Development of a Prototype Machine Shop Safety System for Vocational Training

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ABSTRACT

In this research, a sample of machine shop safety automation was designed in order to prevent occupational accidents taking place in machine shop environments. The developed prototype system is a special occupational safety system with PLC and HMI controls. The prototype system checks spindle speed, machine safety covers and machine collision safety. The system is also used for determining the parameters of environment lightening and temperature.

The developed system was tested in conjunction with use of the area and machines by students of Namik Kemal University Corlu Engineering Faculty Machinery Laboratory. In the experimental studies which were done, it was determined that the developed system worked successfully provided that the students did not work above determined spindle speed values. The system functions to prevent damage or injury which may occur as a result of the collisions in machines as well as ceasing the operations when the system is utilized without the safety and protection covers.

Keywords: Occupational safety in vocational training, occupational safety, occupational safety automation

Mesleki Eğitim Uygulamalari için Prototip Bir Atölye Güvenlik Sisteminin Geliştirilmesi

ÖZ

Bu araştırmada, atölye koşullarında meydana gelen iş kazalarının önlenebilmesi amacı ile örnek bir atölye güvenlik otomasyonu tasarlanmıştır. Geliştirilen prototip sistem, PLC ve HMI kontrollü özel bir iş güvenliği sistemidir. Prototip sistem torna tezgahlarının çalışma devirlerini, makine güvenlik kapaklarının kullanım durumunu ve makine çarpma güvenliğini denetlemektedir. Ayrıca sistem ortam aydınlatma ve sıcaklık parametrelerini denetlemek için de kullanılmaktadır.

Geliştirilen sistem, Namik Kemal University Corlu Engineering Faculty Machinery Laboratory öğrenci uygulamaları esnasında test edilmiştir. Yapılan deneysel çalışmalarda geliştirilen sistemin öğrencilerin belirlenen değerlerin üzerindeki çalışma hızlarında çalışmalarına izin vermeyerek başarılı bir şekilde çalıştığı saptanmıştır. Sistem güvenlik ve koruma kapaklarını kullanmadan çalışmalara engel olduğu gibi makinelerde çarpma sonucu oluşabilecek zararları da engelleyebilmektedir

Anahtar Kelimeler: Mesleki eğitimde iş güvenliği, iş güvenliği, iş güvenliği otomasyonu, PLC

1. INTRODUCTION (GİRİŞ)

Certainly, early investments in preventing work-related accidents are ultimately less expensive and more humane than the results and costs associated with work-related accidents. An estimated 2.34 million people die each year from work-related accidents and diseases. Of these, the vast majority, an estimated 2.02 million, die from a wide range of work-related diseases. Of the estimated 6,300 work-related deaths that occur every day, 5,500 are caused by various types of work related diseases. The ILO also estimates that 160 million cases of non-fatal work-related diseases occur annually in the world [1].

Every year, young people start working, often in hazardous workplaces, with a lack job knowledge and experience, and are highly subject to the risk of injury [2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. According to Wallen and Mulloy (2006), one of the central paradoxes of education is the ability of learners to make use of newly acquired knowledge outside of the classroom or learning environment. Frequently, learners who appear to have acquired certain knowledge and skills and can answer questions in the classroom are unable to apply this knowledge and skill in work settings [13]. Although many countries have long-established occupational training systems, educational institutions having integrative laboratory systems are lacking adequate safety literature. As a result of this, the protection against work-related accidents which may occur during the vocational training practices is a main target in this research. Individual security precautions are taken for the students receiving vocational training in order to protect themselves against work-related accidents which they may be exposed to during machine shop practices. The development of a widespread approach for

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integrative occupational safety systems in educational institutions will provide safer occupational training opportunities and will pave the way for the students to receive vocational training in a safer environment.

An experimental setup was presented based on the ABB IRB 2400L robot by Ruz et al. (2012). This setup was designed for the analysis of safety systems that use radio frequency technology. Using this setup, it is possible to emulate some tasks carried out by workers in or near specific areas that pose particular risks for workers, such as an increased likelihood of gashing hands or losing fingers. An RFID prototype was presented in the previous work [15]. This prototype was designed to produce an emergency stop upon detection of a risky situation such as the introduction of a worker's hand into the dangerous area.

In recent years, some studies have been conducted to address specific applications in industrial safety with RFID technology. For example, Chae and Yoshida (2010) propose the application of RFID to prevent collision accidents with heavy equipment such as hydraulic excavators and cranes [14].

Work-related accidents are preventable provided a systematic safety approach is carried out in enterprises and safety systems are developed and in place. Technological advances can give rise to improvement in productivity and in occupational health and safety [17].

The research focuses on a central and safe automatized approach for machinery shops and laboratories. Each machine shop has its own independent safety risks and applicable protocols according to its own safety standard. These precautions are generally the ones which have been set by CE norms and they don't intervene in working conditions. The workers set spindle speed of the machines and overloading conditions by themselves. In such occasions, work-related accidents mostly occur as a result of exceeding the limits of the machines. The applicable system also checks spindle speed of the machines and overloading conditions while following general safety precautions applied to machines according to CE standards.

On manually operated machines, the most dangerous machine movements are the rotating, cutting, shearing, sawing or pressing movements of tools, particularly on: Presses, drilling machines, milling machines, lathes, metal cutting saws, guillotines and grinding machines. Hands are most frequently injured, the most numerous injuries being cuts and abrasions, many of which are severe. Broken bones and dislocations are also numerous, while amputations of fingers and hands are less frequent. There are some fatalities, often arising from entanglements, every year. Eye injuries are also common [18].

According to Ruz et al (2012), industrial safety is a constantly developing and evolving field, and yet there are still aspects that require improvement. In particular, the importance of reducing the risk of accidents in the machinery sector is emphasized by several regulations, such as the Machinery Directive [19]. Worker safety must be secured as much as possible, especially when potentially hazardous machinery is involved. There exist a variety of situations in which a worker needs to handle pieces that extend out of the operation region, or that require precise placement on the machine. Due to the flexibility needed in metal manufacturing processes, there are occasions where the use of standard guards or devices (e.g. physical barriers or light curtains) is infeasible.

Workers between the ages of 15 and 25, along with those who had worked for less than six months, were exposed to more occupational accidents when compared with all other workers (p=0.002, p=0.001, respectively) [20].

In this research, one of the main objections is the development of a safe prototype automation system as a substitute to human interaction which is also practical and easily applicable. The struggle against work-related accidents will become should advance as long as it is carried out by automation systems which have been purged from human involvement with the developing technologies.

2. MATERIAL AND METHOD (MALZEME VE YÖNTEM)

2.1. Material (Malzeme)

The research was carried out in manufacturing laboratory of Namik Kemal University, Corlu Engineering Faculty, Department of Mechanical Engineering (Fig. 1). In the research, four desktop lathes which existed in the manufacturing laboratory were used.

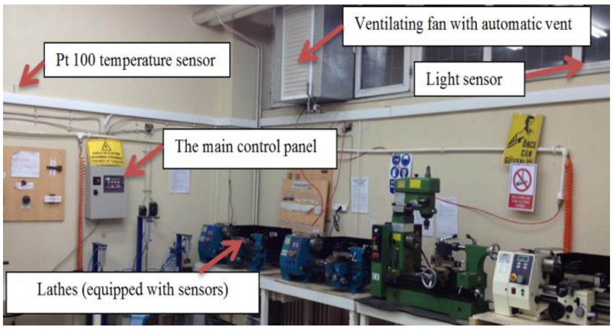

Figure 1. Manufacturing laboratory (İmalat laboratuvarı)

The manufacturing laboratory is ventilated with a ventilating fan which works with a triphase 0.3 Kw electric motor in diameter of 50 cm. There is a vent with electro-pneumatic control in front of the fan which is controlled by the developed system. The compressed air of 6,5 bar needed by the laboratory is provided with screw type compressor. Enda ELC-186R PLC as Programmable Logic Controller (PLC) and two expansion modules were used in the developed safety system. These are digital input / output module and thermocouple modules. The CPU's which support Modbus TCP can be used in all SCADA applications.

Enda Soft PLC editor and compiler was used as PLC programmer.

HMI (Human Machine Interface) panel was used for controlling and alterations of system parameters through main control. The operator panel used is compatible with many known PLC brands. HMI screen program was created by using Enda V1.6 Enu HMI programmer editor and compiler.

Inductive proximity sensors were used for machine speed, controlling of safety covers and safeguarding system bread downs. Sensors are PNP output with 4 mm detection length and M8 scale.

Temperature controller was used for controlling environment temperature. The controller which was used provides temperature measurement with a PT100 temperature sensor. Depending upon the exceeding condition of determined temperature limit values, the controller used switches ventilating fan and vent into working position or stops them automatically.

The laboratory lightening system is checked by a light sensor in order to obtain appropriate lightening values regularly, which is described as 100-200 lux (HSG, 1999) in terms of occupational safety.

The electronic controller unit consists of a fuse unit and a contactor group which provides mechanical control of the system according to the signals coming from electronic controller unit. The control of the main contactor was by remote control on the developed system. In case of an accident which may occur while working, the one who is responsible for the machine shop can prevent the work-related accident from escalating by shutting off the machine shop contacts remotely instead of racing to shut off the master switch. Likewise, a button typed emergency switch was placed under the main panel (Fig. 2).

2.2. Methods (Yöntem)

The designed prototype occupational security system was designed in such a way that rom one center it can observe spindle speed of the machines connected to the system in the machine shop environment and the condition of safety applications instantaneously and it also can stop the working of the machines by shutting them off when necessary. The system has a flexible developable design where different sensors and controllers can be joined. Four lathes and the machine shop environment are monitored through a system which is controlled by a central operator panel. Connecting RS485 port of PLC to the HMI operator panel, the communication was carried out by the protocol of mod bus. The prototype safety automation with PLC-based designed in the research centrally observes and controls the machines according to the data being received from proximity sensors assembled on lathes. On the subject of occupational safety and worker's health which is the main topic of the research, it was aimed to provide appropriate environment conditions for workers by checking the parameters (temperature and light intensity) affecting negative environment conditions which arise out of machine shop conditions with the help of sensors used. The ventilation system and the lightening system are put into use when the quality of air and light isn't appropriate for the environment.

Working conditions are observed constantly by means of HMI operator panel used in the developed system and the data taken from the sensors can be recorded in a flash disk assembled on the panel.

The automation program of the system was designed by using Enda PLC and Endasoft PLC programming editor and its compiler is presented in Fig. 3.

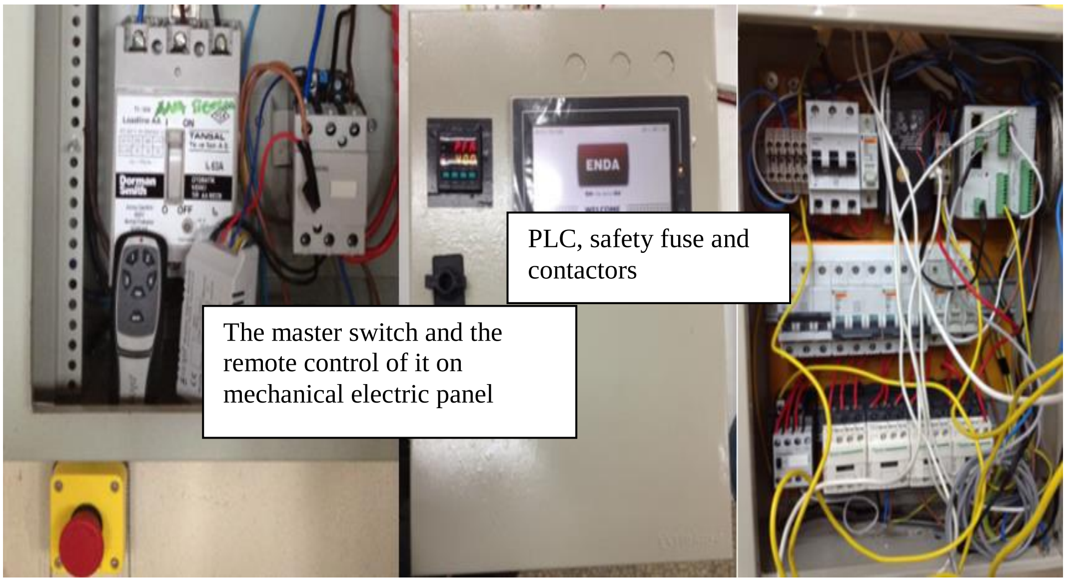

Figure 2. Electronically control cabinet of the system (Elektronik kontrol panosu)

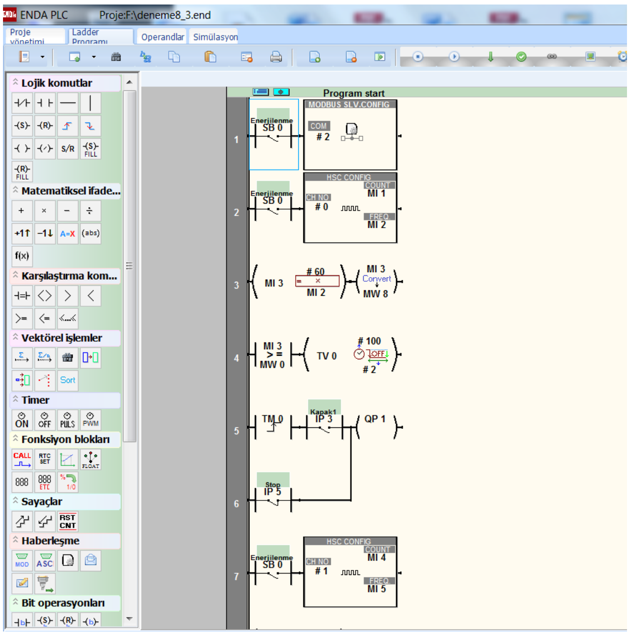

Figure 3. Endasoft PLC programming editor/compiler and a short view of program (Endasoft PLC programlama editor programı)

The data coming from sensors with the software generated by ladder programming method is evaluated by PLC and necessary operations are done. The system algorithm is presented in Fig. 4. This algorithm is a flexible expandable form depending on the purpose with different software and different sensors to be attached accordingly.

Observing and controlling of the developed safety system by users is carried out by means of HMI operator panel. The user can follow spindle speed and the condition of safety covers at all times via this panel. Additionally, desired spindle speed restrictions for machines can be controlled and set values for spindle speed can be entered by interacting with spindle speed area of the associated machine via the panel. The system shows the current working condition in real time but it turns off the associated machine when the set limiting values are exceeded.

In the research, the connections to be established between sensors used and PLC's have critical importance. The spindle speed measurements of lathes are carried out by proximity sensors (Fig. 5).

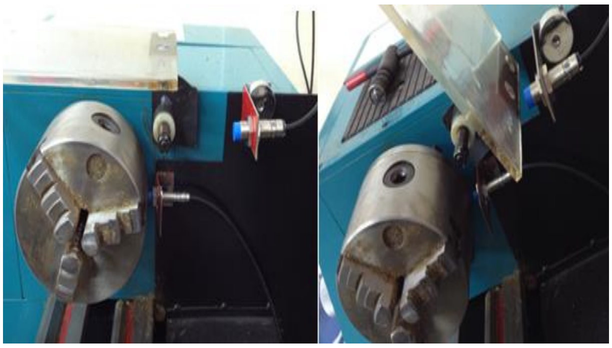

Figure 5. Spindle speed control sensors assembled on lathe (Devir control sensörlerinin torna tezgahı üzerindeki montajı)

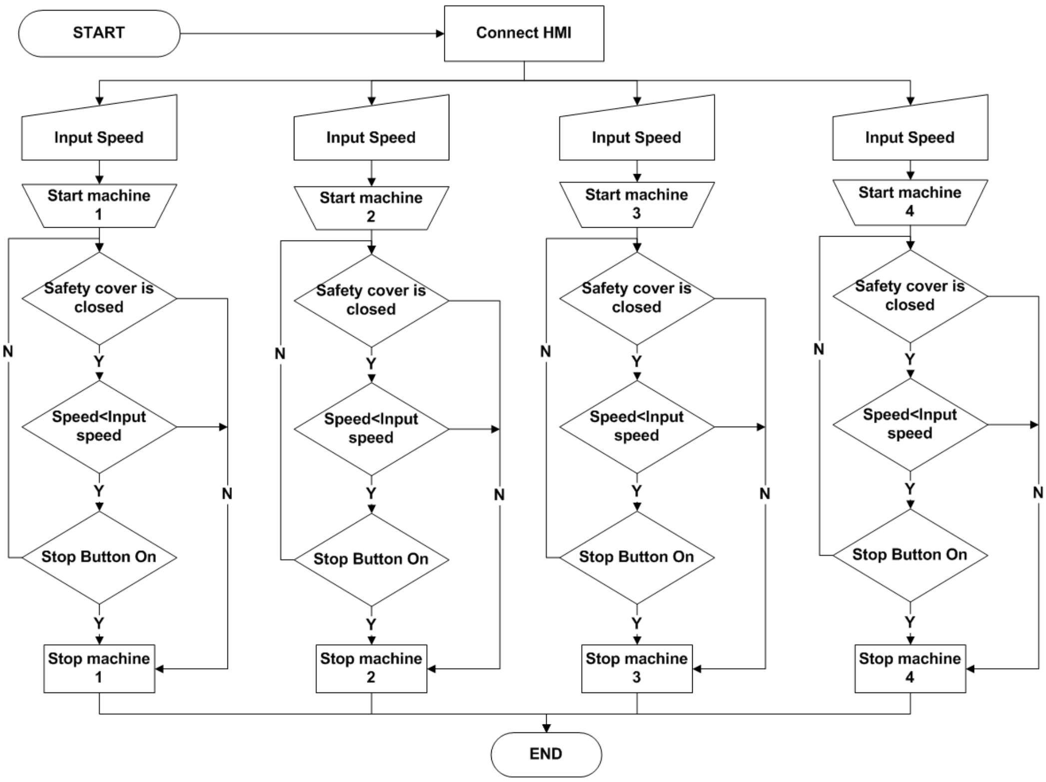

Figure 4. The algorithm of PLC (PLC program algoritması)

The accuracy of these sensors' measurement values, in other words its calibration, is quite important. Extech 461880 tachometer was used while calibrating the sensor to be used. With this tachometer, comparing the values which sensors read, the spindle speed calibration of the system was done by entering coefficients determined according to seen difference value in PLC program.

The controlling of safety covers on the machines is enabled by proximity sensors, too. These sensors are also used in controlling of lathe carriage's hitting the chuck and the machine is turned off in case of danger.

The PLC uses controls contactors to which the machines are connected with 24 V output signal. The system can turn on or turn off the machines in this way. Using neodymium magnet collision prevention sensors are attached to the through L shaped sheet attachment brackets (Fig. 6). The sensors can be located on any needed place with the help of magnetic attachments. This system becomes crucial especially in the operations of threading. The determined limits can be defined by scrolling the used sensor on the machine. The system stops the machine when the lathe carriage approaches to the sensor in 4 mm distance.

With the help of Pt100 temperature sensor attached on should be at least 16°C unless work involves severe physical effort, in which case the minimum should be 13°C. Provide at least five L/s per occupant (eight is recommended for comfort) and air movement in the workshop of at least 0.1 to 0.15 m/s [21].

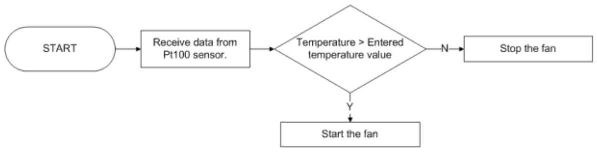

Figure 7. The algorithm of ventilation system (Havalandırma sistemi algoritması)

The lightening of the environment is constantly monitored by light sensors. When the lightening of the environment drops down below the determined threshold values, a secure lightening environment is provided with the control system's turning on the lights of the lab automatically. The general rule in terms of occupational safety is that the lightening should be at the level in which workers can see the details of the work they do. For machine shops, these values should be 200 lux on average, at least 100 lux [21].

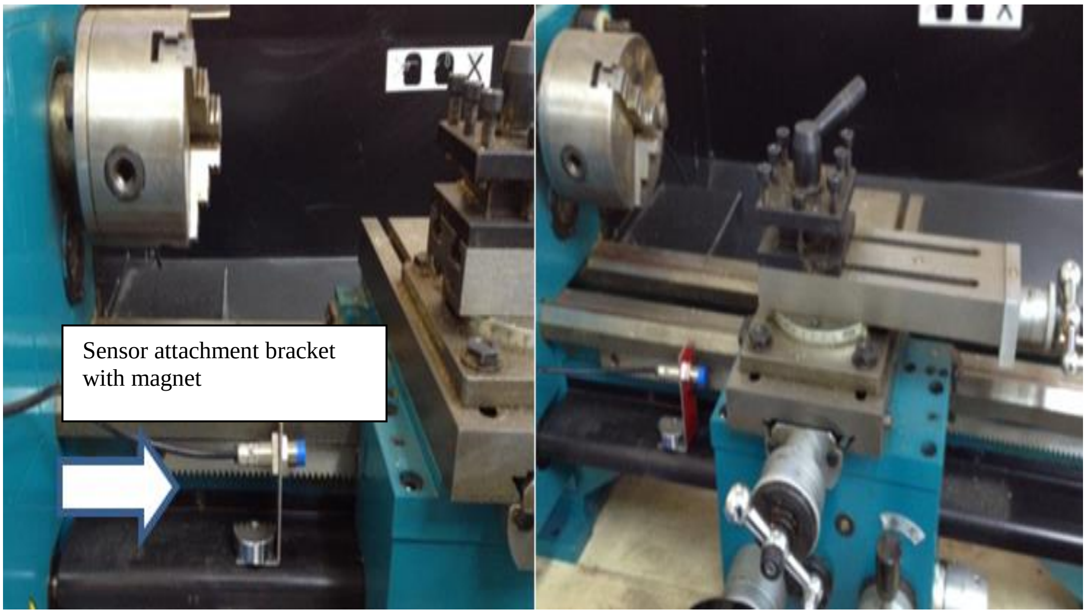

Figure 6. Sensor attachment bracket with magnet for collision prevention system (Çarpma önleme sistemi mıklatıslı sensor tutucusu)

Enda ETC 4420 PID temperature controller used in the system, the temperature of environment is controlled and cooling of the environment is provided by starting ventilating fan when the determined value is exceeded. In the designed system, there is a vent which closes in the stop position against heat loss emanating from fan zone especially in winter. The vent is controlled by a temperature controller along with the fan and it opens when the fan starts working and it closes when the fan stops. The algorithm of ventilating system is presented in Fig. 7. In machine shop conditions, the temperature

3. RESULTS AND DISCUSSION (SONUÇLAR VE TARTIŞMA)

The main subject of the study is to be able to prevent work-related accidents arising from negligence of trainers, employers and workers. The prototype of the developed system for this purpose checks working conditions of the workers and ensures pre-determined protocols are followed when the machines are in use. The developed system is in the form of expandable. It has a flexible form in which machine inspections and different environments are conducted through different modules to be supplemented and different sensors.

Security violations which the workers cause are inspected by the designed safety automation through the sensors put on the machines in Mechanic laboratory of Corlu Engineering Faculty, where the research is carried out. The developed automation system takes advantage of PLC systems. Whether the safety covers are used and the spindles speeds of machines are checked by are determined by the sensors installed on the machines. The planned system for checking four machines also controls environment temperatures and the level of lightening. By entering set values for machines via the operator board used in the system, the desired spindle speed can be set and higher speeds restricted.

It was observed that the system worked properly in the tests of the developed system. The machine speed can be controlled by the system, the ventilating fan is put into use according to environment temperatures and the lightening system is put into use when the light intensity drops down below 100 lux. At the same time, the trainer can stop all the machines with the remote control he carries depending upon the extent of the emergency.

Operator panel (operator paneli),

The operator panel of the developed system is presented in Fig. 8. Whether there is a collision on the machine or momentary spindle speed can be observed via this panel.

The operator panel consists of three pages.

1st page is password page. It is desired to block unauthorized people who want to change the parameters.

2nd page is the page of parameter. Machine speed is defined on this page. Besides, the desired machine can be stopped with On/Off button.

3rd page is observation page. Spindle speed of machine, the conditions of safety covers and collision situations can be observed from this page.

The operator panel can record working conditions on flash disk as a .xls file at set times. Some historical data values which are saved every second are given in Table 1. Historical data can be save a daily file or a single file. Thus, the data, working conditions and the spindle speed of the machines, received from system sensors, can be stored.

Table 1. Historical data of work conditions (Çalışma koşulları verileri)

	Speeds (RPM)				
Time (s)	Machine 1	Machine 2	Machine 3	Machine 4	Temp. (°C)
17:18:56	820	800	0	800	22
17:18:57	825	800	0	820	22
17:18:58	815	780	0	850	22
17:18:59	825	780	0	850	22
17:19:00	825	800	0	850	22

The measurement of spindle speed, (Ayna devir sayısının ölçümü)

0 and 1 numbered digital input ports of PLC, used in the research, are quick counters.

While measuring of speeds may be carried out with proximity sensors, in order to measure high speed on the other ports, the measurement may also be performed by upsizing the measuring range of the sensors. For this

Figure 8. The pages of operator panel (Operatör paneli sayfaları)

reason, the measurements were carried out by countering lathe chuck back bolts instead of pulley gears and the calibrations of them were done with a tachometer.

Temperature control (Sıcaklık kontrolü),

The system is controlled by Enda 4420 temperature control according to the data received from Pt 100 temperature sensor which was placed in the laboratory. The temperature controller controls ventilating fan and front vent together. The vent and the fan is opened and closed according to received temperature data. The system can be adjusted to the desired warmth easily and it works safely.

The usage of light sensor (Işık sensörünün kullanımı)

Because the light intensity minimum values of light sensor were too low, the sensor was wrapped with black electrical tape in order to be put into use in higher light intensity situations. Thus, the light sensor's was able to react with appropriate light intensity as necessary. When the sensor is placed in the laboratory, it sends signals for going out again because of the lights which are on. As a result of this, it was attached to the outer of laboratory window and it was calibrated to work according to daylight in order not to be affected by the lights which are on.

4. CONCLUSIONS (SONUÇLAR)

In developing and using a safety automation system in machine shops, workshops and laboratories which are used in educational institutions it was determined that security risks are still present. The developed system is also essential for students to be able to protect themselves against work-related accidents which they may be exposed to in machine shop practices during vocational training. The approach of the developed safety automation presented here reduces the risks which trainers experience during training and practice runs. This provides trainers the ability to teach lessons in a less restricted and safer way. Installing the developed prototype system in the laboratory of Engineering Faculty is going to also create awareness for occupational safety in students and future engineers educated in this institution.

Preventing work-related accidents has an effect of reducing the costs as well as increasing the productivity. It shouldn't be forgotten that actions to be taken for preventing work-related accidents are pubic responsibilities not only for vocational schools and enterprises but also for society. Because of significance of this, it is important to do research for preventing work-related accidents which naturally leads one to consider an integrative automation system approach for preventing work-related accidents.

As a result of the developed prototype safety system becoming widespread, the awareness created in enterprises and training institutions will improve the perception of an integrative safety approach. As a result of this approach, enterprises and institutions will prevent accidents and injury with little investments. More research is necessary to continue the development of a comprehensive job security automation system which defines and encompasses all areas of security and safety in the workplace

5. ACKNOWLEDGEMENTS (TEŞEKKÜR)

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6. REFERENCES (KAYNAKLAR)

1) The Prevention Occupational Diseases. ***International Labor Organization***, ISBN 978-92-2-127447-6, pp. 4 (2013).

2) Cloutier E. ''The effect of age on safety and work practices among domestic trash collectors in Québec'' ***Safety Science***, 17:291–308, (1994).

3) Cellier J. M., Eyrolle H., Bertrand A. ''Effects of age and level of work experience on occurrence of accidents'' ***Perceptual and motor skills***, 80:931–940, (1995).

4) Laflamme L., Menckel E. ''Aging and occupational accidents. A review of the literature of the last three decades'' ***Safety Science***, 21:145–161, (1995).

5) McCaig L. F., Burt C. W., Stussman B. J. ''A comparison of work-related injury visits and other injury visits to emergency departments in the United States, 1995–1996'' ***Journal of Occupational and Environmental Medicine***, 40:870–875, (1998).

6) Salminen S. ''Have young workers more injuries than older ones? An international literature review'' ***Journal of Safety Research***, 35:513–521, (2004).

7) Chau N., Mur J. M., Touron C., Benamghar L., Dehaene D. ''Correlates of occupational injuries for various jobs in railway workers: A case–control study'' ***Journal of Occupational Health***, 46:272–280, (2004).

8) Chau N., Gauchard G., Dehaene D., Benamghar L., Touron C., Perrin P., Mur J. M. ''Contributions of occupational hazards and human factors in occupational injuries and their associations with job, age and type of injuries in railway workers'' ***International Archives of Occupational and Environmental Health***, 80:517–725, (2007).

9) Chau N., Bourgkard E., Bhattacherjee A., Ravaud J. F., Choquet M, Mur J. M. ''Lorhandicap group. associations of job, living conditions and lifestyle with occupational injuries in working population:Apopulation based study'' ***International Archives of Occupational and Environmental Health***, 81:379–389, (2008).

10) Breslin F. C., Tompa E., Zhao R., Pole J. D., Amick Iii B. C., Smith P. M., Hogg- Johnson S. ''The relationship between job tenure and work disability absence among adults: A prospective study'' ***Accident Analysis & Prevention***, 40:368–375, (2008).

11) Chau N., Dehaene D., Benamghar L., Bourgkard E., Mur J. M., Touron C. and Wild P. ''Roles of Age, Length of Service and Job in Work-Related Injury: A Prospective Study of 63,620 Person-Years in Female

Workers'' ***American Journal of Industrial Medicine***, 57:172–183, (2014).

12) Wallen, E., Mulloy, K. ''Computer-based training for safety:comparing methods with older and younger workers'' ***Journal of Safety Research***, 37 (5): 461–467, (2006).

13) Stuart A. ''A blended learning approach to safety training: Student experiences of safe work practices and safety culture'' ***Safety Science***, 62: 409–417, (2014).

14) Ruz M.L., Vázquez F., Salas-Morera L., Cubero-Atienza A. ''Robotic testing of radio frequency devices designed for industrial safety'' ***Safety Science***, 50: 1606–1617, (2012).

15) Ruz, M.L., Vázquez, F., ''An RFID prototype providing industrial security features in the manufacturing environment'' ***International Journal of Internet Protocol Technology***, 4 (4): 240–246, (2009).

16) Chae, S., Yoshida, T., ''Application of RFID technology to prevention of collision accident with heavy equipment'' ***Automation in Construction***, 19 (3): 368–374, (2010).

17) Fabiano, B., Currò, F., Reverberi, A.P., Pastorino, R. ''Port safety and the container revolution: A statistical study on human factor and occupational accidents over the long period'' ***Safety Science***, 48: 980–990, (2010).

18) Health and safety in engineering workshops, HSG129, ***HSE Books***, ISBN 978 0 7176 1717 3, p.43

19) EC, Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on Machinery, and Amending Directive 95/16/EC (recast), (2006).

20) Ada E., Sever M., Aksay E. ''Assessment of Vocational Training and Workplace Safety from the Perspective of the Injured Worker'' ***Türkiye Acil Tıp Dergisi - Tr J Emerg Med.***, 13(3):105-113 doi: 10.5505/1304.7361.2013.75046, (2013).

21) Health and safety in engineering workshops, 1999, *HSE Books*, ISBN 0 7176 1232 5, p. 17-19