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Design of an automated cyanide gas detection and control system for a gold mine

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Abstract

Cyanidation is an essential process that uses sodium cyanide in gold production. The use of sodium cyanide poses the risk of cyanide gas (HCN gas) poisoning, which has been a challenge in gold mines for many years. A gap exists in the literature regarding systems that simultaneously detect and control dangerous levels of HCN gas. Significant literature sources report HCN gas monitoring systems that detect and record gas concentration levels in the air at different intervals. Furthermore, most reported treatment methods focus on controlling free cyanide in processing effluent, not the HCN gas. Therefore, this paper presents the design of an automated, real-time HCN gas detection and control system for a gold mine using the Internet of Things (IoT). The designed system can detect any rise above the OSHA legal airborne HCN gas permissible exposure limit (PEL) of ten parts per million. In case of detection, the sensor sends a signal to the microcontroller, which triggers a warning alarm to alert workers to evacuate the area. Simultaneously, a signal is sent to the solenoid valve to close the cyanide tank supply. The DC fan immediately provides an air supply that neutralizes the toxic levels of HCN gas.

Keywords: Cyanide gas; gold mining; Internet of Things (IoT); real time monitoring; control

1. Introduction

Gold mining makes a valuable contribution to the world's economy. The precious mineral naturally occurs in low concentrations below 10 grams per tonne. The hydrometallurgical extraction of gold essentially consists of ore extraction, crushing and grinding, pre-treatment, leaching, and refining. Gold is insoluble in water and requires the leaching process, where cyanide is the most common solvent introduced to dissolve it from the ore [1]. Elsner's equation represents the leaching process [2].

$$4\mathrm{Au} + 8\mathrm{NaCN} + 2\mathrm{H_2O} + \mathrm{O_2} \rightleftharpoons 4[\mathrm{NaAu(CN)_2}] + 4\mathrm{NaOH}$$

$\mathrm{Au(CN)_2^-}$ is a stable ion that brings gold to solution form. Gold is then extracted from the cyanide solution by adsorption onto activated carbon, which has a higher affinity for the cyanide ion. Cyanide remains today's primary reagent for gold processing because it efficiently extracts gold from low-grade ore (up to 95% gold), is economical, and is readily available [3]. However, cyanide's toxicity adversely impacts people's health and the environment. Therefore, an emphasis on monitoring and controlling employees' cyanide exposure significantly improves the well-being of workers in gold mines.

Cyanide gas (HCN gas) poisoning has been a challenge in gold mines for many years, posing the need for continuous research in cost-effective ways of detecting and controlling its exposure. This study designs an automated, real-time HCN gas detection and control system for a gold mine using the Internet of Things (IoT). It contributes to sustainable gold production by promoting a toxic-free and healthy environment for mine workers.

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The rest of the paper is organized as follows: Section 2 highlights a literature overview on the adverse impacts of cyanide and monitoring and control systems, while Section 3 outlines the development of the automated HCN gas detection and control system. Section 4 specifies the system design, and Section 5 presents and discusses the study results. Section 6 concludes the paper.

2. Literature Overview

2.1. Cyanide adverse impact on human health and the environment

Failure to detect and control HCN gas levels adversely impacts mine workers' health as cyanide gas is a highly toxic and harmful pollutant. Minimum exposure can cause headaches, vomiting, and breathing difficulties. Prolonged exposure to levels above ten parts per million (ppm) can lead to cardiac arrest, hypoxic brain injury, or in worst cases, death [4].

Free cyanide in gold processing wastes presents noticeable environmental risks [5]. It causes severe environmental problems when the ions present in wastewater get discharged into water bodies. The effluent puts the lives of land and aquatic animals in danger and causes degradation of the biological, physical, and chemical nature of soil [6]. Therefore, undetected and uncontrolled cyanide concentration adversely contributes to environmental sustainability.

2.2. Cyanide gas monitoring and control systems

Several studies have reported systems that monitor cyanide levels. Greenawald et al. [7] developed a red, green, and blue (RGB) colour sensor that generates a colour difference upon detecting HCN gas at concentrations of 1.0−10.0 ppm as a function of 25%, 50%, and 85% relative humidity. In another study, Zain et al. [8] researched air quality control in residential areas around gold mines by developing a system for determining the HCN gas concentration in residential ambient air, 0.1, 1.0, and 2 km away from a gold mine, using solid-phase microextraction (SPME) and gas chromatography-mass spectrometry (GC–MS). The results show that the concentration is significantly higher as one gets closer to the mine, thus justifying the need for HCN gas detection and control to minimize exposure. Although several novel HCN gas sensors exist in the literature, they do not apply to the gold mining industry. For example, Deji et al. [9] developed a novel HCN gas sensor to detect gas released during burning material.

Table 1 presents a literature overview of cyanide detection and control systems. The studies were selected for their detailed contribution to the mining industry's cyanide detection and control applications.

2.3. Literature Gap

Literature significantly presents studies focusing on detecting HCN gas using various sensing methods and treatment methods focusing on controlling free cyanide in processing effluent, not cyanide gas. However, a gap exists in scholarly publications on systems that detect and control dangerous levels of HCN gas. The paper, therefore, presents the design of an automated, real-time HCN gas detection and control system for a gold mine using the Internet of Things (IoT) principles. The developed system aims to reduce the risk of HCN gas poisoning by using wireless sensors that detect the presence of HCN gas and send the collected data to the processors, which analyze and provide control action.

Table 1. Cyanide detection and control system literature overview.

Reference	Study Focus	Methodology	Key contribution
Greenawald et al. (2017) [7]	Development of an inexpensive red, green, blue colour sensor for detecting HCN gas	Development of sensor through experimentation.	A HCN gas monitoring sensor that could provide "a real time respirator end-of-service-life alert for HCN".
Boltz (2001) [10]	Describing cyanide treatment process used in mines.	Review cyanide destruction and recovery processes.	A summary of various application of identified cyanide treatment processes.
Akcil (2006) [11]	Cyanide management at a gold-silver mine.	A case of Ovacik gold-silver mine in Turkey.	Cyanide risk management process. Leak detection systems that actuate an alarm.
Botz et al. (2005) [12]	Providing details of cyanide treatment process, both with full scale proven success and those with potential in the mining environment.	Review of cyanide treatment methods providing details of the chemistry involved.	Details of cyanide treatment processes and a preliminary guide to selecting cyanide treatment process.
Kuyucak and Akcil (2013) [13]	Discussing commercially available and emerging methods of cyanide treatment.	Review treatment processes to remove cyanide.	Detailed discussion of cyanide treatment processes.
Mpongwana et al. (2019) [14]	Biological methods to degrade free cyanide in wastewater treatment plants.	Review of the biological remedial strategy to limit the inhibition of simultaneous nitrification and aerobic denitrification by free cyanide.	The applications of free cyanide degrading microorganisms to reduce its negative impact in wastewater treatment.
Anning et al. (2019) [15]	Focuses on the determination and detoxification of cyanide found in gold mine tailings.	Review of determination and detoxification processes.	Cyanide determination methods and cyanide detoxification procedures.
Vuono et al. (2021) [5]	Optimisation of ultraviolet radiation and hydrogen peroxide to the removal of cyanide from gold processing waste.	Experimentation at a mineral processing facility.	Testing of various ultraviolet radiation hydrogen peroxide treatment methods in minimising cyanide in processing waste.

3. Development of an Automated Cyanide Gas Detection and Control System

The design of an automated HCN gas detection and control system was based on IoT principles. Three concepts were developed and screened against a reference model using the Pugh Matrix rating method.

3.1. Concepts Alternatives

3.1.1. Reference Model: RGB color sensor

Greenawald et al.'s [7] red, green, and blue (RGB) colour sensor is a reference model in this study. The RGB colour sensor generates a colour difference upon detecting HCN gas at concentrations of 1.0−10.0 ppm as a function of 25%, 50% and 85% relative humidity. A rapid colour change indicates the presence of HCN gas.

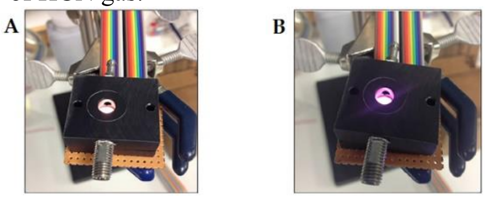

Fig. 1. RGB Color Sensor [7]

3.1.2. Concept 1: NodeMCU model system

Fig.2 shows the NodeMCU model system. It is an open-source platform that works as an Arduino and has an ESP8266 chip that connects to a WIFI network [16]. A program is sent to the microcontroller and is interpreted by an Arduino language. This model monitors and analyses HCN gas levels in real time. It logs data to a remote server, updating it over the internet. An alarm goes off if the threshold range is exceeded, notifying the employees to vacate the facility.

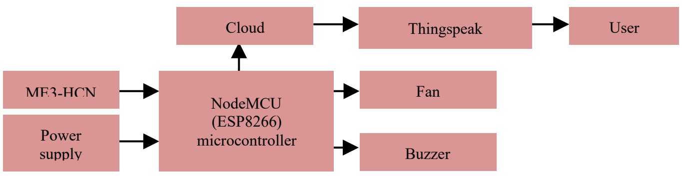

Fig. 2. NodeMCU Model System [16]

3.1.3. Concept 2: Arduino Model System

This concept uses an Arduino Uno microcontroller, as presented in Fig 3. A sensor senses the HCN gas levels. A set of instructions, written in the Arduino software using the Arduino programming language, is sent to the microcontroller on the board [17]. The buzzer, fan, and liquid crystal display are interfaced with Arduino's input/output pins.

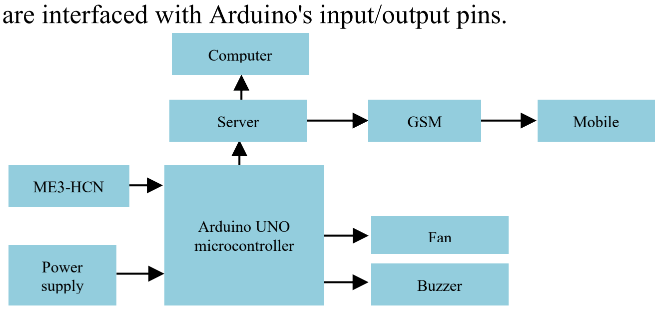

Fig. 3. Arduino Model System [16]

3.1.4. Concept 3: Leonardo Model System

This model analyses the cyanide levels and processes and presents the data on a liquid crystal display [18]. A buzzer rings if the standard set limit varies from the required standards.

Fig. 4. Leonardo Model System [18]

3.2. Concept Selection using Pugh Matrix Rating

Table 2 shows an extract of the Pugh matrix rating used to evaluate the concept alternatives. The concepts were rated using the Pugh Matrix. The concepts are evaluated in terms of detection distance, installation cost, ease of operation, minimum human interference, reliability, ease of manufacturing, and maintainability. The steps are as follows:

i. Preparation of the Selection Matrix
- The reference concept is used against which other concepts are weighed.
- The concepts and criteria are entered into a matrix.

ii. Rating the concepts
- '+' is indicated if the concept is judged better than the datum.
- '–' is assigned if the concept is worse than the datum.
- '0' score is given if the concept is judged to be the same as the datum.

iii. Rank the concepts
- All the '+' and '-' are summed up for each concept.
- The net score is calculated by subtracting the '-' from the '+'.

iv. Select One or More Concepts
- Lower scoring concepts are removed, and the process repeated iteratively until a decision is reached.

Table 2. Pugh Matrix Concept Screening.

	Reference concept: RGB Color Sensor	Concept 1: NodeMCU Model System	Concept 2: Arduino Model System	Concept 3: Leonardo Model System
Efficiency	0	+	+	+
Detection distance	0	+	+	+
Installation cost	0	–	–	–
Ease of operation	0	+	–	+
Minimum human interference	0	+	+	+
Reliability	0	+	+	+
Ease of manufacture	0	+	+	–
Maintainability	0	+	–	+
∑ +	0	7	5	6
∑ -	0	1	3	2
∑ score	0	6	3	4
Rank	N/A	1	3	2
Decision	N/A	Develop	Discard	Discard

4. System Design

4.1. Concept development

The Pugh matrix ranks the NodeMCU Model System (concept 1) as the best potential solution. Hence, the study employs this concept in developing a wireless data device for detecting and controlling cyanide gas levels. The data collected is sent to a NodeMCU controller and verified against the threshold values in the control section. The decision-making process is based on the instructions installed in the controller. The generated data on the web page is accessed through the Think Speak application or via notifications in the form of emails. All communications are done on the web server and facilitated by the microcontroller system. Fig. 5 shows the developed concept.

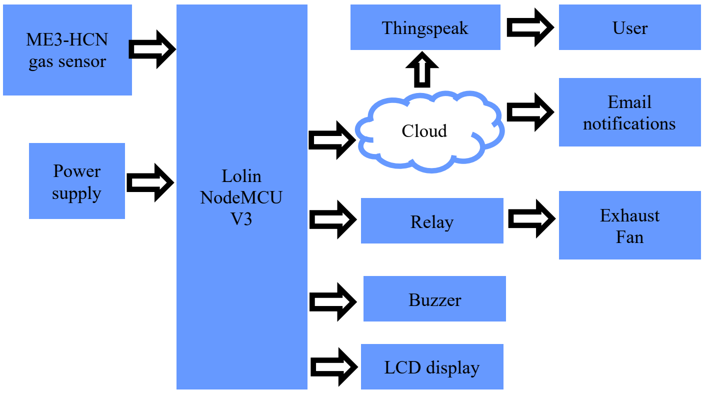

Fig. 5. Developed Concept – Cyanide Gas Detection and Control System

4.2. System architecture and product decomposition

The system has a sensing unit, a control unit, and a visual interface. The sensing unit (ME3-HCN sensor) feeds into the control unit, consisting of the microcontroller, system algorithm, and actuator. The output is displayed on the visual interface via the LCD. The hardware comprises a ME3-HCN gas sensor, Lolin NodeMCU microcontroller, buzzer, DC fan, LCD, single channel relay module, and the MB102 breadboard power supply module. A top-down functional decomposition tree of the cyanide gas detection and control system is employed in the research. The system product decomposition is shown in Fig. 6.

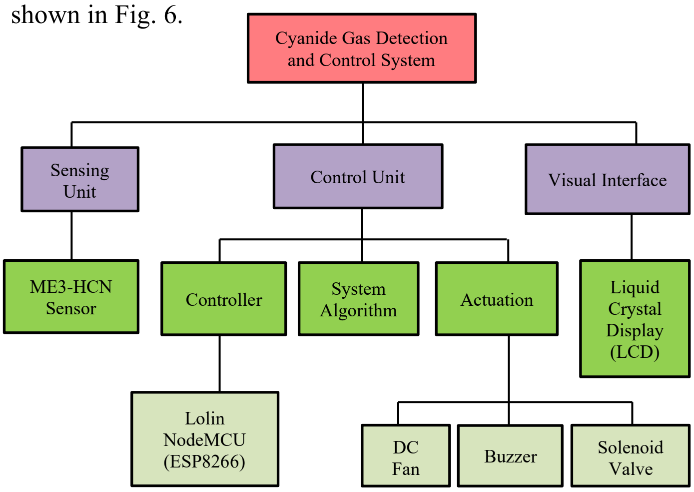

Fig. 6. System product decomposition.

- The Lolin NodeMCU microcontroller is programmed using the Arduino programming language and the Arduino development environment. The USB connects the Lolin NodeMCU microcontroller to an external power supply. External power is from a battery or an AC to a DC adapter. The power source is selected automatically. The built-in ESP8266 module collects and processes the data and displays the real-time readings on the ThinkSpeak dashboard.
- The ME3-HCN gas sensor is significantly sensitive to HCN gas. It is a widely used in industrial and environmental fields with a detection range of up to 150 ppm. The sensitivity of the digital pin can be varied using the potentiometer.
- The Buzzer sends a signal when the air condition in the workplace reaches dangerous cyanide levels.
- The DC Fan provides an air supply for neutralization and removes the toxic air from the workplace.
- The LCD is a user interface medium to provide system users with the status or process conditions during operation.
- The Single Channel Relay Module is the electromagnetic device that uses an electric current to open or close the contacts of a switch allowing the control action to take place when current flows to the fanning system.
- The MB102 Breadboard Power Supply Module powers the system's circuits. The module has an on/off switch to control the external input switch, and along with the DC port, the breadboard module has a USB port.

4.3. Parameters monitored and controlled

The HCN gas level is the main parameter to be controlled. The system algorithm was developed to offer control action based on the data received from the sensors. Table 3 shows the modeling of the HCN gas air quality, and Fig. 7 presents the system flow diagram.

Table 3. Air Quality Modelling.

ID	ME3-HCN Sensor Detects	Air Quality Value (AQV)	Display Result
1	HCN gas	AQV ≤ 1 ppm	Cyanide level low
2	HCN gas	AQV ≥ 5 ppm	Cyanide level high

4.4. System coding

The software used to implement this project is the Arduino Integrated Development Environment (IDE), written in function from C and C++, one of the cross-platform applications. The IDE software application has a user-friendly interface for writing and editing code, as well as tools for compiling, debugging, and uploading code to a microcontroller. This design project uses it to compose and transfer programs to the NodeMCU development board.

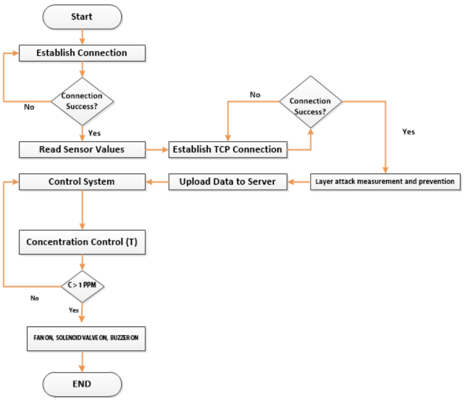

Fig. 7. System flow diagram.

4.5. Circuit Design

Fig. 8 shows the electronic representation of the system. Simulations were run on the circuit to ensure the system functioned as expected. Based on the simulation results, a physical prototype of the system was constructed.

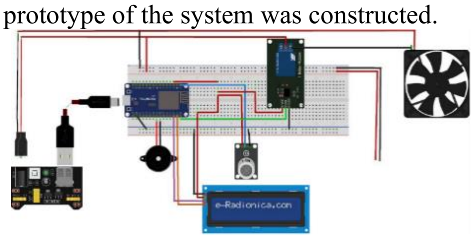

Fig. 8. System circuit diagram

5. Results and discussion

This section outlines the results obtained from the development of the system.

5.1. Final design model

The ThinkSpeak platform application was developed to monitor and provide live updates on the HCN gas levels. The software was implemented in Arduino IDE and programmed in the function C language. The ME3-HCN Gas Sensor is used to detect and collect cyanide air data. The collected data was connected to a cloud network to monitor the level of cyanide gas according to the air quality index (AQI). The concentration of cyanide gas was analyzed using MATLAB. The prototype was developed to represent the actual layout of the physical system and the respective connections between the significant constituent components. Fig. 9 shows the physical prototype.

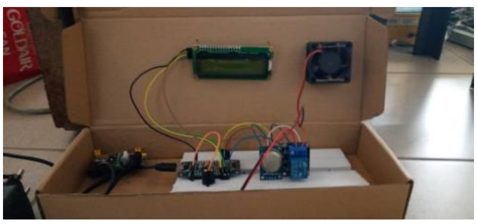

Fig. 9. Prototype.

5.2. Communication technology

The system has two sets of communication. These are communication between sensors and controller and communication with the user.

5.2.1. Communication between sensors and controller

Any rise above the OSHA legal airborne HCN gas permissible exposure limit (PEL) of ten ppm is detected by the ME3-HCN sensor, and a signal is sent to the Lolin NodeMCU microcontroller for processing. This triggers a warning alarm to alert the workers to evacuate the area. Simultaneously, a signal is sent to the solenoid valve to close the cyanide tank supply. The DC fan immediately starts to provide an air supply that neutralizes the toxic levels of cyanide by the principle of diffusion, and the solenoid valve automatically closes in case there is a leak from the tanks. The collected data is then displayed on an LCD screen. Fig. 10 shows the LCD for the connection steps after powering on the prototype and the detected HCN gas level.

Fig. 10. LCD output.

5.2.2. Communication with the user

The online application provides global access to the measured data using any device with internet connection capability. Data is collected, analyzed, and passed as a string to update the web page in the remote server. Multiple accounts can be installed through sharing; only authorized users can log in to the platform. Fig. 11 shows the updates sent via email notifications.

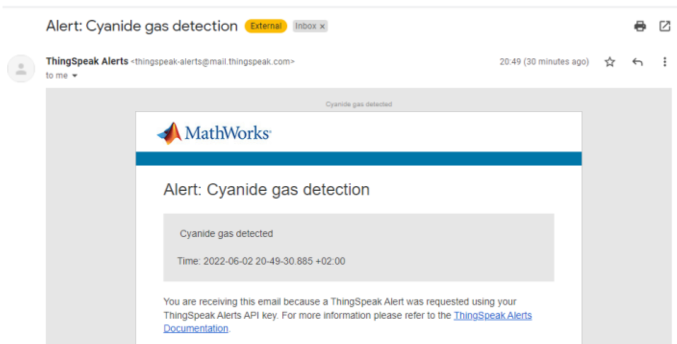

Fig. 11. Email notification.

5.2.3. Monitoring web application

The ThinkSpeak dashboard was utilized as the real time monitoring platform for HCN gas concentration, as presented in Fig. 12. The results are displayed in graphs and gauges on the application dashboard. The information recorded on the graph and gauge represents the cyanide levels at 5-minute intervals. These time intervals help the system to give results at almost real time intervals.

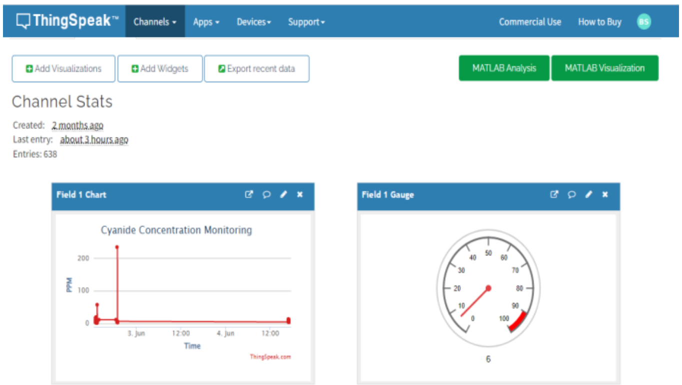

Fig. 12. Data logging.

6. Conclusions and future work

Detection and control of cyanide positively impact human well-being and a sustainable environment. The study contributed to and reduced the literature gap on HCN gas detection and control systems by developing an automated, real-time HCN gas detection and control system for a gold mine using the Internet of Things (IoT) principles. It also addressed the gap in most treatment methods in the literature, focusing on controlling free cyanide in processing effluent, not HCN gas. The developed system provides live updates on the HCN gas levels in the workplace. An alarm sounds whenever HCN gas levels exceed ten ppm, triggering a corrective control action. A physical prototype was developed, demonstrating how the system monitors and controls the levels of HCN gas in a mining environment. The study contributes to sustainable production by creating a toxic-free and healthy environment for mine workers.

As part of the recommendations, the system's maintenance and calibration must be done once every six months. Also, the number of sensors must be increased to widen the detection area. The system detects the presence of HCN gas but does not detect other hazards such as fire. Therefore, future work could focus on a hybrid system that detects other hazards in the mining environment.

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