A competency-based password can be set for security purposes. A client can connect to the server only as long as the server allows it.

Template VI client windows open automatically as the client connects to the server. Data is monitored instantly from these windows.

2.5. Client software

A client's software can be written on any preferred platform. The client, whose software is written in accordance with the determined rules, can easily connect to the server. In this study, Energia software development platform for MSP430F5529 and LabVIEW for Raspberry Pi 2 for Raspberry Pi library is used. In client software, TCP/IP functions and client cards are generally connected to the internet. Clients connecting to the Internet via Wi-fi send a connection request to the server. The client that successfully connects to the server sends the startup information to the server. Sample client window opened with Template VI is shown in Figure 9.

This initial data includes information such as machine name, I/O names, scales, units and data collection times. Communication is achieved when the server creates a

template VI for the client. The client software sent its data to the template VI over the TCP/IP protocol. The client has processed any data from template VI, if any. Thus, the server both controlled the client and collected the client's data. The server stops the client software by sending the "SSS" command to the client.

Virtual clients and clients with operating systems such as Raspberry Pi have the interface. Thanks to these interfaces, users can see the data sent by the clients and the controlled digital output LEDs. Thus, there is no need to change the existing client software for simple operations.

Code block of the client software for MSP430 is shown in Figure 10. Server software interface is shown in Figure 11 and software flow chart of clients is shown in Figure 12.

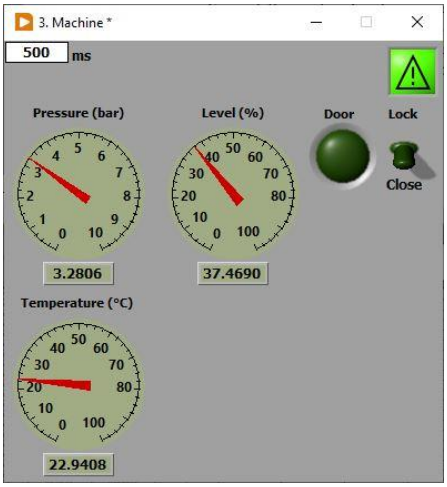

Figure 9. Sample client window opened with Template VI

```
{
 TempVal = analogRead(TempPin);
 TempVal /= 12.42;
 Serial.println(TempVal);
 String TempNew = String (TempVal);
 Serial.print("Temp=");
 Serial.print(TempVal);
 char TempLen = char (TempNew.length());
 String TotalTemp = TempLen + TempNew;
 client.print(TotalTemp);
 delay(500);
}
```

Figure 10. Code block of the client software for MSP430

2.6. Data Encryption

The communication between the server and the clients has been established by encrypting with AES algorithms with a 128-bit key for the security of IoT data. Therefore, the sender encrypted the data with this key. The receiver, on the other hand, decrypted the data with the same key and processed it. Even if the protocol is known, if the key is not known, it cannot be interrupted and the communication is rendered undecipherable. This process has become an IoT security solution suitable for today's crypto technology [16].

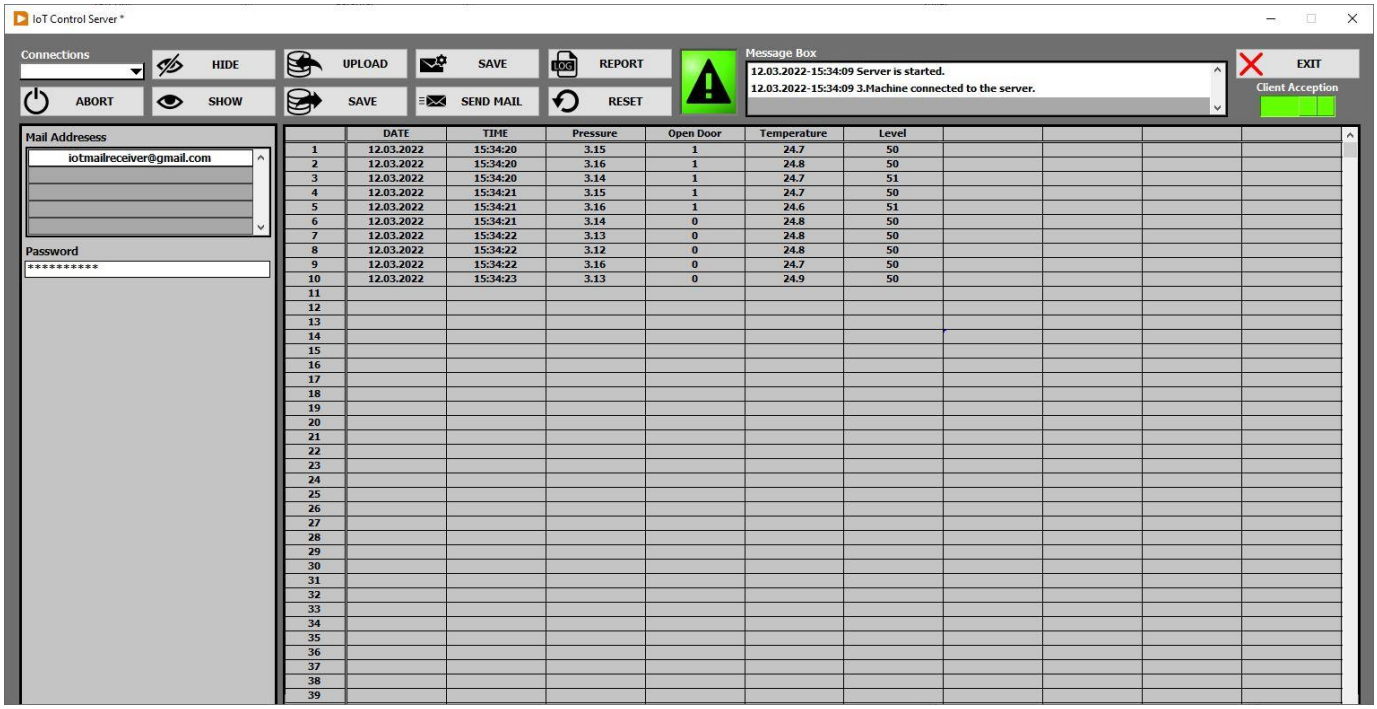

Figure 11. Server software interface

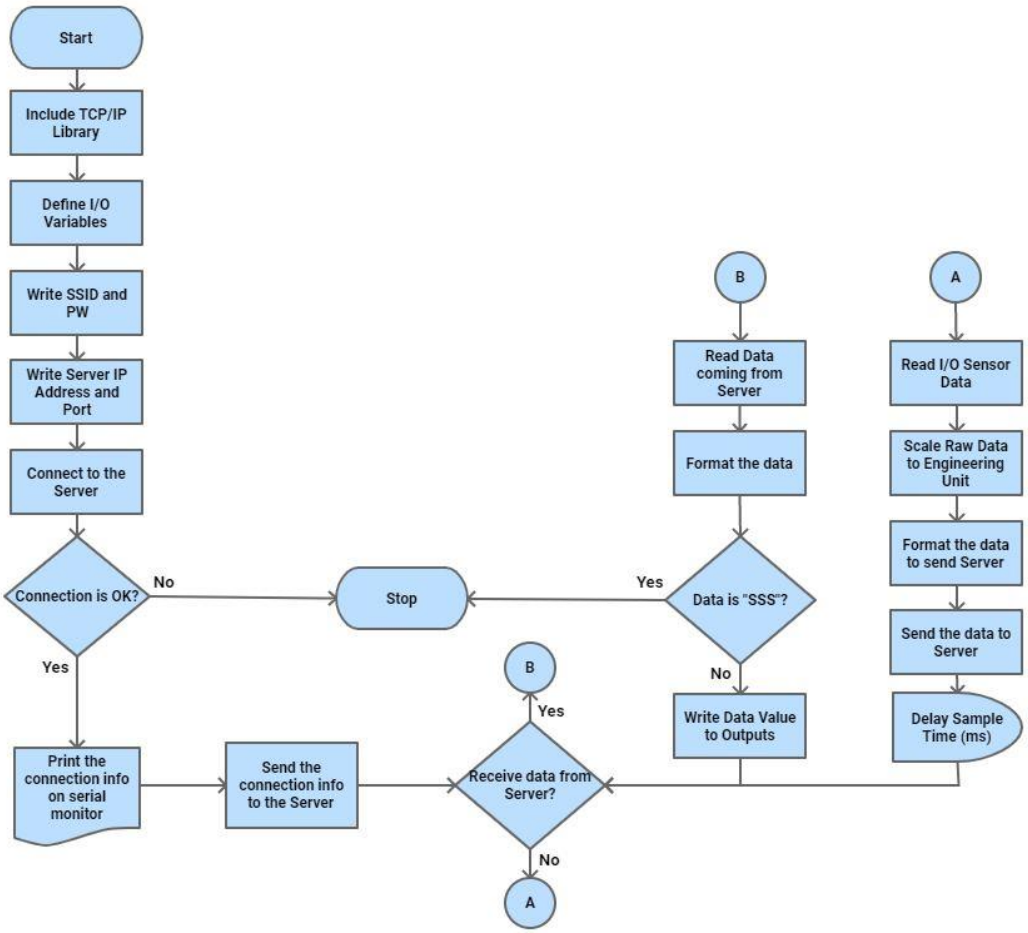

Figure 12. Software flow chart of clients

3. FINDINGS

In this study, a total of six clients, two real and four virtual, were used. By connecting different sensors to all clients, data collection processes were carried out successfully at different data collection times. Since the server receives the data asynchronously with multi-channel software, data collection was carried out full-time independent of the number of clients.

The 1st machine client in 300 milliseconds, the 2nd machine client in 200 msec, the 3rd machine client in 500 msec, the Raspberry Pi client in 300 msec and the MSP430 client in 400 msec. The server managed to collect data at intervals of at least 30 milliseconds. The client and server work simultaneously.

It has been determined that the ideal data collection time is at least 100 milliseconds in terms of ease of tracking the data coming to the computer. Data collection and data control processes do not affect each other. Data control was also provided at the time of data collection. Six clients were connected to the system sequentially and their data was collected and recorded in the database.

4. DISCUSSION AND CONCLUSION

In the implemented system, there is no theoretical limit on the number of clients to be added to the server. However, since each client used calls a template VI, it creates a processing load on the computer the server is running on. The hardware capacity of the server computer is a factor that will limit the number of clients. Six clients were run smoothly on a server computer with Intel Core-i7-4510U, dual core, quad channel, 2.00 GHz processor speed, 4 MB cache, which was used during the experimental study.

In this study, it was determined that the minimum data collection rate was 30 milliseconds. This period can be further reduced by increasing the bandwidth of the internet infrastructure used or by increasing the hardware capacity of the computer used.

Table 1. Comparison of the current thesis study with the study of Kaya et al. [2]

Parameters	Design and implementation of flexible automation systems data tracking system [2]	LabVIEW and Embedded System based New IoT Solution for Industrial applications
Sample Rate	Unclear	Min. 30 milliseconds depending on system hardware and internet speed
Cost	More cost	Less cost
Communication Protocol	TCP/IP	TCP/IP and Plug-in architecture application protocol
Scalable Structure	Not have	Easy Plug-in without stopping
Software Architecture	Static	AMC – Dynamic
Client Availability	Only PLC	Hardware independent
Maximum Client Number	8	Theoretically unlimited
Server Software Language	LabVIEW	LabVIEW
Client Software Language	PLC, LabVIEW	Software independent
Data Record Option	Text, Excel	Text, Excel, MySQL (MariaDB)
User Warning System	E-mail, LED	SMTP protocol, E-mail, LED

As given Table 1, the advantages of the current thesis study over other studies can be listed as follows:

- Instead of putting a costly computer per machine, the cost of working is reduced by using inexpensive industrial-based embedded system cards that can be connected to the monitor, called mini-computers.
- Thanks to the AMC software architecture built on the dynamic structure used in the study and the plug-in application protocol created, the cost is reduced as it becomes easy to integrate new machines to the system by connecting client cards to the server without changing the server software.
- As a hardware and software-independent client structure is created, the dependency on a single type of data collection device is eliminated, and the integration of different systems into the server increases the variety for needs.

The applications that can be made in addition to this study can be summarized as follows:

- With the mobile application, the data can be tracked on the mobile phone.
- By opening the server to the outside world with port forwarding, data can be collected from every client connected to the internet.
- The data storage size problem can be eliminated by uploading the data to the cloud system.

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