Mühendislik Bilimleri ve Tasarım Dergisi
12(1), 64 – 74, 2024
e-ISSN: 1308-6693

Journal of Engineering Sciences and Design
DOI: 10.21923/jesd.1407043

Araştırma Makalesi | Research Article

PLC BASED SCADA SYSTEM DESIGN FOR INSTANT MONITORING AND EARLY WARNING MECHANISM OF TOXIC GASES IN UNDERGROUND MINES

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Keywords

PLC,
SCADA,
Underground Mines,
Toxic Gas Measurement,
Early Warning System.

Abstract

In this study, a real-time toxic gas measurement and early warning mechanism is proposed to prevent accidents that may occur in underground mining facilities. Temperature, oxygen (O_2), hydrogen sulfide (H_2S), methane (CH_4), carbon monoxide (CO) and dust density sensor data are read via Arduino Mega analog inputs. All sensor data is transferred to the PLC-SCADA (Programmable Logic Controller - Supervisory Control and Data Acquisition) system via ethernet in real time. Thanks to the designed SCADA screen, sensor values can be monitored instantly. In addition, it can be checked whether the system is alarm and whether the ventilation system works. According to the underground coal mine regulations, work cannot be done in places where the mine air contains less than 19% oxygen, more than 2% methane, more than 50 ppm (0.005%) carbon monoxide and other hazardous gases. The highest permissible hydrogen sulfur ratio for 8 hours of operation is 20 ppm (0.002%). An early warning mechanism was created with the algorithm written taking these limits into consideration. The tests of the designed system were carried out in a laboratory environment and successful results were observed.

YERALTI MADEN OCAKLARINDA ZEHİRLİ GAZLARIN ANLIK TAKİBİ VE ERKEN UYARI MEKANİZMASI İÇİN PLC TABANLI SCADA SİSTEMİ TASARIMI

Anahtar Kelimeler

PLC,
SCADA,
Yeraltı Maden Ocakları,
Zehirli Gaz Ölçümü,
Erken Uyarı Sistemi.

Öz

Bu çalışmada yeraltı maden tesislerinde oluşabilecek kazaların önüne geçilebilmesi için geliştirilen gerçek zamanlı zehirli gaz ölçümü ve erken uyarı mekanizması önerilmektedir. Sıcaklık, oksijen (O_2), hidrojen sülfür (H_2S), metan (CH_4), karbon monoksit (CO) ve toz yoğunluğu sensör verileri Arduino Mega analog girişleri üzerinden okunmaktadır. Tüm sensör verileri ethernet üzerinden PLC-SCADA (Programmable Logic Controller - Supervisory Control and Data Acquisition) sistemine gerçek zamanlı olarak aktarılmaktadır. Tasarlanan SCADA ekranı sayesinde sensör değerleri anlık olarak izlenebilmektedir. Ayrıca sistemin alarm durumuna geçip geçmediği ve havalandırma sisteminin çalışıp çalışmadığı da kontrol edilebilmektedir. Yeraltı kömür madeni yönetmeliğine göre maden havasında %19'dan az oksijen, %2'den fazla metan, 50 ppm'den (%0.005) fazla karbon monoksit ve diğer tehlikeli gazların bulunduğu yerlerde çalışma yapılamaz. 8 saatlik çalışma için izin verilen en yüksek hidrojen kükürt oranı 20 ppm'dir (%0.002). Bu sınırlar dikkate alınarak yazılan algoritma ile erken uyarı mekanizması oluşturulmuştur. Tasarlanan sistemin testleri laboratuvar ortamında gerçekleştirilmiş ve başarılı sonuçlar alındığı görülmüştür.

Alıntı / Cite

Ilten, E., Unsal, M. E., (2024). PLC Based SCADA System Design for Instant Monitoring and Early Warning Mechanism of Toxic Gases in Underground Mines, Journal of Engineering Sciences and Design,12(1), 64-74.

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Makale Süreci / Article Process	
Başvuru Tarihi / Submission Date	20.12.2023
Revizyon Tarihi / Revision Date	24.02.2024
Kabul Tarihi / Accepted Date	10.03.2024
Yayım Tarihi / Published Date	25.03.2024

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Highlights

- Temperature, oxygen, hydrogen sulfide, methane, carbon monoxide and dust density are measured.
- All sensor data obtained Arduino Mega are sent to SCADA via ethernet to display in real-time.
- When sensor values exceed the limits in mining regulations, early warning mechanism is activated.

Graphical Abstract

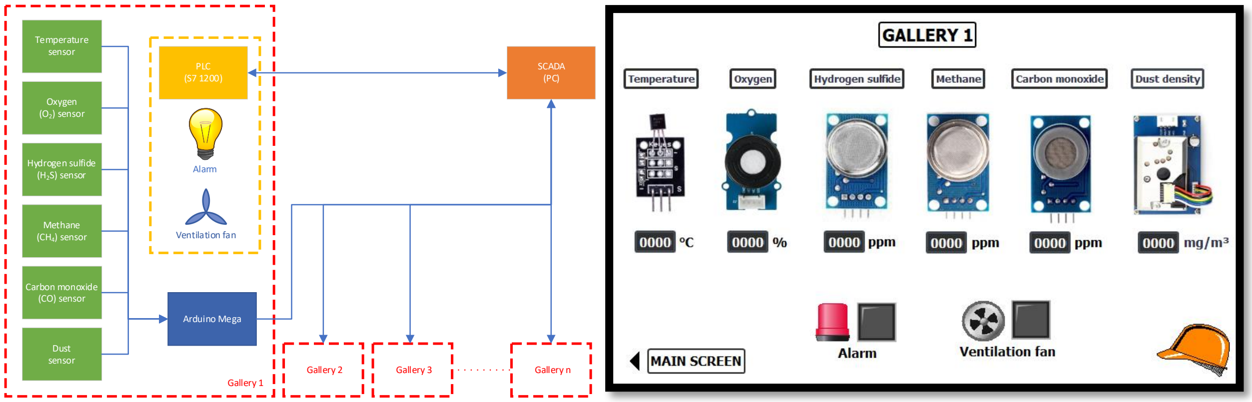

Figure. Graphical Abstract

Purpose and Scope

In this study, an early warning mechanism is developed to ensure the safety of employees by real-time measurement of toxic gases in underground mining facilities.

Design/methodology/approach

Temperature, oxygen, hydrogen sulfide, methane, carbon monoxide and dust density are measured from sensors by Arduino Mega analog inputs. The received sensor information is sent to the PLC-SCADA (Programmable Logic Controller - Supervisory Control and Data Acquisition) system over ethernet. All sensor values are displayed in real time on the designed SCADA screen. Thanks to the algorithm prepared by taking sensor values into consideration, conditions that will create a dangerous situation are immediately detected and the alarm and ventilation system is activated.

Findings

In laboratory tests, it is seen that all sensors are read with high accuracy, transferred to the SCADA system successfully and the early warning mechanism is activated at the right time.

Practical implications

The prepared experimental setup is suitable for testing in the field. It is planned to make this setup compact in order to start practical use.

Originality

The originality of this study is the ability to measure all gases, temperature and dust density on a single low-cost board, to transfer data to the SCADA system in real time, and to the early warning mechanism developed by taking into account the safety limits determined according to the mining regulations.

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1. Introduction

Beneath the surface of the Earth lies a realm of industry and exploration that has shaped the course of human history for centuries - the world of underground mines. These subterranean labyrinths, carved into the depths to extract valuable minerals, ores, and resources, represent a testament to human ingenuity and perseverance. From the days of pickaxes and candlelight to the modern era of advanced machinery and safety protocols, underground mines have played a vital role in fueling economies, driving technological progress, and satisfying the ever-growing demands of our world (Hamrin *et al.*, 2001).

Underground mining is a vital industry that has played a crucial role in extracting valuable minerals and resources from the depths of the Earth for centuries. However, the pursuit of these riches often takes place in a challenging and hazardous environment (Tekin *et al.*, 2023). One of the most significant threats to the safety of miners in these underground settings is the presence of toxic gases (Li, Si, *et al.*, 2023). These invisible and potentially lethal substances pose a constant and silent danger, and understanding their sources, types, and management is of paramount importance for the well-being of those who work in these subterranean worlds.

In an age marked by industry, technology, and urbanization, the measurement of toxic gases has become an indispensable aspect of ensuring the health and safety of both the environment and the people who inhabit it (Rajakumar and Choi, 2023). The detection and quantification of hazardous gases are critical not only for the preservation of air quality but also for preventing potentially life-threatening incidents in various settings, including industrial, residential, and environmental contexts. These measurements are the cornerstone of proactive risk management and emergency response.

Safety is paramount in the world of underground mining, and early detection and response to potential risks are vital. To address this challenge, the concept of an "Early Warning Mechanism in Underground Mines" has emerged as a crucial innovation. This system leverages technology and expertise to proactively identify and communicate impending dangers, allowing miners to take necessary precautions and mitigate potential disasters (Li, Kong, *et al.*, 2023).

Early warning systems used in real mines today basically work on the principle of instant measurement of toxic gases and activating the warning-alarm mechanism at the right time. A significant portion of occupational accidents related to mine ventilation are caused by firedamp explosions, CO poisoning and fires inside the mine. The main reason for gas explosions that occur in the world and in our country, especially in coal mines, is the failure to detect in time that the gas concentrations in the environment are above the determined limit values (Mallı *et al.*, 2014). For this reason, the gas potential of each mine must be measured and if an early warning system is needed, it must be installed. The possibility of an accident can be minimized if all precautions are taken meticulously and in a timely manner.

In the realm of industrial automation, Programmable Logic Controllers (PLCs) are the unsung heroes that drive precision, reliability, and efficiency in countless processes (Alsabbagh and Langendörfer, 2023). These compact yet powerful digital computers have become the backbone of modern manufacturing, enabling the control and automation of intricate tasks with a level of speed and accuracy that was once unimaginable. From production lines in factories to the systems that manage critical infrastructure, PLCs play a pivotal role in ensuring that operations run smoothly and without error.

In the age of complex and interconnected industrial processes, Supervisory Control and Data Acquisition (SCADA) systems have emerged as the linchpin that facilitates the monitoring, control, and management of critical infrastructure (Melo *et al.*, 2023). These powerful systems serve as the eyes and ears of a diverse array of industries, from power plants to water treatment facilities, and from transportation networks to manufacturing plants. SCADA systems empower operators and engineers to oversee and manipulate processes in real-time, ensuring efficiency, safety, and responsiveness.

In the ever-evolving world of industrial automation and control, PLCs with SCADA systems has ushered in a new era of efficiency, responsiveness, and control (Tomar *et al.*, 2023). This powerful combination, often referred to as PLC-based SCADA systems, has become the backbone of modern industrial processes, enabling seamless monitoring (Kumru and Vural, 2023), control, and data acquisition in a wide range of applications.

The Arduino microcontroller stands as a beacon in the realm of open-source hardware and electronics prototyping. Developed with the aim of providing an accessible platform for enthusiasts, students, and professionals alike, Arduino has become synonymous with creativity and innovation in the world of embedded systems (McRoberts, 2013). At its core, an Arduino is a compact and versatile microcontroller board that empowers users to bring their electronic ideas to life. Arduino, with its user-friendly interface and flexible architecture, provides an ideal platform for interfacing with various sensors to measure and interpret the physical world. Measuring sensors, also known as transducers, are devices that convert physical quantities such as temperature, light, pressure, or distance into electrical signals that can be interpreted by electronic circuits (Akal and Akan, 2022). When combined with Arduino, these sensors become powerful tools for collecting data, monitoring environments, and creating interactive projects.

In the study conducted by Bołoz in 2020, automation and robotic systems used in underground mines in Poland were examined (Bołoz and Biały, 2020). It has been emphasized that underground mining machines are of great importance for hard coal, which is underground and has the greatest market power in some countries. It has been stated that with the development of technology in hard coal mining, where production was mostly based on manpower in the early days of mining, safer and more economical results were achieved by operating the machines remotely or autonomously.

Yaman presented a study on the internet of things-based transformer monitoring system in 2019 (Yaman, 2019). In this study, the temperature of the windings, oil level, current-voltage values were monitored with various sensors placed on the transformer. When there is an overload on the transformers, the insulation value decreases due to the increase in the temperature in the windings, causing a malfunction in the transformer. In order to avoid an unexpected malfunction and to extend its service life, the transformer must be monitored instantly. With the designed prototype, it is aimed to detect possible faults in the transformer early and extend the service life of the transformer.

In the study presented by Dündar et al., work accidents and occupational diseases occurring in the mining sector in Turkey were analyzed (Dündar *et al.*, 2018). The mining sector is a sector that has guided and shaped civilizations from past to present. However, since the mining sector has harsh working environments, it is considered the riskiest working sector in the world in terms of occupational health and safety. In this study, it was concluded that the necessary systems regarding occupational health and safety, especially in underground mining, should be established, implemented and constantly inspected.

Kul worked on remote monitoring of 1500 kVA power generator sets and high voltage breakers with 6.3 kV output voltage using PLC-SCADA (Kul, 2009). A SCADA system was designed to control the currents, voltages, power factors and frequencies of the generator group used in this study from a single point. Vijeo Citect software was used for the SCADA system. With the designed SCADA system, oil pressure level, winding temperature and winding insulation value can also be monitored. It has been shown that the system can operate faster and more efficiently by predicting the malfunctions that may occur as a result of the study.

A study is presented by Bekiroglu about early detection of faults that may occur in transformers (Bekiroglu, 2009). In this study, it is aimed to reduce the cost of the business, provide a safe working environment and examine possible malfunctions. Fault situations such as decrease in insulation value, excessive current draw, phase-to-phase short circuit in transformers have been analyzed. A PLC-based SCADA system has been designed to detect and intervene in advance about malfunctions that may occur in the transformer. Thanks to this SCADA system, occupational safety in the enterprise is increased.

In this study, a mechanism is proposed to accurately measure toxic gases frequently encountered in underground mining facilities and provide early warning in case of danger. To achieve this, a PLC-based SCADA system is designed. The designed system has been tested in a laboratory environment.

This paper is organized as follows. Material and method are explained in Section 2. In Section 3, the experimental results are demonstrated, and Section 4 represents the result and discussion.

2. Material and Method

In the designed mine gas measurement system, temperature, oxygen, hydrogen sulfide, methane, carbon monoxide and dust density are measured. Block diagram of the measurement system is presented in Figure 1.

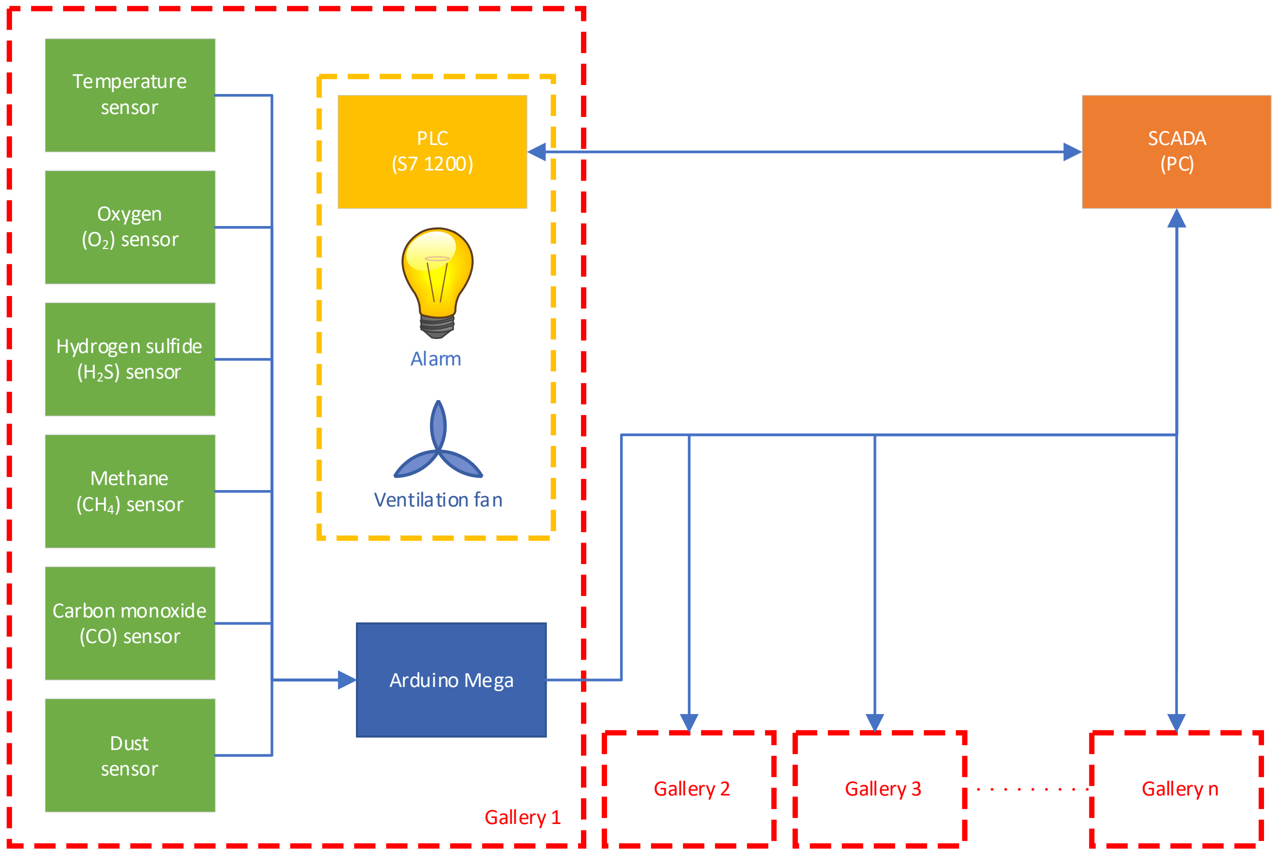


Figure 1. Block Diagram Of The Measurement System.

In Figure 1, outputs of all sensors are read by Arduino Mega board via analog inputs for each gallery. The main reason why Arduino Mega board was preferred for reading analog sensors in this study is the high cost of PLC analog input modules. The S7 1200 CPU model we use has only 2 analog inputs, so an additional analog input module must be used. Since the additional module would increase the cost considerably, it was preferred to use the Arduino Mega board in the sensor reading part of the study. Another reason is that it is planned to turn the sensor measurement unit into a mobile device in future studies. Obtained sensor data is send to SCADA system with Arduino Ethernet Shield module. All sensor data is presented in real-time on the designed SCADA screens. The methods used to read data from each sensor are explained sequentially below.

Temperature sensor: LM35 integrated circuits are used to measure the gallery temperatures. LM35 is given in Figure 2.

Figure 2. LM35 Temperature Sensor.

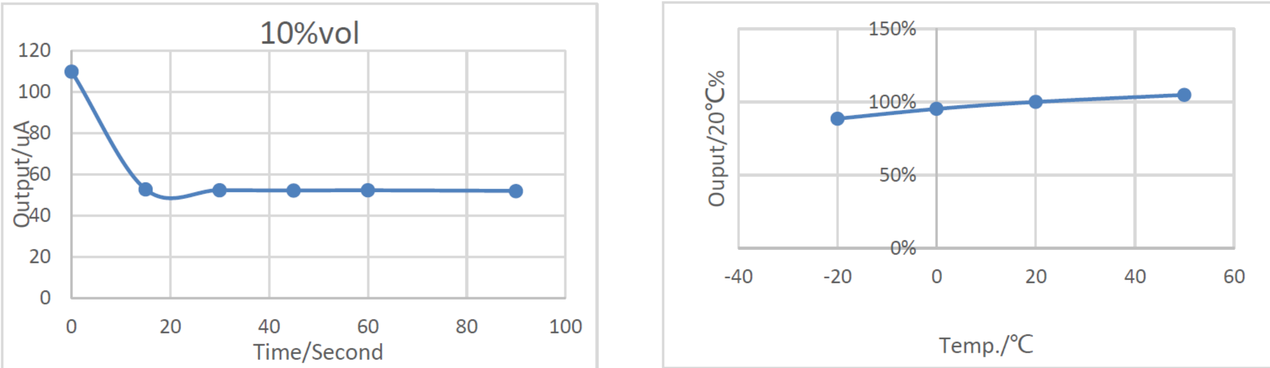
The transfer function of LM35 is given as follows (Texas_Instruments, 2017).

$$V_o = 10\ \mathrm{mV}/^{\circ}\mathrm{C} \times T \tag{1}$$

Where V_o is the output voltage of LM35, T is the temperature in °C.

Oxygen (O_2) sensor: MIX8410 electrochemical oxygen gas sensor is used to measure the concentration of oxygen in galleries. The sensor is illustrated in Figure 3. The sensitivity characteristics and the temperature dependency of MIX8410 is presented in Figure 4 (Mixsen, 2020).

Figure 3. MIX8410 Electrochemical Oxygen Gas Sensor.



a **b**

Figure 4. A) Sensitivity Characteristics (25°C, Linear Output), **B)** Temperature Dependency.

Hydrogen sulfide (H_2S) sensor: MQ-136 hydrogen sulfide gas sensor is used to measure the concentration of hydrogen sulfide. MQ-136 gas sensor is given in Figure 5. MQ-136 test circuit and sensitivity curve is illustrated in Figure 6 (Winsen, 2015).

Figure 5. MQ-136 Hydrogen Sulfide Gas Sensor.

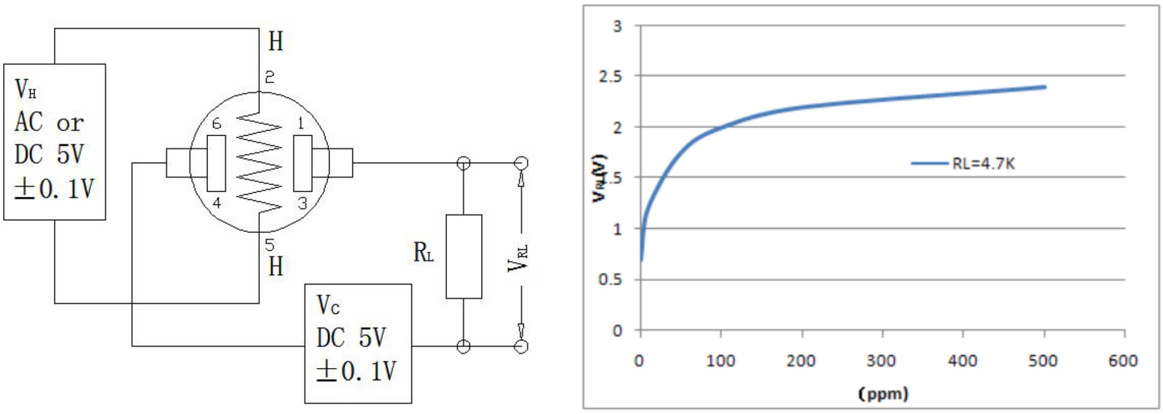


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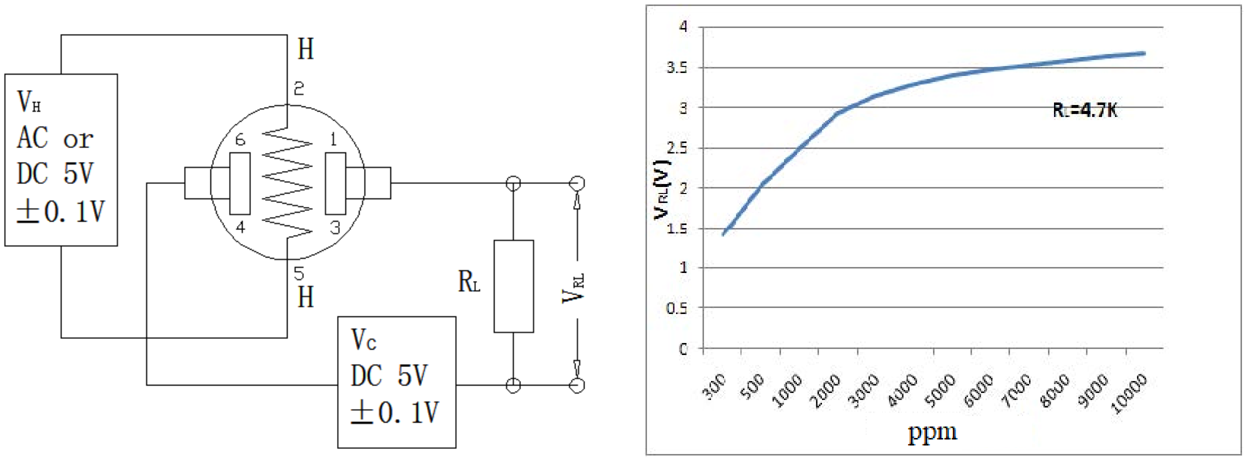
Figure 6. A) MQ-136 Test Circuit, **B)** MQ-136 Sensitivity Curve.

In Figure 6, V_H is the supply voltage, V_c is the circuit voltage, R_L is the load resistance and V_{RL} is the voltage of R_L. The concentration of Hydrogen sulfide can be measured between 0-200 ppm with MQ-136.

Methane (CH_4) sensor: MQ-4 flammable gas sensor is used to measure the methane concentration in galleries. MQ-4 is demonstrated in Figure 7. MQ-4 test circuit and sensitivity curve is illustrated in Figure 8 (Winsen, 2018).

Figure 7. MQ-4 Flammable Gas Sensor.



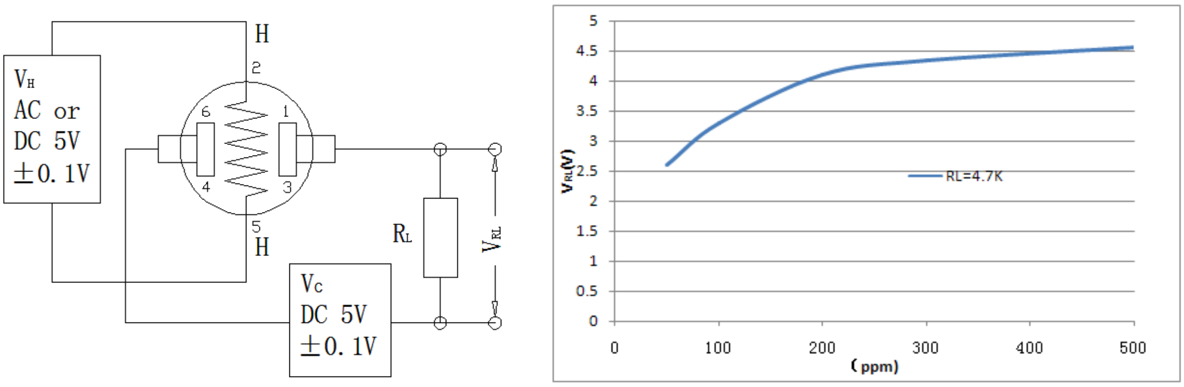
a b

Figure 8. A) MQ-4 Test Circuit, **B)** MQ-4 Sensitivity Curve.

In Figure 8, V_H is the supply voltage, V_c is the circuit voltage, R_L is the load resistance and V_{RL} is the voltage of R_L. The concentration of methane can be measured between 300-10000 ppm with MQ-4.

Carbon monoxide (CO) sensor: MQ-7 toxic gas sensor is used to measure the carbon monoxide concentration in galleries. MQ-7 is presented in Figure 9. MQ-7 test circuit and sensitivity curve is illustrated in Figure 10 (Winsen, 2014).

Figure 9. MQ-7 Toxic Gas Sensor.



a b

Figure 10. A) MQ-7 Test Circuit, **B)** MQ-7 Sensitivity Curve.

In Figure 10, V_H is the supply voltage, V_c is the circuit voltage, R_L is the load resistance and V_{RL} is the voltage of R_L. The concentration of carbon monoxide can be measured between 10-500 ppm with MQ-7.

Dust sensor: GP2Y1010AU0F optical dust sensor is used to measure the dust density in galleries. GP2Y1010AU0F is given in Figure 11 (Sharp, 2006). Output voltage vs. dust density curve is presented in Figure 12.

Figure 11. GP2Y1010AU0F Optical Dust Sensor.

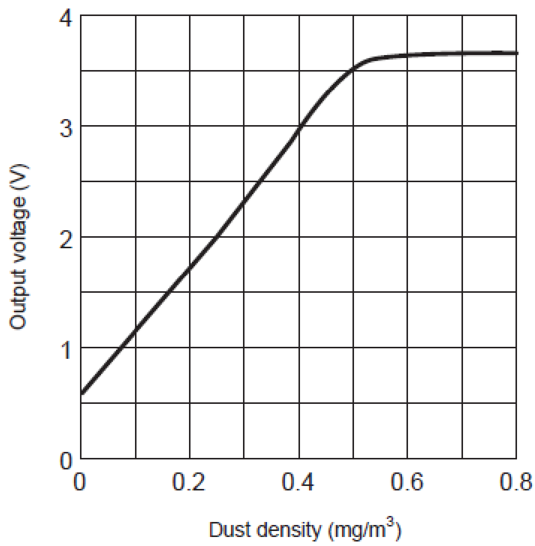


Figure 12. Output Voltage Vs. Dust Density Curve.

Dust density can be measured between 0-0.65 mg/m^3 with GP2Y1010AU0F.

Arduino Ethernet Shield Module is used to transfer sensor data from Arduino Mega to the PC. The module is presented in Figure 13.

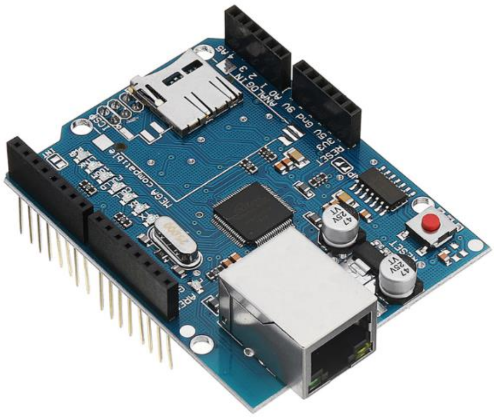


Figure 13. Arduino Ethernet Shield Module.

TCP/IP (Transmission Control Protocol / Internet Protocol) method is used for communication. Arduino and PC devices are first connected to the same local network. Static IP addresses are defined for Arduino and PC. These addresses are 192.168.0.20 and 192.168.0.10 respectively. The port number is entered as 50000. Sent data size is [6x1]. Sensor data sent to the PC as a [6x1] package is displayed in real-time on the designed SCADA screen.

Alarm mechanism and ventilation fan control is carried out by PLC S7 1200 1214C CPU. A static IP (192.168.0.30) is also defined for the PLC and connected to the same local network. The data sent from Arduino to the PC is also sent to the PLC. Thanks to the algorithm written for the PLC using the TIA Portal program, the alarm and ventilation fan can be activated and deactivated according to the measured sensor values.

3. Experimental Results

The experimental setup of the measurement system is illustrated in Figure 14. The experimental setup consists of four temperature sensors, an oxygen sensor, a hydrogen sulfide sensor, a methane sensor, a carbon monoxide sensor, a dust sensor, an Arduino Mega board. Arduino board is connected to PC SCADA system via ethernet shield module. Sensors outputs are measured with analog inputs of Arduino board. Obtained voltages are converted the measured units with the written algorithms according to information from sensor datasheets. All measured data are sent to PC and displayed in real-time on the designed SCADA screens. Measurement SCADA screen for a gallery is presented in Figure 15. The flow chart of the early warning mechanism is illustrated in Figure 16.

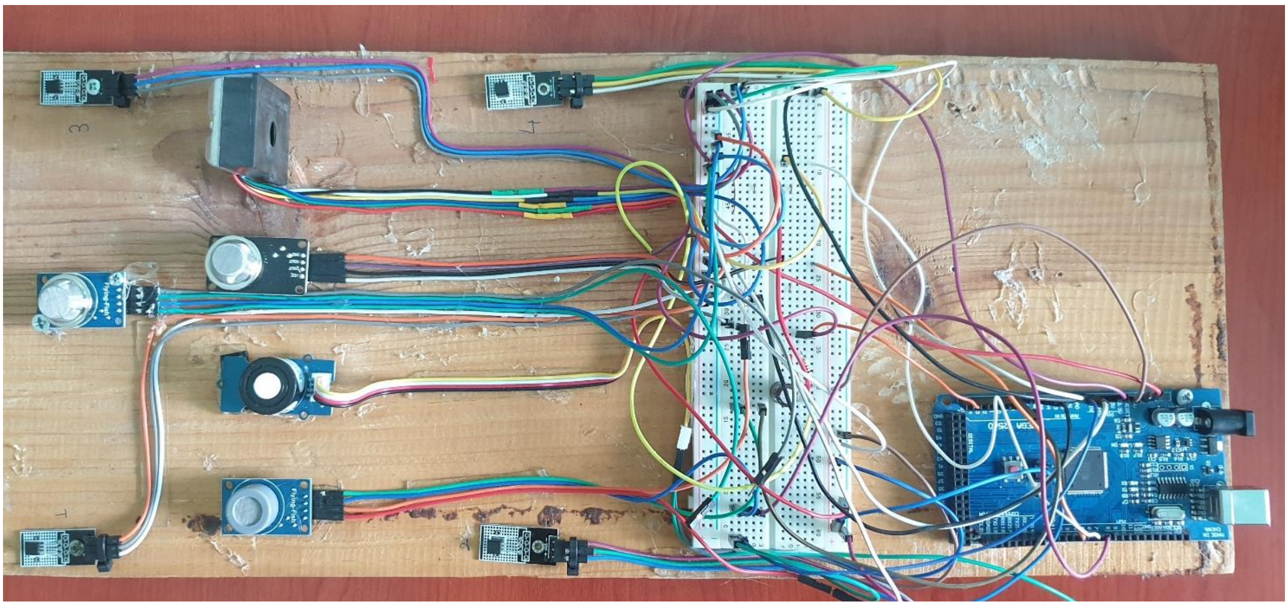


Figure 14. The Experimental Setup.

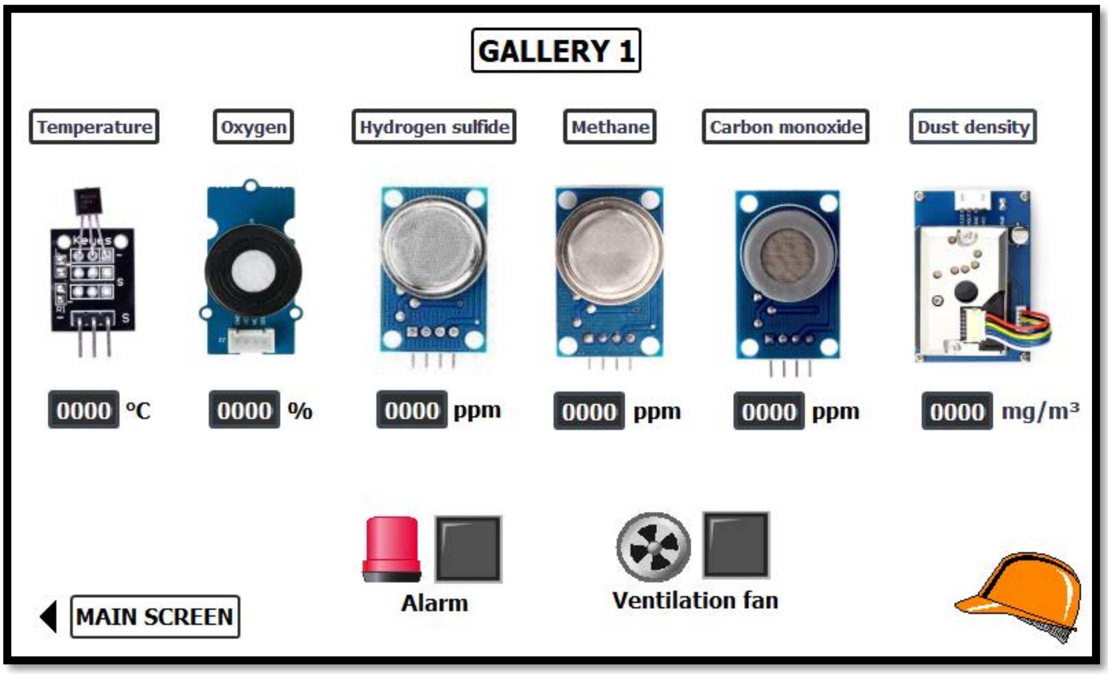


Figure 15. Measurement SCADA Screen For A Gallery.

TIA Portal / WinCC program is used to design the SCADA screen. On this screen, each sensor value is displayed separately in digital indicators. The operating status of the alarm and ventilation fan can be monitored with warning lamps displayed on the screen. There are no control elements on this screen that the user can intervene. The screen is used only for real-time monitoring of data. Activation of alarm and fan systems occurs automatically thanks to the written algorithm.

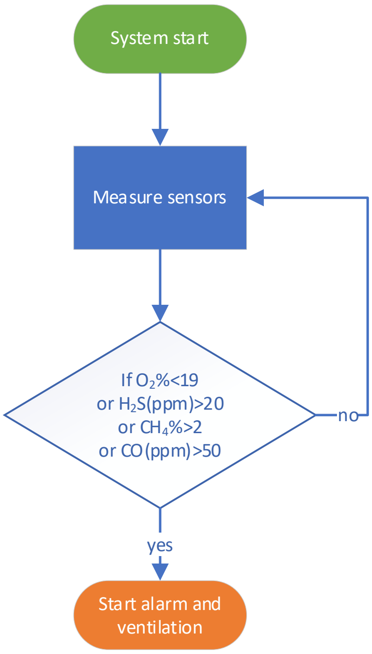


Figure 16. Flow Chart Of The Early Warning Mechanism.

According to the underground coal mine regulations, work cannot be done in places where the mine air contains less than 19% oxygen, more than 2% methane, more than 50 ppm (0.005%) carbon monoxide and other hazardous gases. The highest permissible hydrogen sulfur ratio for 8 hours of operation is 20 ppm (0.002%). Thanks to the algorithm prepared by taking these values into consideration, conditions that will create a dangerous situation are immediately detected and the alarm and ventilation system is activated as seen in Figure 15. Thanks to the alarm in this early warning mechanism, the evacuation of the employees is started, and the ventilation system is used to evacuate the toxic air.

4. Result and Discussion

In this study, measuring gas concentrations in underground mining facilities and developing an early warning mechanism for occupational safety were studied. Arduino Mega board is used to measure gases. Sensor values measured with Arduino are sent to the PLC-SCADA system via ethernet. Sensor data received with the PLC-SCADA system is evaluated and when dangerous conditions are detected, the alarm and ventilation mechanism is activated. Tests of reading sensor data, transferring data to SCADA, and operating alarm and ventilation systems were carried out in a laboratory environment. Experimental results showed that all sensors were read with high accuracy and transferred to SCADA, and alarm and ventilation systems were activated at the right time. In future studies, it is planned to make the measurement unit compact and to conduct field tests of the system.

Acknowledgement

This study was supported by Balikesir University Scientific Research Projects Unit within the scope of project number BAP-2022/014.

Conflict of Interest

No conflict of interest was declared by the authors.

References

Akal, D. and Akan, A.E. (2022), "Edirne iklim şartlarında çevre sıcaklığı ve rüzgar hızının polikristal fotovoltaik panel çıkış gücüne etkilerinin incelenmesi", *Mühendislik Bilimleri ve Tasarım Dergisi*, Süleyman Demirel Üniversitesi, Vol. 10 No. 1, pp. 91–102.

Alsabbagh, W. and Langendörfer, P. (2023), "Security of Programmable Logic Controllers and Related Systems: Today and Tomorrow", *IEEE Open Journal of the Industrial Electronics Society*, IEEE.

Bekiroglu, E. (2009), "Transformatör Merkezlerinin Güvenlik Amaçli Uzaktan İzlenmesi Ve Otomasyonu", *Engineering Sciences*, E-Journal of New World Sciences Academy, Vol. 4 No. 4, pp. 459–470.

Bołoz, Ł. and Biały, W. (2020), "Automation and robotization of underground mining in Poland", *Applied Sciences*, MDPI, Vol. 10 No. 20, p. 7221.

Dündar, S., Bilim, N. and Bilim, A. (2018), "Ülkemizdeki maden sektöründe meydana gelen iş kazası ve meslek hastalıklarının analizi", *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi*, Bitlis Eren Üniversitesi, Vol. 7 No. 2, pp. 423–432.

Hamrin, H., Hustrulid, W. and Bullock, R. (2001), "Underground mining methods and applications", *Underground Mining Methods: Engineering Fundamentals and International Case Studies*, SME Littleton, CO, pp. 3–14.

Kul, N. (2009), *1500 KVA Gücünde 6.3 KV. Çıkış Gerilimli Generatör Grubu ve Yüksek Gerilim Kesicilerinin PLC-SCADA Ile Uzaktan Izlenmesi*, Karadeniz Teknik Üniversitesi, Fen Bilimleri Enstitüsü.

Kumru, C.F. and Vural, M.S. (2023), "Design and application of IoT based weather station for high voltage laboratories", *Mühendislik Bilimleri ve Tasarım Dergisi*, Süleyman Demirel University, Vol. 11 No. 3, pp. 1190–1201.

Li, F., Kong, D., Li, Q., Shang, Y., Cheng, Z. and He, L. (2023), "Failure analysis and prediction of roof instability in end face under repeated mining using early warning system", *Scientific Reports*, Nature Publishing Group UK London, Vol. 13 No. 1, p. 8764.

Li, L., Si, J. and Li, Z. (2023), "Characteristics of the spatial and temporal evolution of the environmental parameters for belt fire in underground coal mine roadway", *Case Studies in Thermal Engineering*, Elsevier, Vol. 49, p. 103346.

Mallı, T., Kun, M. and Köse, H. (2014), "Yeraltı Kömür İşletmelerinde Gaz İzleme ve Erken Uyarı Sistem Teknolojisinin İş Kazalarının Önlenmesindeki Önemi", *Dokuz Eylül Üniversitesi Mühendislik Fakültesi Fen ve Mühendislik Dergisi*, Dokuz Eylul University, Vol. 16 No. 46, pp. 59–67.

McRoberts, M. (2013), *Beginning Arduino*, Apress.

Melo, J.J.R., Ishraque, M.F., Shafiullah, G.M. and Shezan, S.A. (2023), "Centralized monitoring of a cost efficient PLC-SCADA based islanded microgrid considering dispatch techniques", *The Journal of Engineering*, Wiley Online Library, Vol. 2023 No. 8, p. e12293.

Mixsen. (2020), *MIX8410 Electrochemical Oxygen Gas Sensor*.

Rajakumar, J.P.P. and Choi, J. (2023), "Helmet-mounted real-time toxic gas monitoring and prevention system for workers in confined places", *Sensors*, MDPI, Vol. 23 No. 3, p. 1590.

Sharp. (2006), *GP2Y1010AU0F Optical Dust Sensor*.

Tekin, A., Nalbant, M.O., Orhan, M., Tekin, F., Suvaydan, F., Berki, K., Gümüş, S., *et al.* (2023), "Statistical analysis of noise exposure of workers in the underground mining in the Soma basin of Turkey", *Mühendislik Bilimleri ve Tasarım Dergisi*, Süleyman Demirel University, Vol. 11 No. 2, pp. 449–458.

Texas_Instruments. (2017), *LM35 Precision Centigrade Temperature Sensors*.

Tomar, B., Kumar, N. and Sreejeth, M. (2023), "Real Time Automation and Ratio Control Using PLC & SCADA in Industry 4.0.", *Computer Systems Science & Engineering*, Vol. 45 No. 2.

Winsen. (2014), *MQ-7 Toxic Gas Sensor*.

Winsen. (2015), *MQ-136 Hydrogen Sulfide Gas Sensor*.

Winsen. (2018), *MQ-4 Flammable Gas Sensor*.

Yaman, O. (2019), *Nesnelerin Interneti (IoT) Tabanlı Transformatör Izleme Sistemi*, Düzce Üniversitesi, Fen Bilimleri Enstitüsü.