DESIGN AND IMPLEMENTATION OF A TRAINING SET FOR DISTRIBUTED SYSTEM AND MECHATRONIC APPLICATIONS: PROJECT BASED LEARNING

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Nowadays, with the development of information technology, real-time and reliable devices have been developed for users and system control. Commonly used ones are programmable logic controller and operator panels. Programming of these devices, learning the communication with the controller and the hardware installations have gained great importance especially for technical staff and engineering students. In this study, automation and control technique training sets were developed for the applications used widely in industrial applications. In the training sets, programmable logic controller (PLC) and human machine interface (HMI) were used for the control. With the training sets both automation education and control techniques such as P, PI, and PID are compared. At the same time, skills and logical programming abilities of the students studying in the training were attempted to be improved with this application. In order to measure and evaluate, 18 technical staff working in the industrial sector, 14 students studying automation engineering and eight students studying pre-license training, a group of 40 people in total was formed and performances were measured at the end of the training.

Keywords: automation; distributed system; servo systems, training set

Oblikovanje i implementacija seta za učenje za primjenu na distribuiranom sustavu i mehatronici: učenje na temelju projekta

Danas, s razvojem informatičke tehnologije, razvijeni su suvremeni i pouzdani uređaji za korisnike i upravljanje sustavom. Najviše korišteni su paneli za operatera i regulatori logike za programiranje. Programiranje ovih uređaja, učenje kako komunicirati s kontrolnim i hardverskim instalacijama postalo je vrlo važno posebice za tehničko osoblje i studente inženjerstva. U ovom radu, razvijeni su setovi za učenje tehnika za automatizaciju i upravljanje koji se uvelike rabe u industrijskim aplikacijama. U tim su se setovima za upravljanje koristili regulator logike za programiranje (PLC) i sučelje između čovjeka i stroja - human machine interface (HMI). U setovima za učenje paralelno su se uspoređivale i uvježbavale tehnike automatizacije i regulacije kao P, PI i PID. U isto vrijeme, s tom su se aplikacijom pokušavale popraviti vještine i sposobnosti logičkog programiranja obučavanih studenata. U svrhu mjerenja i evaluacije, formirana je grupa od 40 ljudi - 18 pripadnika tehničkog osoblja iz industrijskog sektora, 14 studenata inžinjerstva automatizacije i 8 studenata pripremanih za rad prije stjecanja diplome, čije su se sposobnosti mjerile po završetku obuke.

Ključne riječi: automatizacija; distribuirani sustav; servo sustavi; set za učenje

1 Introduction

Automatic control systems are the basis of many structures used in industrial applications. The main purpose of the automatic control system is automatic usage of the process after the user's control. The control is based on the principle of moving the mechanical systems with electric motors. Even though electric machines show differences in structure, all of them convert electrical energy to mechanical energy [1]. For the control used in the industrial control systems, all electric engines may not be suitable. In this case, depending on the size to be controlled, a proper motor selection must be made. While step motor or servomotors are usually used in the applications in which position control is needed, in many applications, asynchronous motors are preferred. Asynchronous motors are the most used electric motors in industry because of their simple structure, low cost and low maintenance need. Asynchronous motors are manufactured in 1-phase and 3-phase [2]. The usage of 70 % of the energy produced in the world on these motors shows their importance and usage frequency [3]. Single phase asynchronous motors are widely used in home appliances [4].

One of the biggest problems of countries trying to take steps towards industrialization is the setting up of the automation and the lack of staff who can intervene in case of any problems while at the same time checking and setting up the automation system. A special learning environment was created by gathering participants at an industrial college and engineering students. In addition to theoretical training, skills training education for practical purposes was also given to the trainees.

Various academic studies have been performed related to mechatronic applications and significantly successful results have been obtained [5, 6]. Among these studies, applications related to electrical machines and their controls [7÷13], which may provide contributions to engineering education, coincide in the literature. In addition, virtual lab applications are also very prevalent.

In today's world, asynchronous motors are used much more commonly to meet electro-mechanical energy needs. The disadvantage of AM when compared to Direct Current (DA) motors is that they require complex control and transformation algorithms. The reason for this is that the machine has a nonlinear structure. Developments in power electronics have made the semi-conductor circuit elements with high current and high voltage available as reliable and economically beneficial. Thus in a very wide power range, it is possible to produce frequency and voltage adjustable systems which are needed for the speed and moment control of the AM. Nowadays, AM's are controlled by microprocessor-controlled power electronics circuits. Use of automation systems is considered to be one of the methods used to increase the speed and quality of production in industry. The network is an important component in automation systems. Many different network structures are used in these systems [1].

2 Materials and methods

2.1 Human Machine Interface (HMI) and Programmable Logic Controller (PLC)

Programmable logic controller (PLC) is an intelligent device used to perform command and control circuits of industrial automation systems [14]. PLC is also an important control unit automatically running the program posted in the internal structure according to the user requirements. Depending on the developed technology, PLCs have started to be used widely in industrial automation circuits. Today's PLCs also contain commands for making arithmetic and special mathematical operations in addition to logic-based transactions. As a result of the expansion of the command set, more complex command and control functions are performed [15]. HMI are touch screens, through which users can control the system, used widely in industrial applications. They are also referred to as a kind of mini-computer. In this study, in order to provide user control, an NB series Omron brand operator panel was used and training was provided. The developed training sets have PLC-based and HMI control; the flow diagram of the training sets is given in Fig. 1.
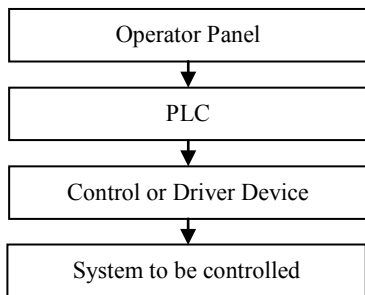

Figure 1 Flow diagram of the training sets setup

In order to develop the software of the operator panel, the algorithm in PLC used as a controller must be completed. Addressed data suitable to the developed algorithm and the addresses at which these data can be reached must be defined. Software developed as object-oriented by using operator panel software was installed in the internal memory of the operator panel through a USB port. Omron NB-Designer program suitable for the hardware was used for the software of the operator panel. An important feature of NB-Designer program is that it can run simulations.

2.2 Installation of experiment sets

Due to the frequent use of electrical machines in industrial applications, it is important for students studying in these areas to master the subject. Solving problems about the systems they might encounter for graduate students and the staff working in this area is possible with education [16].

Industrial control systems are used in every aspect of our daily lives, mainly in materials handling and formation machines. Knowing the working principles of electrical machines, obtaining their characteristics, and understanding the reactions in various load and working conditions are extremely important. For this reason, faculty members teaching in the field of industrial control systems should support theoretical education with practical experiments. The quality of the education given to students about this subject can be achieved by practical knowledge transfer in addition to intense theoretical knowledge. Supporting the theoretical knowledge given in education with the application increases the stability in education [17]. Students must have the choice of how they can learn with an intense education and test opportunity as well as their own learning styles [18].

Considering the current control systems, versatile, sophisticated and easy to understand training sets are needed in order to teach these subjects. Training sets are available in control systems in the commercial sense. In these training sets, alternative current (AC) or direct current (DC) motors are used and one-way position and speed controls are performed. In addition, these types of training sets are based on developing hardware and software running this hardware; one-way control was provided by using operator control panel or computer. For the motors used in this study, speed control depending on the user's requirement, position control, directional control and automatic working mechanism have been formed. In addition to these, control techniques such as P, PI and PID and stability of the control systems are described.

2.3 Three phase asynchronous motor setup and test results

For 3-phase asynchronous motors, speed, rotation and torque control applications can be made. With the training set, a flexible structure where control methods such as P, PI and PID can be used was established. The training set about which education was given and the HMI control units are shown in Fig. 2a and 2b.
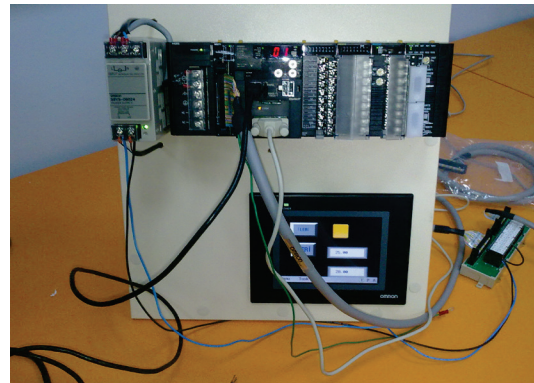
a) Three-phase asynchronous motor training setup

b) HMI control panel
Figure 2 AC motor training set

Block diagram of training set developed for the applications of three-phase asynchronous motor is given in Fig. 3.
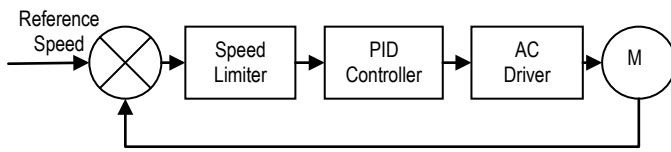

Figure 3 Block diagram of sensor less asynchronous motor control

Stator phase currents obtained by using Vissim program, speed and torque graphs are given in Figs. 4, 5, 6 and 7, respectively.
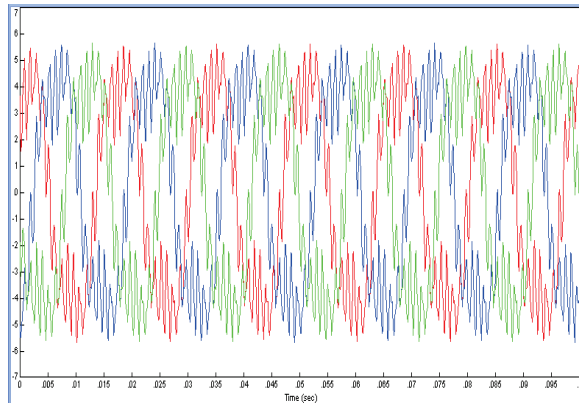

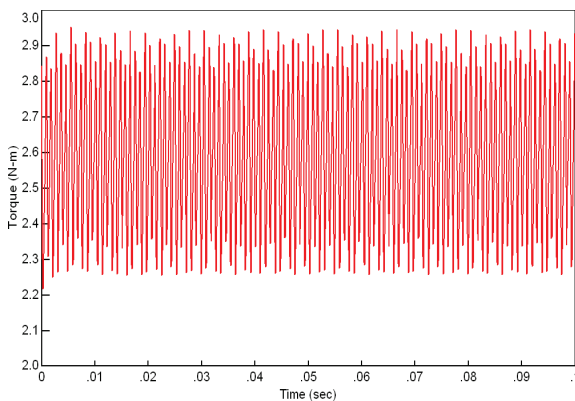**Figure 4** The stator phase currents graph

Figure 5 Torque graph
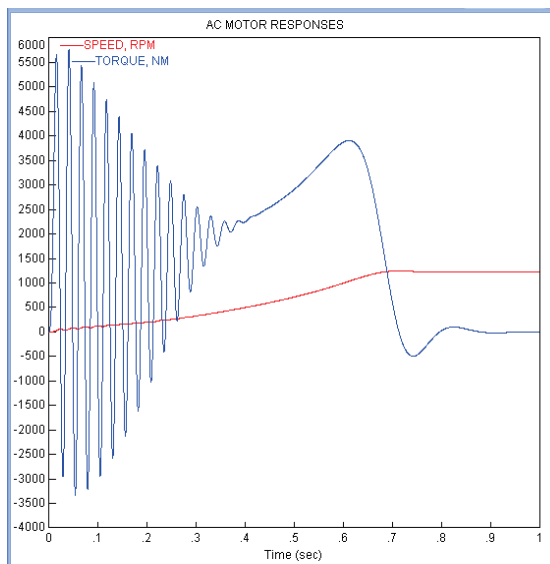

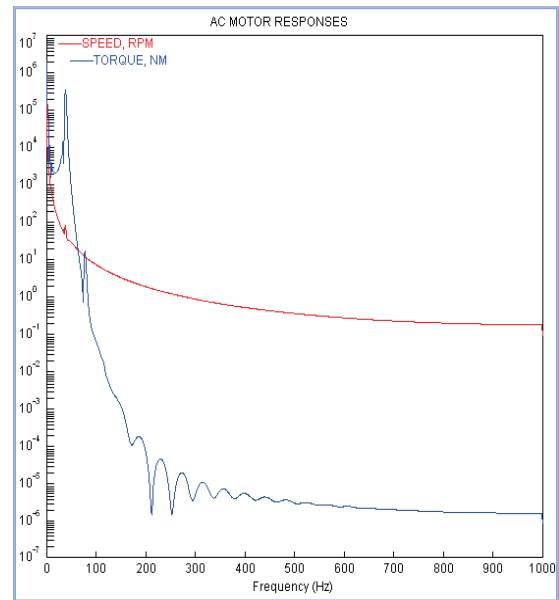**Figure 6** AC motor speed and torque graph (t-domain)

Figure 7 AC motor speed and torque graph (z-domain)

2.4 Servomotor test setup and test results

With the servomotor training set, a structure which can achieve the control of position, speed and direction was formed. By using PID function located in Omron CX-Programmer software, the effects of control techniques have been investigated. Measurements depending on the operating mode of the servomotor were performed using P, PI and PID control techniques on servo control system. With Proportional gain (K_p), Integral gain (K_i) and differential gain (K_d) parameters, the most appropriate step response was attempted.

Speed, position and torque control model developed for servomotor experimental set is shown in Fig. 8.
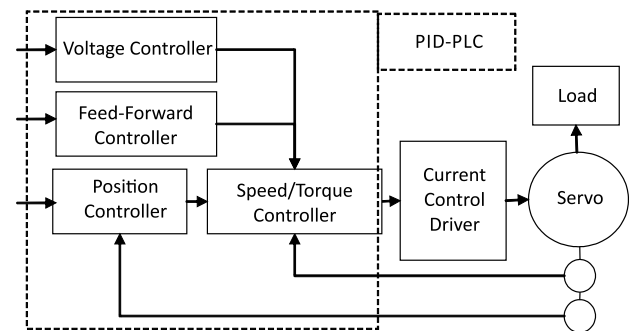
Figure 8 Servomotor control block diagram

The purpose of motor speed control by close circuit system is to adapt the output magnitude to the desired reference value. In servomotor surveillance, speed and position information can be obtained by tachometer, encoder or potentiometer from the motor shaft [19÷21]. In this study, feedback was achieved by encoder.

As the hardware unit of the servomotor control experiment set, servomotor, driver, PLC, HMI and computer are present. In the software unit the software for realization of PLC, HMI and SCADA application is present.

Servomotor experimental set and screenshot of HMI control panel are shown in Figs. 9a and 9b.
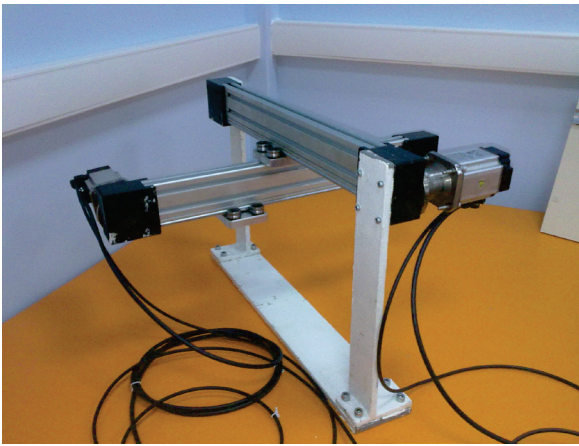
a) Servomotor test setup

b) Screenshot of HMI control panel
Figure 9 Servomotors training set

Servomotor technical properties are shown in Tab. 1.

Table 1 Servomotor technical properties

Servomotor		
Nominal power		400 W
Nominal torque		1,3 N·m
Nominal speed		3000 r/min
Maximum rotation speed		6000 r/min
Maximum torque		3,8 N·m
Nominal current		2,4 A(rms)
Maximum current		10,2 (0-p)
Rotor Inertia	Without brake	$0,26 \times 10^{-4}$ kg·m^2
	With brake	$0,28 \times 10^{-4}$ kg·m^2
Mechanical time constant	Without brake	0,43 ms
	With brake	0,46 ms
Electrical time constant		3,4 ms

In the servomotor control system, three different position options are presented. The first one of these is to move in the current position; for example, let us say servomotor moved 20°, if the user wants it to move 12°, then the servomotor will be moved with a total angle of 42°. The second case is done by moving servomotor to the home position. For example, assuming that the servomotor moved 12°, when the user wanted it to move 22°, then servomotor comes to the home position first and it moves a total of 22°. The last position is the angular control done according to the current situation. With this option, the user enters the desired angles step by step to the servo. For example, the user first decides whether he/she wants to bring the servo in the home position or not. If the user wants it in the home position, it comes to the point which is accepted as the starting point automatically. After this decision, the user can position the servo by entering many step values such as 1° for step 1, 5° for step 2, 4° for step 3 etc. If the home position was not chosen, first position values are obtained by summing the current position and the value entered in the first step, the next steps continue by adding them to the previous position value. In this way, the user can pose a prescription for the position of the servo. Driving circuit depending on the position values that the user entered in all three options is given in Fig. 10.
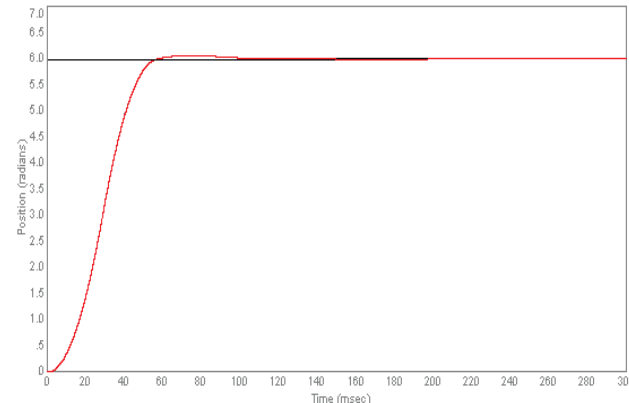

Figure 10 Position control step responses

One of the most important factors used in servomotor systems is to ensure the motor goes to the desired position with the desired speed in the fastest time. In order to reduce the settling and excess times, many control algorithms are applied. In the training sets, P, PI and PID control methods were applied to the servomotor to minimize these times and to show the time differences between the control techniques. Proportional controllers have the effect of reducing the rise time, but they cannot eliminate it completely (the steady-state error). Integra controller (K_i) has an effect on deriving steady state error but this may cause poorer transient response. Differential control (K_d) has an effect on the increase of system stability; it reduces the overshoot and improves the transient response.

These corrections are not exactly valid, because K_p, K_i and K_d are dependent on each other. In other words, change of one of the variables might change the effect of the other two. Therefore, the table is a reference in order to determine the values of K_i, K_p and K_d [22]. The example of PID controller usage in PLC is shown in Fig. 11 [23].
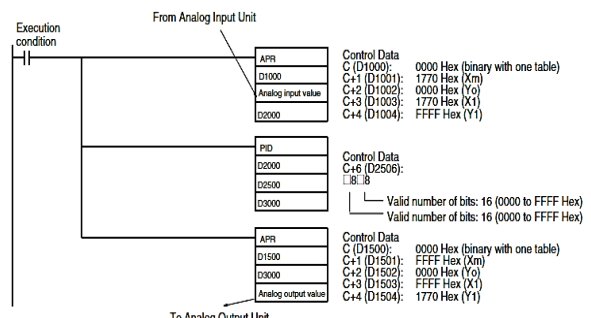

Figure 11 PID usage in PID, Ladder diagram example

PID parameters can be manually adjusted or automatically adjusted through the auto tuning option, which can be selected from the PID parameter adjustment menu placed on the operator panel. PID adjustment window menu is shown in Fig. 12. User has the opportunity to change (numerically) the K_p, K_i and K_d values of PID parameters. Also, the user has the opportunity to change acceleration and deceleration time values in the same window.
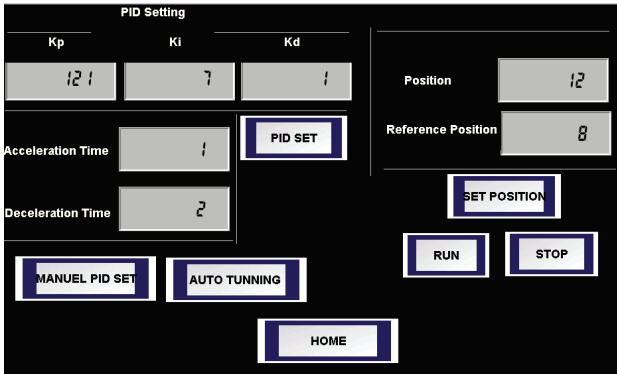

Figure 12 PID parameter adjustment window

Unit step response of Proportional control (P), Proportional-Integral (PI) and Proportional-Integral-Differential (PID) controls used in the servomotor control are presented in Figs. 13, 14 and 15, respectively. In addition, unit step response depending on different values of P-, I and D parameters are shown in Fig. 16.
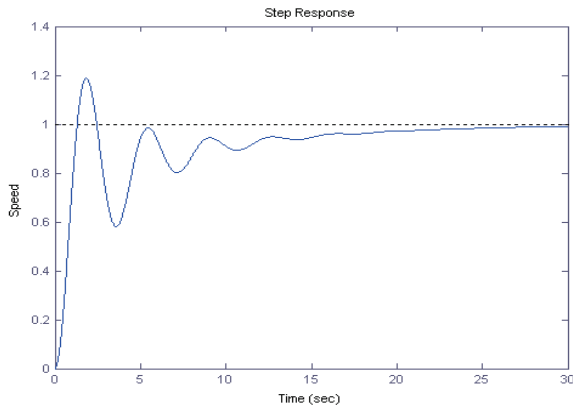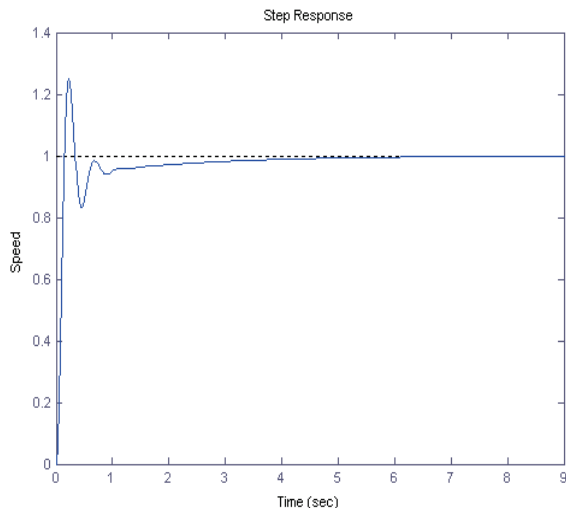

Figure 13 P Control

Figure 14 PI Control
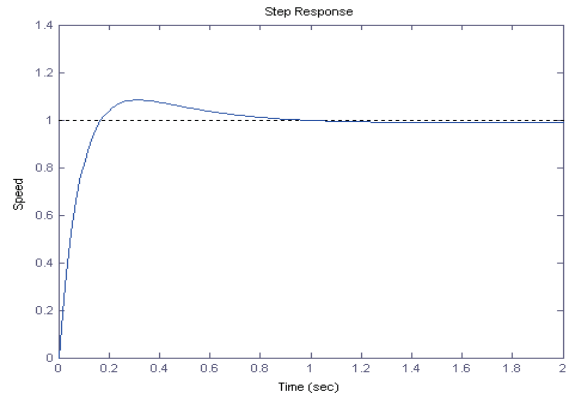
Figure 15 PID Control
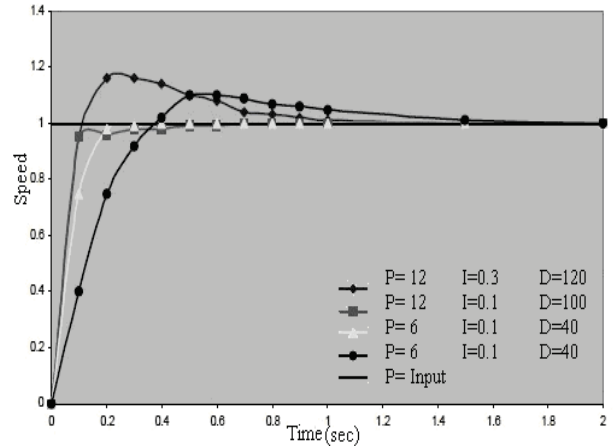
Figure 16 PID control step responses

3 Advantages of the training set

The advantages of the developed training set are as follows;

Since the training sets can be controlled and used in a very versatile way, many applications can be done.

Checking process can be achieved through the network with the training set.

Learning can be improved by animation and simulation techniques.

It has an active learning module as a result of the online simulation feature of PLC and HMI.

It is possible to update the training set software without any hardware change.

4 Overview and comparison

While education sets are designed, a structure is aimed at where frequently used motors will be checked and distributed systems will be checked as well. For the study, Omron brand PLC, driver and motors were preferred. Especially in the control of intensely precise processing benches, providing feedback and performing surveillance operations and accordingly producing algorithms bring pressure on users. As also mentioned in the aim of this study, creating a mathematical model in programs such as Matlab in order to obtain the optimum control parameters in speed, location and torque control applications of motors having the ability of precise working such as servomotors is obligatory. Thanks to this education set, trainees solved this problem easily.

The most important property which separates this

study from others is that these types of experiment sets are generally produced separately and many trials are made on the experiment sets in order to obtain control parameters. In this study, the proposed experiment sets and control parameters were obtained by various methods and real time information was conveyed to the system. Accordingly, PID parameters, auto tuning or manual tuning opportunities have been provided for servomotor or asynchronous motor applications. A single structure has been created for asynchronous and servomotor applications, which are two types of motors that are widely used in industrial applications. This also constitutes a new experiment set developed for distributed systems. Considering the education set functionally, initially a common platform was formed for mechatronic applications and the functions of four or five education sets were redounded to single set. The applications that can be performed with these education sets can be summarized as follows:

Studies related to PLC programming, SCADA project preparation, program simulation, digital input/output applications, analog input/output applications, installation applications, on/off control, regulation and monitoring of servomotor parameters, loaded/unloaded speed, position and torque control and monitoring of servomotors, regulation and monitoring of asynchronous motor parameter values and loaded/unloaded speed, position and torque control and monitoring of asynchronous motors. On the user side, all mechanisms that can be observed in industrial applications are present for these surveillance systems. These are HMI, SCADA and control through PC. When these properties are examined, considering that the prices of current education sets are between USD10,000 – USD15,000 depending on their functions, the developed education set costs almost half this amount. This proves that the education set is economically superior as well.

Another important dimension of this study is that groups having different education levels and groups that are employed in or have education in the mechatronic field have been gathered. When national and international studies about education are examined, it is observed that studies have been focused and evaluated on a single group. Thanks to this course, the interaction of the trainees in three different groups played an important role in the success of the course. The education period being four months is another important detail of this study. Generally, this kind of course lasts a maximum of one week, special applications are explained and an increase in hand skills is not expected. On the other hand, considering as academic education, the fact that this education will last for years is also a disadvantage. For this reason, the study is considered to be one of the concrete steps in university-industry cooperation in terms of the variety of trainee groups and property of education periods.

5 Measurement and evaluation

A group which consisted of 18 technical staff working in the industrial sector, 14 undergrad engineering students and eight community college students was formed. A 4-month training program was applied to this

group. In addition to the theoretical education given through training, applications also had an important place. At the end of the training, the questions shown in Table II were asked and a measurement-evaluation was performed.

Table 2 End of training survey for trainees

Opinions	Trainees feedback		
	Completely agree (%)	Partially (%)	Disagree (%)
Course duration adequacy	84	12	4
Suitability of the course content to the application	87	13	0
Adequacy of the equipment and the documents for effective and efficient application of the course program	92	8	0
Presentation of the subject with the appropriate methods and techniques	93	6	1
Effective and efficient use of time	90	5	5
Teaching the subjects is clear, understandable and appropriate to the level of the participants	86	8	6
Informing the participants about finding the information and using the related sources	78	18	4
Motivation and communication skills	82	10	8
Associating the course content with the current issues and studies	98	1	1
Associating the course contents with the course participants' work area	90	5	5
The course provided a positive contribution to the development of my abilities	89	6	5
The course has given me new knowledge and skills	96	4	0
The course improved my motivation	87	9	4
It helped me to gain new knowledge and skills I can apply in my organization	88	10	2
I gained new professional knowledge and skills that I can share with my colleagues.	98	2	0
Training has increased my interest in the subject	90	6	4
Having trainees from different places increased my motivation	95	4	1
My PLC programming skills have been increased	88	10	2
My HMI programming skills have been increased	88	10	2

When the trainees' responses are examined, the percentage of those who marked the option of disagree was 2,5 %, the rate who chose the option to partially agree was 7,5 %, and the rate of those who chose the option of I agree was 90,0 %.

The study was evaluated on a group of 40 trainees and the performance of the groups of which all trainees participating in the course were members was evaluated so as to cover the period before and after the end of the course. The analysis results performed before and after the course were evaluated for all three groups. As the population we are working on consists of 40 people, no sampling was performed. The entire group which received education was taken into consideration. Also, non parametric hypothesis test was used depending on the

number of staff in the studied group. First of all, the hl hypothesis, namely "There is a statistical difference between the education final scores for the groups which trainees are a part of." was tested. Kruskal Wallis test was used for the test and the analysis results are shown in Tab. 3. According to Tab. 3, it is observed that the tested hypothesis is correct. (Asymp. Sig. <%5).

Table 3 Evaluation analysis results of the education

Test statistics a, b						
Type	N	Mean rank	Chi-square	df	Asymp sig.
Technical Staff	18	25,00			
Automation Engineering Staff	14	23,2	34,914	2	,000
Prelicense Training Staff	8	4,56			
Total	40				
a. Kruskal Wallis Test					
b. Grouping Variable: Type					

As a result of the analysis, binary comparisons were conducted in order to observe which group caused the difference and the results are shown in Tabs. 4, 5 and 6. (Mann-Whitney Test U was used in binary comparisons.) When the obtained results were examined, it was observed that there was no difference between employees in Technical Staff and the trainees receiving automation engineering education. (When Exact. Sig > 5 % h0 hypothesis is accepted, in case of contrary h1 is accepted)

Table 4 Evaluation analysis results between industry staff and groups having automation engineering education.

Ranks				
	Tip	N	Mean rank	Sum of ranks
A	Technical staff	18	17,00	306,00
	Automation engineering	14	15,86	222,00
	Total	32		

Test statistics[b]	
	A
Mann-Whitney U	117,000
Wilcoxon W	222,000
Z	−1,134
Asymp. Sig. (2-tailed)	,257
Exact sig. [2*(1-tailed Sig.)]	,750[a]
a. Not corrected for ties.	
b. Grouping variable: Type	

Table 5 Evaluation analysis results between industry staff and groups having associate degree education

Ranks				
	TIP	N	Mean rank	Sum of ranks
A	Technical staff	18	17,50	315,00
	Prelicense training staff	8	4,50	36,00
	Total	26		

Test statistics[b]	
	A
Mann-Whitney U	,000
Wilcoxon W	36,000
Z	−4,891
Asymp. sig. (2-tailed)	,000
Exact Sig. [2*(1-tailed Sig.)]	,000a
a. Not corrected for ties.	
b. Grouping variable: TIP	

The fact that there was a difference between employees working as technical staff and trainees having associate degree education and that there was a difference between those having automation engineering education and those having associate degree education are shown in Tabs. 5 and 6.

Table 6 Evaluation analysis results between groups having automation engineering and groups having associate degree education

Ranks				
	Type	N	Mean rank	Sum of ranks
A	Automation Engineering	14	15,46	216,50
	Prelicense Training Staff	8	4,56	36,50
	Total	22		

Test Statistics[b]	
	A
Mann-Whitney U	,500
Wilcoxon W	36,500
Z	−4,251
Asymp. Sig. (2-tailed)	,000
Exact Sig. [2*(1-tailed Sig.)]	,000[a]
a. Not corrected for ties.	
b. Grouping Variable: Type	

On the other hand, the analysis results performed according to trainee groups are shown in Tabs. 7 and 8. At this point, the proposed hypothesis namely "effect of education program before and after the course on trainees" and if it is effective "its effect in basis of groups" was tested.

Table 7 Evaluation analysis before and after the course

Ranks				
		N	Mean rank	Sum of ranks
After- Before	Negative ranks	0[a]	,00	,00
	Positive ranks	31[b]	16,00	496,00
	Ties	9[c]		
	Total	40		
a. After< Before				
b. After> Before				
c. After= Before				

Test Statistics[b]	
	After- Before
Z	−5,568[a]
Asymp. Sig. (2-tailed)	,000
a. Based on negative ranks.	
b. Wilcoxon Signed Ranks Test	

Table 8 Effect of education program before and after the course on basis of groups

Ranks					
Type			N	Mean Rank	Sum of Ranks
Technical Staff	After Before	Negative Ranks	0[a]	,00	,00
		Positive Ranks	14[b]	7,50	105,00
		Ties	4[c]		
		Total	18		
Automation Engineering	After Before	Negative Ranks	0[a]	,00	,00
		Positive Ranks	11[b]	6,00	66,00
		Ties	3[c]		
		Total	14		
Prelicense Training Staff	After Before	Negative Ranks	0[a]	,00	,00
		Positive Ranks	6[b]	3,50	21,00
		Ties	2[c]		
		Total	8		
a. After< Before					
b. After> Before					
c. After= Before					

Test Statistics[b]		
Type		After- Before
Technical Staf	Z	-3,742[a]
	Asymp. Sig. (2-tailed)	,000
Automation Engineering	Z	-3,317[a]
	Asymp. Sig. (2-tailed)	,001
Prelicense Training Staff	Z	-2,449[a]
	Asymp. Sig. (2-tailed)	,014
a. Based on negative ranks.		
b. Wilcoxon Signed Ranks Test		

As observed in the analysis results in Tab. 7, as the Asymp. Sig. (2-tailed) value is smaller than 5 % the

hypothesis namely "effect of education program before and after the course on trainees" is accepted to be correct.

The analysis results related to the effect of the education program before and after the course on the basis of groups are shown in Tab. 8.

According to Tab. 8, hypothesis was accepted for each group. When the findings obtained from analysis results were examined it was observed that the trainees employed as technical staff completed the course more efficiently. They were followed by the students having automation engineering education. Trainees having associate degree education were ranked last. The reason for that is interpreted as the lower (compared to the other two groups) theoretical and practical knowledge of trainees having associate degree education.

6   Conclusion

The best learning method for people working and studying in the automation field is 'try and see'. With the automation and control techniques training set, in addition to the training of HMI and PLC, essential elements of automation systems, programming, hardware installations, control techniques, and practical education are given. In the evaluation survey, the participants stated that in addition to hardware installation of PLC and HMI, their programming skills have been increased by 88,0 %. The study is also an example of applications within the framework of university-industry cooperation.

7   References

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