



IMPLEMENTATION OF SMART PERSONAL RESPIRATORY PROTECTIVE DEVICES IN UNDERGROUND MINING OPERATIONS

D. A. Sulkhonov 1

1Master's Student, Group 3M-25FQKQ, Department of Mining Engineering, Faculty of Mining, Almalyk State Technical Institute
E-mail: sulxonovdiyorbek2gmail.com

U. T. Toshtemirov 2

2Associate Professor, Department of Mining Engineering, Faculty of Mining, Almalyk State Technical Institute, Doctor of Philosophy (PhD) in Technical Sciences

Abstract

This paper presents a comprehensive analysis of the theoretical foundations and practical implementation of smart personal respiratory protective equipment (PRPE) designed for underground mining personnel. The proposed system incorporates advanced environmental sensors, infrared detection modules, microcontroller-based control units, intelligent data-processing algorithms, and wireless remote monitoring technologies. The integration of these components enables continuous real-time monitoring of hazardous atmospheric parameters, automated risk assessment, and adaptive control of respiratory protection functions. The system is intended to enhance occupational safety, improve emergency responsiveness, and optimize operational reliability in underground mining conditions characterized by elevated dust concentration, toxic gases, and limited ventilation.

Keywords: Underground excavation, personal respiratory protective equipment, smart respirator, infrared sensor, miner, microcontroller, remote monitoring.

Introduction

Ensuring safety in underground mines is one of the most critical challenges in the mining industry. The lives of miners are frequently exposed to hazardous conditions, including complex geological environments, gas accumulation, airborne dust, and oxygen deficiency. Therefore, the development of an effective system for monitoring Personal Respiratory Protective Equipment (PRPE) and enabling its remote, real-time supervision would significantly enhance occupational safety in mining operations.

Workers employed in underground mines are continuously exposed to inhalable dust, methane (CH₄), carbon dioxide (CO₂), and other harmful gases. These factors contribute to respiratory diseases, occupational illnesses, and may lead to emergency situations. According to occupational health and safety regulations, miners are required to wear respirators at all times while working underground. However, in practice, some workers temporarily remove their respirators due to discomfort or negligence. This behavior poses serious health risks and reduces overall industrial safety.

Addressing these issues requires the implementation of advanced monitoring solutions in mining enterprises, particularly considering the following limitations:

- Although PRPE serves as the primary protective equipment for miners, the capability to monitor its operational status in real time remains limited;
- Conventional monitoring systems primarily track general environmental parameters and fail to provide comprehensive data on the individual protective status of each miner;
- In emergency situations, the lack of prompt and accurate information complicates evacuation procedures and emergency response operations.

The objective of this proposed development is to design and implement a cost-effective and reliable automated system for monitoring respirator usage in underground mines and to evaluate its operational efficiency and safety performance.

Main Section

In the development of the proposed system, both hardware and software approaches were applied to ensure reliability, real-time monitoring capability, and

cost-effectiveness under underground mining conditions. The overall system configuration includes the following essential modules:

- ✓ **Infrared (IR) Proximity Sensor** – used to detect whether the respirator mask is properly worn or removed. The sensor operates based on reflected infrared radiation and continuously monitors the position of the mask relative to the worker's face.
- ✓ **ESP32 Microcontroller** – serves as the central processing unit of the system. It processes incoming sensor data, performs time tracking, manages logical control algorithms, and coordinates communication tasks.
- ✓ **Buzzer Module** – provides a local audible alarm when improper respirator usage (e.g., mask removal beyond a predefined time threshold) is detected. This ensures immediate feedback to the miner.
- ✓ **Wi-Fi Communication Module (integrated within ESP32)** – enables wireless transmission of status data to supervisory personnel. In the event of non-compliance or abnormal conditions, real-time alerts are sent to responsible safety officers for prompt action.
- ✓ **Lithium-ion (Li-ion) Battery** – functions as an independent power supply, ensuring uninterrupted system operation in underground environments where wired power sources are impractical.

The integration of these components forms a compact, autonomous, and scalable monitoring system capable of operating in harsh underground mining environments while maintaining continuous supervision of individual respiratory protection compliance.



Figure 1. Smart Respirator

The sensor detects whether the respirator mask is being worn (see Figure 1). If the mask is removed, the system automatically activates a three-minute timer. If the mask is not re-worn within this specified time interval, an alert signal is generated and the worker is notified through an audible warning.

Once the mask is properly reattached, the system automatically resets and returns to normal operating mode without requiring manual intervention.



Figure 2. Technological Schematic Diagram of the Control Module.

Expected Results

The implementation of the proposed intelligent respiratory monitoring system is expected to yield the following outcomes:

- ✓ Enhancement of individual safety levels among underground miners through continuous supervision of respirator usage;
- ✓ Establishment of rapid and effective emergency response mechanisms by providing timely alerts in critical situations;
- ✓ Provision of real-time, comprehensive operational data to mine management and safety supervisors;
- ✓ Improvement of overall production efficiency and strengthening of safety culture in the mining industry through the integration of innovative technologies.



Conclusion

The development of an intelligent control and remote monitoring system for personal respiratory protective equipment in underground mines represents a significant advancement in mining safety management. The proposed system not only safeguards miners' health and lives by ensuring proper respirator compliance but also enables mine operators to maintain continuous, real-time oversight of individual protective status. By adopting this innovative technological approach, it is possible to simultaneously enhance occupational safety standards and operational efficiency within underground mining environments.

References

1. World Health Organization (WHO). (2021). Respiratory Protective Devices: Technical Specifications and Guidelines. Geneva, Switzerland.
2. Chen, Y., & Wang, L. (2020). Smart Respirator Systems for Industrial Safety. *Journal of Safety Research*, 72, 45–53.
3. European Committee for Standardization (CEN). (2022). EN 149: Respiratory Protective Devices – Filtering Half Masks to Protect Against Particles. Brussels, Belgium.
4. Kalandarov, I. I., & Xojiev, A. M. (2025). Yer osti kon ishlarida mehnat sharoitlari xavfsizligining huquqiy asoslari va xalqaro amaliyot. *Sanoatda Raqamli Texnologiyalar / Digital Technologies in Industry*, 3(1). ISSN: 3030-3214. <https://cyberleninka.ru/article/n/yer-osti-kon-ishlarida-mehnat-sharoitlari-xavfsizligining-huquqiy-asoslar-va-xalqaro-amaliyot/viewer>.
5. Sulxonov, D. A., & Toshtemirov, U. T. (2025). Yer ostida xavfsiz ish sharoitini yaratishda smart texnologiyalardan foydalanish. *Строительство и образование*, (3), 295-297.
6. Erkaboyeva, S. I., & Toshtemirov, U. T. (2025). Dunyodagi chuqur karyerlar bilan tanishish va ularni tahlil qilish. *Строительство и образование*, 4(2), 60-62.
7. Khasanov, A., Khasanov, U., Toshtemirov, U., Abdurakhmanov, D., & Melnikova, T. (2024). RETRACTED: Studying the condition of tungsten-containing man-made waste in the territory of Uzbekistan. In *E3S Web of Conferences* (Vol. 538, p. 03023). EDP Sciences.

8. Mutalova, M., Khasanov, A., Toshtemirov, U., Melnikova, T., & Yuldashava, N. (2024). RETRACTED: Modern technology for enrichment of tailings from an enrichment plant processing tungsten ores. In E3S Web of Conferences (Vol. 538, p. 01002). EDP Sciences.
9. Raimqul, R., & O'G, T. U. T. L. (2024). TEXNIKA FANLARINI O'QITISHDA IXTIROCHILIK MUAMMOLARINI HAL QILISH NAZARIYASI TEXNOLOGIYASIDAN FOYDALANISH. *Строительство и образование*, 3(2), 114-119.
10. Yormatov, O. S., & Toshtemirov, U. T. (2023, September). SHPURLAR TO 'PLAMINI PORTLATILISHIGA QO'YILADIGAN TALABLAR. In International conference on multidisciplinary science (Vol. 1, No. 2, pp. 71-73).
11. Yormatov, O. S., & Toshtemirov, U. T. (2023). RAQAMLI TEXNOLOGIYALARDAN FOYDALANISH ASOSIDA SMART SHAXTALARNI TASHKIL QILISH. QO 'QON UNIVERSITETI XABARNOMASI, 257-258.
12. Yormatov, O. S., & Toshtemirov, U. T. (2023, September). SHPURLAR TO 'PLAMINI PORTLATILISHIGA QO'YILADIGAN TALABLAR. In International conference on multidisciplinary science (Vol. 1, No. 2, pp. 71-73).
13. Yormatov, O. S., Mamirov, U. M., Yulchiboyev, I. I., Safarov, M. M., & Toshtemirov, U. T. (2023). ELASTICITY-DEFORMATION OF ROCKS OF MINE SOIL WALLS STATUS STUDY. *Galaxy International Interdisciplinary Research Journal*, 11(2), 184-186.
14. Nishonov, A. I., & Toshtemirov, U. T. (2023). STUDY OF THE GRAPH ANALYTIC METHOD OF DETERMINING THE WORKING MODE OF A PUMP DEVICE FOR REDUCING THE MINE FROM GROUNDWATER. *Galaxy International Interdisciplinary Research Journal*, 11(2), 181-183.
15. Yormatov, O. S., & Toshtemirov, U. T. (2023). SHAXTA VA RUDNIKLARDAGI YER OSTI KON ISHLARI HOLATINI KO'RISH UCHUN OLIY TA'LIM DARGOHLARIDA VIRTUAL SAYOHAT AUDITORIYASINI TASHKIL QILISH. *Journal of Science-Innovative Research in Uzbekistan*, 1(2), 126-128.

16. Yormatov, O. S., & Toshtemirov, U. T. (2023). THE SCIENTIFIC BACKGROUND OF METHODS FOR INCREASING SUSTAINABILITY UNDERGROUND MINING WITH THE USE OF ANCHORING. Yangi O'zbekistonda Tabiiy va Ijtimoiy-gumanitar fanlar respublika ilmiy amaliy konferensiyasi, 1(5), 15-18.
17. Yormatov, O. S., & Toshtemirov, U. T. (2023). YER QA'RIDA MASSIVNING TABIIY SHAROITIDA DINAMIK JARAYONLARNI SODIR BO'LISHINI TAHLIL QILISH. МЕДИЦИНА, ПЕДАГОГИКА И ТЕХНОЛОГИЯ: ТЕОРИЯ И ПРАКТИКА, 1(1), 1317.
18. Toshtemirov, U. T., & Ismatullayev, N. A. (2023). NIMQAVATNI QULATIB QAZIB OLIISH TIZIMINI TANLASHGA TA'SIR ETUVCHI OMILLAR TAHLILI. PEDAGOG, 6(12), 286-290.
19. Shamayev, M. K., Toshtemirov, U. T., Alimov, S. M., Melnikova, T. E., Berdiyeva, D. K., & Ismatullayev, N. A. (2022). Determination of the Installation Density of Anchors in the Walls of a Working with a Quadrangular Cross Section. Child Studies in Asia-Pacific Contexts, 12(1), 362-367.
20. Yormatov, O. S., & Toshtemirov, U. T. (2022). METHODS FOR INCREASING HOLE DEPTH AT A CONSTANT MINING SECTION. Multidisciplinary Journal of Science and Technology, 2(2), 15-17.
21. Шамаев, М. К., Ахмадов, А. У., Рахматуллаев, И. М., & Тоштемиров, У. Т. (2022). ИЗВЕСТНЯК В ПРИРОДЕ, ТЕХНОЛОГИЯ ПРОИЗВОДСТВА И НЕКОТОРЫЕ ИХ СВОЙСТВА ПРИ ИСПОЛЬЗОВАНИИ. АРХИТЕКТУРА, МУХАНДИСЛИК ВА ЗАМОНАВИЙ ТЕХНОЛОГИЯЛАР ЖУРНАЛИ, 1 (4), 26–30. АРХИТЕКТУРА, МУХАНДИСЛИК ВА ЗАМОНАВИЙ ТЕХНОЛОГИЯЛАР ЖУРНАЛИ, 1(4), 26-30.
22. Ахмадов, А. У., Мельникова, Т. Е., & Тоштемиров, У. Т. (2022). Анализ микроклиматических условий карьера Кальмакыр. Евразийский журнал академических исследований, 2(12), 1207-1216.
23. Шамаев, М. К., & Тоштемиров, У. Т. (2022). Добыча щебня и требования предъявляемые к их качеству. Та'lim va Rivojlanish Tahlili, 2(10), 131-137.
24. Toshtemirov, U. T. (2022). Construction of log cabins and schemes of development of the log strip. Scienceweb academic papers collection.

25. Исмаилов, М. Р., & Тоштемиров, У. Т. (2021). ОБЕСПЕЧЕНИЕ БЕЗОПАСНОСТИ РАБОТНИКОВ ПРИ ЭКСПЛУАТАЦИИ ЗДАНИЙ. ТА'ЛИМ TIZIMIDA INNOVATSIYA, INTEGRATSIYA VA YANGI TEXNOLOGIYALAR ИННОВАЦИЯ, ИНТЕГРАЦИЯ И НОВЫЕ ТЕХНОЛОГИИ В СИСТЕМЕ ОБРАЗОВАНИЯ INNOVATION, INTEGRATION AND NEW.
26. Toshtemirov, U. T., & Raimkulova, S. (2021). Mahkamova Kh. Современные методы оценки устойчивости пород и расчета анкерной и набрызг-бетонной крепей горных выработок. *Central Asian Journal of Theoretical and Applied Sciences*, 2(5), 29-37.
27. Toshtemirov, U. T. (2021). ANALYSIS OF LOG CABIN DESIGNS AND SELECTION OF OPTIMIZATION CRITERIA FOR THE FORMATION OF LOG CABIN CAVITIES. *Scienceweb academic papers collection*.
28. Qosimov, M. O., Shakarov, T. L. I., & Toshtemirov, U. T. (2021). Reduction and prevention of environmental hazards in underground construction. *Academicia: An International Multidisciplinary Research Journal*, 11(1), 975-981.
29. Akbarov, T. G., & Toshtemirov, U. T. (2020). Nurkhanov Kh., Khojakulov A. Recommended Support Structures for Excavations in Difficult Mining and Geological Conditions. *International Journal of Advanced Research in Science, Engineering and Technology (IJARSET)*.–India, 7(2), 12798-12802.
30. MK, I. U. S., & Toshtemirov, U. T. (2020). Selection And Justification Of Methods For Opening The Southbay Field. *IJARSET» International Journal of Advanced Research in Science, Engineering and Technology*, 7(2), 12849-12853.
31. Toshtemirov, U. T. (2020). Analysis of methods for calculating rational parameters of drilling and blasting operations during the transition of mining solder. *The international interdisciplinary research journal ACADEMICIA, published by the South Asian Academic Research Journals CDL College of Education*, 10(11), 1923-1930.
32. Toshtemirov, U. T. (2020). Analysis of methods for calculating the rational parameters of drilling-blasting operations in the transition of mining solder. *ACADEMICIA: An International Multidisciplinary Research Journal*, 10(11), 1918-1925.
33. Toshtemirov, U. T., Raimkulova, S. M., & Mahkamova, K. S. (2020). Analysis of the stress state in the rock mass around the horizontal

- productions. Asian Journal of Multidimensional Research (AJMR), 9(11), 245-251.
34. Toshtemirov, U. T., Raimkulova, S. M., & Mahkamova, K. S. (2020). Analysis of the stress state in the rock mass around the horizontal productions. Asian Journal of Multidimensional Research (AJMR), 9(11), 245-251.
35. MK, I. U. S., & Toshtemirov, U. T. (2019). Selection and Substantiation of the Method of Exploiting the Tebinbulak Deposit. IJARSET» International Journal of Advanced Research in Science, Engineering and Technology, 6(11), 11828-11833.
36. Akbarov, T. G., Toshtemirov, U. T., Solikhov, J. T., & Abduvohidov, J. U. (2019). Determining the Length of Anchors for Vertical Works. IJARSET.«International Journal of Advanced Research in Science, Engineering and Technology, 6(11), 11849-11854.
37. Акбаров, Т. Г., & Тоштемиров, У. Т. (2015). Анализ технологии проведения горных выработок на горнодобывающих предприятиях Республики Узбекистан. In Reproduce of the resources, low-waste and environmental technology exploitation of mineral resources (pp. 89-91).
38. Меликулов, А. Д., & Тоштемиров, У. Т. (2015). Современные технологии тоннелестроения на службе развития международных связей Узбекистана вдоль древнего великого шелкового пути.
39. Akbarov, T. G., & Toshtemirov, U. T. (2015). Analysis of mining technology at mining enterprises of the Republic of Uzbekistan. In Materials of the XIV International Scientific and Technical Conference on the topic:" Resource-reproducing, low-waste and environmental technologies of subsurface development (pp. 89-91).
40. Erkaboyeva, S., & Toshtemirov, U. T. YER QA'RI RESURSLARIDAN FOYDALANISHDA EKOLOGIK XAVF OMILLARINI KAMAYTIRISH. ISLOM KARIMOV NOMIDAGI TOSHKENT DAVLAT TEXNIKA UNIVERSITETI, 364.
41. ТОШТЕМИРОВ, У. ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ БУРОВЗРЫВНЫХ РАБОТ ПРИ ПРОВЕДЕНИИ ПОДЗЕМНЫХ ГОРИЗОНТАЛЬНЫХ ГОРНЫХ ВЫРАБОТОК.