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All Correspondences to:
Editor-In-Chief,
Nigeria Journal of Engineering and Applied Sciences (NJEAS),
Federal University of Technology, P. M. B. 65, Minna, Nigeria.
E-Mail: njeas@futminna.edu.ng, Website: njeas.futminna.edu.ng

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ENHANCING INDUSTRIAL WORKPLACE SAFETY WITH INTERNET OF THINGS USING ARDUINO MICRO-CONTROLLER

[*]Oyewobi, S. S.1; Usman, A. U .1; Innocent, C.1; Abdulbaki, O. A.1; & Jack, K. E. 2

[1]Department of Telecommunications Engineering, Federal University of Technology,
PMB 65 Minna Niger State, Nigeria

[2]Department of Mechatronics Engineering, Federal University of Technology,
PMB 65 Minna Niger State, Nigeria

oyewobistephen@futminna.edu.ng

ABSTRACT

IoT (Internet of Things) technologies are widely used in many industrial sectors as a result of their rising technological performance and reduced buying costs. For these reasons, IoT has been considered for use in many emerging fields of application, such as workplace safety. The industry workplace which comprises human and nonhuman factors is becoming more saturated on a daily. These rising activities expose and make the industrial environment prone to uncertainties, e.g. accidents, injuries, explosions, fire outbreaks, and other industrial hazards that undermine man's industrial environment safety. However, over the past few years, IoT technologies have proffered industrial solutions for a variety of industrial projects, particularly to dynamically manage safety levels at complex workplaces. In this work, an enhanced IoT-based industrial safety system is developed and implemented using an Arduino microcontroller. The Arduino serves as an interface between the different sensors that sense signals from the environment and send messages to the Buzzer/GSM module/Internet. The Arduino is programmed to send a signal and activate the buzzer whenever the sensors sense a value <25oc or >35oc (for Temperature sensor) or low intensity (Light sensor) or smoke (Gas sensor) in the environment. A short message (SMS) is delivered to the safety operator/manager's phone whenever the gas sensor, temperature sensor, or light sensor senses gas leakage, low light intensity, and temperature respectively. It will also activate a buzzer and upload data to a web server for remote access. A performance test of the system shows that the system was able to sense gas leakage, low light intensity, and temperature very accurately at a low response time and over a wide range effectively.

Keywords: Arduino, Buzzer, GSM Module, Internet of Things, Sensor, Micro-controller, Industrial safety**.**

INTRODUCTION

The Internet of Things (IoT) is a new and emerging technology. IoT is the interconnection of the physical object with the internet for communicating with each other. Technology is rising exponentially, and new tools are being considered for use in emerging fields of application, such as workplace safety (Savitha and Malathi, 2018). IoT is a network of physical objects or items embedded in electronic devices, sensors as well as network communication that allows these objects to interact and exchange data (Svertoka *et al*., 2021). IoT technologies are widely used in many industrial sectors as a result of its rising technological performance, reduced buying costs and increased long term workshop safety that it provides (Somani et al., 2018). IoT technologies have been created over the past few years for a variety of projects, prototypes, and industrial solutions, particularly to dynamically manage safety levels at complex workplaces (Soh *et al*., 2019).

Currently, the significance of safety in high-risk industrial sectors such as aviation, oil and gas, construction, transportation, steel manufacturing, and mining industries is considered a top priority due to its importance in safeguarding human lives and properties (Haghi *et al*., 2017).

In these industrial environments, different types of injuries, illness and fatalities are sometimes inevitable due to the dangerous working environments. The risks and hazards mechanisms present in the different units in the factory are quite high. However, with adequate safety measures, the injuries can be minimized.

The safety of the working personnel is one of the concerns that cannot be compromised in modern industries. While various safety management measures commonly exist in industries, the deployment of smart devices further consolidates the safety of machines and workers, in addition to making events traceable. These smart devices form the basis for deploying IoT networks in industrial

Environments (Javed *et al*., 2018). The integration of advanced technologies and smart devices transforms traditional industrial framework into an industrial IoT (IIoT) compliant one (Haghi *et al*., 2017) and (Potbhare *et al*., 2022). Besides, this technological integration brings about improved operational efficiency, operation time, quality of service, and safety of personnels. Also, other advantages of the industrial augmentation are better utilization of assets and improved working conditions (Barthwal and Acharya, 2018). The statistics in Fig. 1 shows the need for improvement of safety in many industrial areas.

The IoT industry safety system using Arduino is a system created to guard against industrial losses/accidents resulting from gas leakages, low light intensity, explosions and other similar situations that calls for immediate detection and control using the IoT (Gavuji and Kaza, 2020). Arduino is the microcontroller used by the system to accomplish these operations.

The Arduino board is lightweighted, compatible, small, and developer-friendly

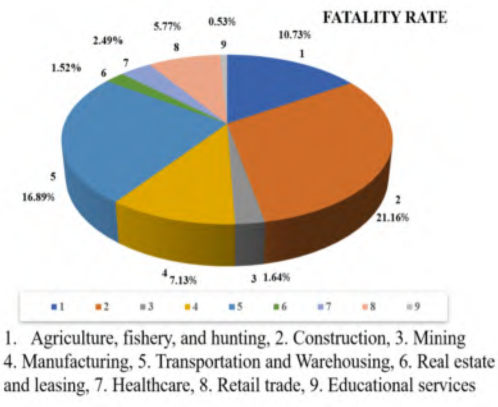

Fig 1: Fatality rates and their causes across various industries in the year 2020.

The system makes use of temperature sensing along with light and gas sensing to detect fire, gas leakage as well as low lighting to avoid any industrial accidents and prevent losses. Similarly, bushfires pose a significant threat to businesses in the petrochemical, oil and gas sectors and have the potential to cause significant harm, property loss, and, most importantly, human fatalities. Therefore, it is crucial to have monitoring system that will keep the area secure and alert the right people as soon as a fire outbreak occurs.

The IoT industry protection system using Arduino is a system designed to protect industrial work environment from losses due to accidents using IoT (Roja and Srihari, 2018). Gas leakages may result to fires leading to huge industrial losses. Therefore, instant fire detection is needed in case of furnace blasts or other conditions. Similarly, low lighting in industrial work environments may create unfitting work conditions increasing the likelihood of accidents (Wilson *et al*., 2003). The system makes use of Arduino to achieve this functionality. The system makes use of temperature sensing along with light and gas sensing to detect fire, gas leakage as well as low lighting to avoid any industrial accidents and prevent losses (Martorell *et al*., 2004). The system consists of light, gas and temperature sensors interfaced with Arduino and LCD screen.

Industrial safety device is an autonomous electronic device that is intelligently programmed to separate specific functions through some sensor assembly. However, some of the available systems either monitors or controls manually, while other systems that can monitor and control industrial applications are limited to short distance. This is due to the transmission range of Bluetooth, WiFi or infrared connectivity.

In the work done by (Gavuji and Kaza, 2020), industrial parameters like production count, illumination intensity, and power consumption were monitored by an IoT based system. The purpose of the research was to minimize cost and not for safety.

In a related work by (Soh *et al*., 2019), an industrial framework was designed using IoT that could automatically track industrial applications and produce alerts/alarms or make intelligent decisions. However, this system was limited by its short coverage distance. This is because Wi-Fi shield was used to serve as a service point between the network and the network connection. Wi-Fi has a short coverage distance typically between $20m$ to $50m$.

In another work by (Yadav *et al*., 2021), Arduino Uno R3 board was utilized as a focal microcontroller, and toxic gas leakage was monitored, and an alert was triggered if the output of the microcontrollers indicates a gas leakage. However, the system could not monitor light intensity. Also, the information communicated via the website will not be accessed by all the people the information is meant to reach as not all mobile phone users are connected to the internet or has internet access.

Wireless industrial and home automation was achieved in the work of (Alkar and Buhur, 2005). The work has two nodes – node 1 and node 2. Node 1 senses three parameters (temperature, vibration and fire) using Temperature sensor, Vibration sensor and Fire sensor. Whereas, node 2 senses two parameters (light and gas) using light and gas sensors respectively. However, this system is very complex as each node has its own power supply, Microcontroller, IoT and Wi-Fi modules. Also, the absence of a GSM module limited the coverage distance of the system to the range of Wi-Fi - $50m$

In this work a low cost IoT based industrial safety monitoring system is presented.

MATERIALS AND METHODOLOGY

In this Section the different modules that forms the entire system are discussed and the steps taken to achieve the assembly of the system are underlined.

Block diagram of the system

A brief explanation of the complete system is presented in this Section. Fig. 2 shows the overall block diagram of the system. Each of the sensors continuously record data and convey it to the Arduino Uno. All of the data is processed by Arduino Uno, which then acts in accordance with the output values of the measurements.

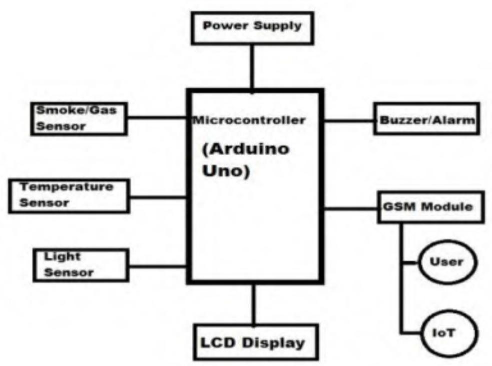

Fig 2: Block Diagram of the system

An SMS message is delivered to the safety manager whenever the Gas sensor, Temperature sensor, or Light sensor sense gas leakage, low light intensity and temperature respectively. It will also activate the Buzzer, and the data is uploaded to a web server for storage and remote access.

Hardware components

The systems consist of the following Hardware:

- Power supply unit
- Light sensor circuit
- Temperature sensor
- Gas sensor
- Arduino uno

Power supply unit

The safety system built in this work uses a switched-mode power supply (SMPS). The SMPS transforms power using switching elements that are turned on and off at high frequencies. In addition, it uses storage elements like inductors or capacitors to supply power while the switching system is in a non-conductive state. The SMPS is very efficient and widely used in a number of electronic devices (Abraham *et al*., 2009). In Fig. 2, the function diagram implemented in this system is presented.

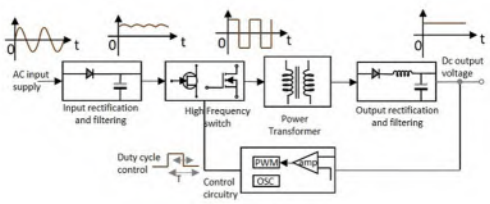

Fig 3: Functional diagram of SMPS

Light sensor circuit

The light sensor circuit implemented in this system is an electronic circuit made up of a light sensor, a light dependent resistor (LDR), a Darlington pair, a relay, diodes, and resistors that are linked as shown by Fig. 3. A battery/a bridge rectifier provides the DC voltage needed by the light sensor circuit. The bridge rectifier converts 230 volts AC into 6 volts DC. A step-down transformer is used in the bridge rectifier circuit to step-down 230 volts to 12 volts. A bridge of linked diodes is then used convert the 12 volts of AC into 12 volts of DC. The circuit receives the 6V DC after the 12V DC has been converted into 6V DC using the IC7806 DC voltage regulator. The load and bridge rectifier must both have a constant 230v AC supply to ensure the light sensor circuit operates without interruption (Orozco, 2014).

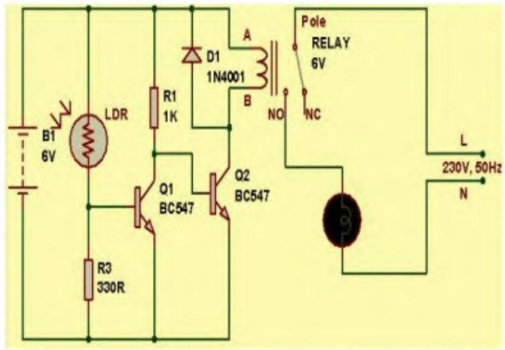

Fig 4: Schematic diagram of a light sensor circuit diagram.

Light sensors come in a variety of forms, including photo resistors, photodiodes, photovoltaic cells, etc. However, the light sensor in this light sensor circuit is an LDR, often known as a photo resistor. The LDR is made up cadmium sulphide, which reduces its electrical resistance from several thousand Ohms in the dark to just a few hundred Ohms when exposed to light. This operating theory makes it possible to determine the amount of light present in a given environment at any given time. Since LDR sensors are robust by nature, they can be used even in unclean and challenging outdoor conditions. Therefore, LDR is preferred over other light sensors since it may be utilized for automatic street lights as well as outdoor illumination for residences. A typical variable resistor that is influenced by light intensity is shown in Fig. 4. Cadmium sulphide, a high resistance semiconductor material with photoconductivity, is used to make LDRs.

Fig 5: LDR Sensor

Temperature sensor (lm35)

The temperature sensor implemented in this IoT safety system is the LM35. The LM35 configuration is a set of precisely timed temperature devices with a yield voltage that is directly correlated to the Celsius temperature(Blessed and Odueso, 2017). It does not require a constant voltage to be subtract from its output to have a good Centigrade scaling unlike linear temperature sensors that are aligned in Kelvin. Additionally, the LM35 is used to provide the needed accuracy of consistent 14°C between room temperature and 34° which is a requirement to implement the industrial safety regulation in this work. Other advantages of the LM35 include handling of a wide range of temperature between 55°C to 150°C without requiring any external modification. The low-yield impedance, straight yield, and exact characteristic alignment of the LM35 gadget make interfacing to a control hardware particularly simple which is in line with the objective of this wok. Another unique characteristic that makes the LM35 device particularly suitable for this system is its low self-warming temperature of under 0.1°C since it only consumes 60 µA.

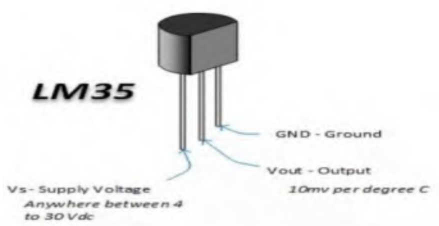

Fig 6: LM35 Temperature Sensor

The LM35 temperature sensor is reasonably accurate, never breaks down, operates in a variety of climatic situations, and does not need any additional parts to function. Additionally, the LM35 sensor does not need to be calibrated and has a typical accuracy of 0.5°C at ambient temperature and 1° cover the entire temperature range of -55°C to +155°C. Figure 5 shows the diagram an LM35.

GAS SENSOR

The MQ2 gas sensor is implemented in this work as the gas sensor. A small heater and an electrochemical sensor are both inside the MQ2 gas sensors. They respond to various gases at ambient temperature. Fig. 6 shows an illustration of an MQ2 gas sensor. The MQ2 sensor collects data from the environment which is then interpreted by the Arduino that then triggers the actuator. The main objective of the entire system is to monitor radiation and dangerous gas leaks. Continuous gas inhaling results in human death. When people are exposed to odorless vapors for a prolonged period of time, it can seriously harm their health. Carbon monoxide, for example, is odorless, causes disorientation and dizziness at concentrations above 350 parts per million (ppm), and will definitely kill a human (Somani *et a*l., 2018). Each gas has unique physical and chemical features that make it challenging to examine without a tool.

Fig 7: Gas Sensor

Depending on their density and concentration, toxic gases are present at various levels (Kalunga et al., 2022). Tables 1 and 2 present the pin description and configuration of the MQ2 gas sensor respectively.

Table 1: MQ2 Gas Sensor Pin Description

Pin No:	Pin Name:	Description
1	Vcc	This pin is used to supply power to the module; the standard working voltage is +5V.
2	Ground	It is utilized to link the module to the grounding scheme.
3	Digital Output	By establishing a threshold value, we can also use this sensor to obtain digital output from the digital pin.
4	Analog Output	This pin produces an analog voltage of 0 to 5 volts according to the gas strength.

Table 2: MQ2 Gas Sensor Pin Configuration

1	H – Pins	One of the two H pins is connected to the supply, and the other pin is connected to the ground.
2	A-Pins	A and B pins can be used in place of one another. The supply voltage will be connected to these pins.
3	B-Pins	Both the A and B pins can be used interchangeably. While the other pin is pulled to ground, one pin will be used as an output.

The MQ2 gas sensor uses 800mW of power and operates on 5V DC as shown in Fig. 7. Between 200 and 10,000 ppm, it is capable of detecting the presence of LPG, smoke, alcohol, propane, hydrogen, methane, and carbon monoxide. The MQ2 works on the principle of transforming the surface of tin dioxide as it is heated to high temperatures in the atmosphere. In an environment free of gas leaks, Tin dioxide, which contains donor electrons, attracts oxygen that has been deposited on the surface of the sensing material. As result, electrical current does not flow due to increase resistance. However, when gas is present in the environment, and Tin dioxide interacts with the gas, the surface density of the adsorbed oxygen drops. Tin dioxide is subsequently given an electron release, allowing the current to flow freely through the sensor. The connection diagram of the gas sensor is shown in Fig. 8.

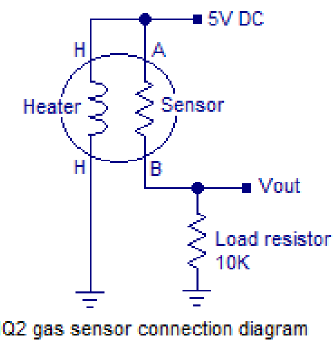

Fig 8: Gas Sensor Connection Diagram

Arduino uno

The Arduino-Uno unit is the project's heartbeat. It receives input signals from the gas sensor, temperature sensor, and light sensor modules and processes the entire unit in accordance with preset configurations. Fig. 9 shows the system circuit diagram of Arduino connected to the sensors.

Communication and programming of arduino- uno:

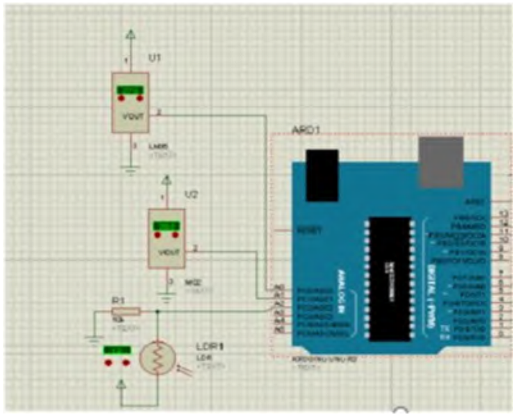

Fig 9: sensors Connection to Arduino Uno

The Arduino Uno module is interfaced with different controllers and computing devices using the computerized pins - pin 1 (Tx) for information transmission and pin 0 (Rx), for information retrieval to complete a sequential correspondence. To send or receive text data to or from the panel, the Arduino software is connected to a serial monitor. The software that acts as a computer-generated port for the software program also includes FTDI drivers. As data is exchanged between the FTDI and USB connections to the device, an LED on the Tx and Rx pins blinks. Additionally, serial communication between the system and the device is achieved via the Arduino Software Serial Library. The Arduino Uno Device now supports I2C and SPI communications in addition to serial. The I2C transport uses the wire library found in the Arduino program. The Arduino IDE software, which is a common program used for a wide variety of boards that may be accessed, is used to personalize the Arduino Uno. Basically, in this work, the relevant applications are downloaded and the appropriate board needed for implementation of the design was chosen. Windows with the in-circuit sequent programming header was used to program the Arduino Uno.

LCD display

The Liquid Crystal Display (LCD) is used for displaying the parameters, real-time clock and alarm system.

Internet

The system is also connected to the internet which enables the safety manager to control and monitor the system using their mobile phone from any place.

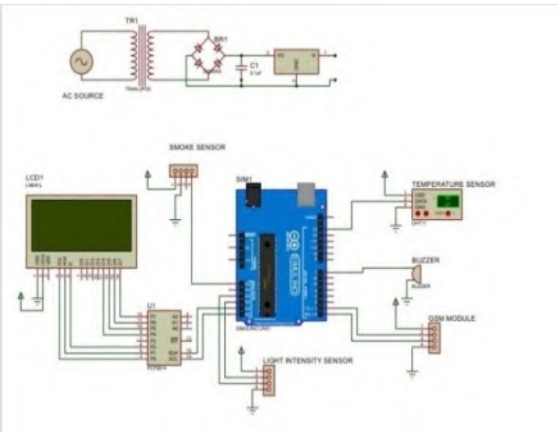

Fig 10: The schematic diagram of the system

Principle of Operation

The project's working principle is based on data, which is collected through several sorts of sensors like gas sensors, temperature sensors and humidity sensors. These sensors are systematically deployed in the industry. These sensors gather data continuously and communicate it to the microcontroller (Arduino UNO). Arduino UNO is programmed to compare the sensors value with threshold value. If the value is less than the threshold, the situation is normal. If it exceeds the threshold value, the Arduino UNO sends a signal to the corresponding output such as authorized mobile phone, cloud, buzzer. In addition, all data are displayed on the LCD panel. The schematic diagram and flow chart of the system is shown in Figs. 10 and 11 respectively.

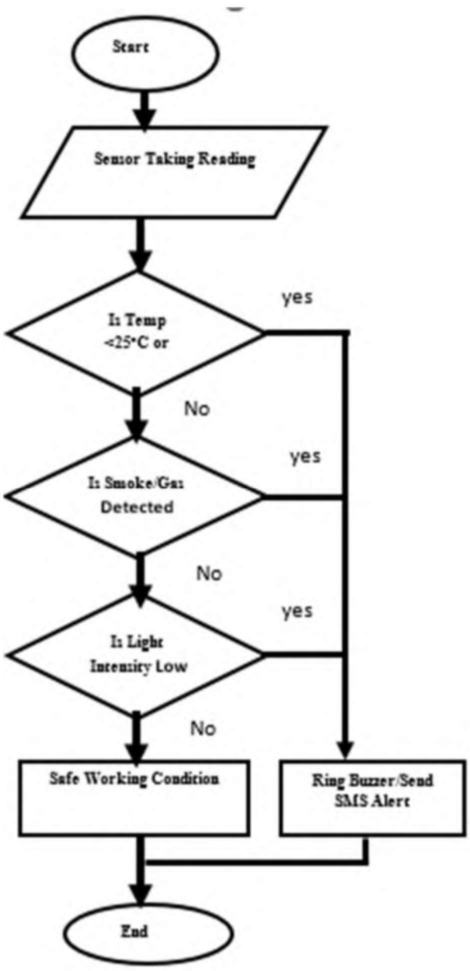

Fig 11: System Flowchart

RESULTS AND DISCUSSION

System performance evaluation

The system performance was evaluated to determine its effectiveness and efficiency. The performance evaluation metrics used in this work are given and further discussed as follows:

Accuracy: This metric measures the capability of the system to accurately detect changes in temperature, humidity, gas leakage and light. The accuracy should be consistent across all tests.

Response Time: This measures the time taken by the system to detect changes in the environment. Lower response time means better performance.

Range: This measures the distance over which the system is able to detect changes in the environment. Greater range means higher coverage.

Connectivity: This measures the capability of the system to connect to the Internet. Better connectivity means better usability.

RAMD analysis of the system

In this section, mathematical models of all the subsystems are presented and Markov birth–death process is used to obtained Chapman–Kolmogorov differential. Fig. 12a-e and Table 3 shows transition diagrams for all the subsection and failure and repair rates of all the subsystems respectively. The RAMD analysis of subsystems are as follows.

Table 3: STP failure rate and repair rate of all the subsystems

Subsystems	Failure rate (λ)	Repair rate (π)
S_1	Power (λ_1) = 0.003	Power (π_1) = 0.5
S_2	Display (λ_2) = 0.005	Display (π_2) = 0.7
S_3	Sensing (λ_3) = 0.007	Sensing (π_3) = 0.8
S_4	Processing (λ_4)= 0.001	Processing (π_4) = 0.1
S_5	Output (λ_5)= 0.006	Output (π_5) = 0.9

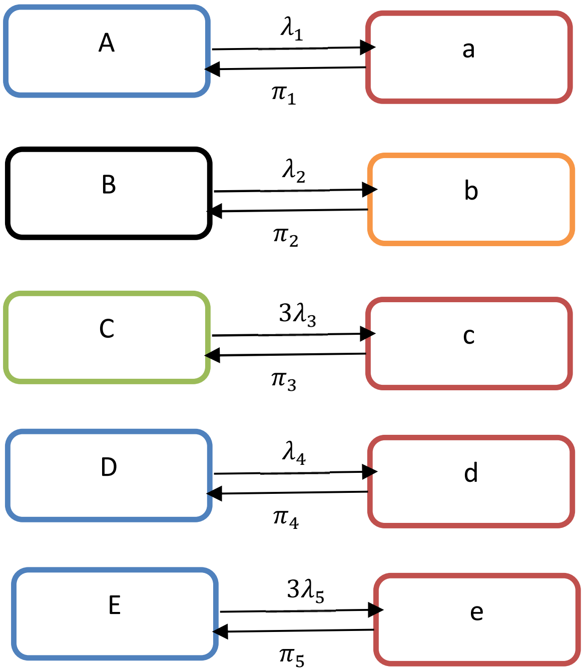

Fig 12: Transition diagrams for all the subsection

RAMD indices for subsystem s_1

In subsystem power module, there is only one unit consist in series configuration with other subsystems and failure of it cause the failure of complete system. Based on birth–death processes from Fig. 12 the differential-difference equations for the subsystem are derived. The recurrence relations are as follows:

$$Y_0(t) = -\lambda_1 X_0(t) + \pi_1 X_1(t) \quad (1)$$

$$Y_1(t) = -\pi_1 X_1(t) + \lambda_1 X_0(t) \quad (2)$$

Solving Equation (1) and (2) with help of Initial condition and $t \to \infty$. Using normalization condition

$$\sum X_i = 1; \quad i = 0,1; \quad X_0 + X_1 = 1 \quad (3)$$

Hence, Availability of the system is as follows:

$$\text{Availability} = A_{S_1} = \left[1 + \frac{\lambda_1}{\pi_1}\right]^{-1} = 0.994035$$

$$\text{Reliability} = R_{S_1}(t) = e^{-\lambda_1 t} = e^{-0.003t}$$

$$\text{Maintainability} = M_{S_1}(t) = 1 - e^{-\pi_1 t} = 1 - e^{-0.5t}$$

RAMD indices for subsystem s_2

In the display part only one unit consist in series configuration and failure of it does not causes the complete system failure.

RAMD indices for subsystem s_3

In sensing subsystem, three unit are connected with equal failure and repair rates and failure of the units cause subsystem failure and results the system failure. C–K differential equations for this subsystem are derived using Markovian approach on the basis of state transition diagram appended in Fig. 12c. Recurrence relations are as follows:

$$Y_0(t) = -3\lambda_3 X_0(t) + \pi_3 X_1(t) \quad (4)$$

$$Y_1(t) = -\pi_3 X_1(t) + 3\lambda_3 X_0(t) \quad (5)$$

Solving Equation (4), and (5) with help of Initial condition and $t \to \infty$. Using normalization condition

$$\sum X_i = 1; \quad i = 0,1; \quad X_0 + X_1 = 1 \quad (6)$$

Hence, Availability of the system is as follows:

Availability = $A_{S_3} = \left[1 + \left(\frac{3\lambda_3}{\pi_3}\right)\right]^{-1} = 0.974421$

Reliability = $R_{S_3}(t) = e^{-3\lambda_3 t} = e^{-0.021t}$

Maintainability = $M_{S_3}(t) = 1 - e^{-\pi_3 t} = 1 - e^{-0.7t}$

RAMD indices for subsystem s_4

In subsystem power module, there is only one unit consist in series configuration with other subsystems and failure of it cause the failure of complete system. Based on birth–death processes from Fig. 12d the differential-difference equations for the subsystem are derived. The recurrence relations are as follows:

$$Y_0(t) = -\lambda_4 X_0(t) + \pi_4 X_1(t) \quad (7)$$

$$Y_1(t) = -\pi_4 X_1(t) + \lambda_4 X_0(t) \quad (8)$$

Solving Equation (7) and (8) with help of Initial condition and $t \to \infty$. Using normalization condition

$$\sum X_i = 1; \quad i = 0,1; \quad X_0 + X_1 = 1 \quad (9)$$

Hence, Availability of the system is as follows:

Availability = $A_{S_4} = \left[1 + \frac{\lambda_4}{\pi_4}\right]^{-1} = 0.99009$

Reliability = $R_{S_4}(t) = e^{-\lambda_4 t} = e^{-0.001t}$

Maintainability = $M_{S_4}(t) = 1 - e^{-\pi_4 t} = 1 - e^{-0.1t}$

RAMD indices for subsystem s_5

The Output subsystem consists of two units and failure rate of both units is same. The failure of one unit causes subsystem failure that results the complete system failure. C–K differential equations for this subsystem are derived with the help of Fig. 12e. using Markovian birth death process. Recurrence relation are as follows:

$$Y_0(t) = -3\lambda_5 X_0(t) + \pi_5 X_1(t) \quad (10)$$

$$Y_1(t) = -\pi_5 X_1(t) + 3\lambda_5 X_0(t) \quad (11)$$

Solving Equation (10), and (11) with help of Initial condition and $t \to \infty$. Using normalization condition

$$\sum X_i = 1; \quad i = 0,1; \quad X_0 + X_1 = 1 \quad (12)$$

Hence, Availability of the system is as follows:

Availability = $A_{S_5} = \left[1 + \left(\frac{3\lambda_5}{\pi_5}\right)\right]^{-1} = 0.98039$

Reliability = $R_{S_5}(t) = e^{-3\lambda_5 t} = e^{-0.018t}$

Maintainability = $M_{S_5}(t) = 1 - e^{-\pi_5 t} = 1 - e^{-0.9t}$

RAMD of the system

Since the system comprises five subsystems in series configuration and failure of any one cause the complete failure. The reliability, Availability, and Maintainability of a series system is equal to the product of all the reliability, Available and Maintainability of all the component respectfully.

Hence, overall system reliability is:

$$R_{Sys}(t) = R_{S_1}(t) \times R_{S_2}(t) \times R_{S_3}(t) \times R_{S_4}(t) \times R_{S_5}(t) = e^{-(\lambda_1+3\lambda_3+\lambda_4+3\lambda_5+)t} = e^{-0.043t} \quad (13)$$

The overall availability of the system is:

$$A_{Sys}(t) = A_{S_1}(t) \times A_{S_3}(t) \times A_{S_4}(t) \times A_{S_5}(t) = 0.94020 \quad (14)$$

The overall system Maintainability is given as:

$$M_{Sys}(t) = M_{S_1}(t) \times M_{S_3}(t) \times M_{S_4}(t) \times M_{S_5}(t) = 1 - e^{-0.4013t} \quad (15)$$

Equation (13) and (15) is used to obtain variation in reliability and maintainability of the system respectively with respect to time and appended in Table 4.

Table 4: Variation in reliability and maintainability of the system respectively with respect to time

Time (days)	$R_{Sys}(t)$	$M_{Sys}(t)$
10	0.6505	0.9819209234
20	0.4232	0.999673147
30	0.2752	0.9999940908
40	0.1790	0.9999998932
50	0.1165	0.9999999981
60	0.0757	1

RESULT

The results obtained for the temperature, humidity and gas detection are presented in this section.

Result for temperature

The result of the temperature as read by the temperature sensor is presented below in Table 3 and Fig. 11. The status as displayed on the LCD is presented accordingly as well as the time taken for the LCD to display the data. The response time was recorded through the use of a stopwatch.

Table 5: Accuracy and response time of temperature sensor

Temperature (°C)	Status	Response time (s)
20	LOW	00:00:08
25	LOW	00:00:09
30	NORMAL	00:00:05
35	NORMAL	00:00:03
40	HIGH	00:00:08

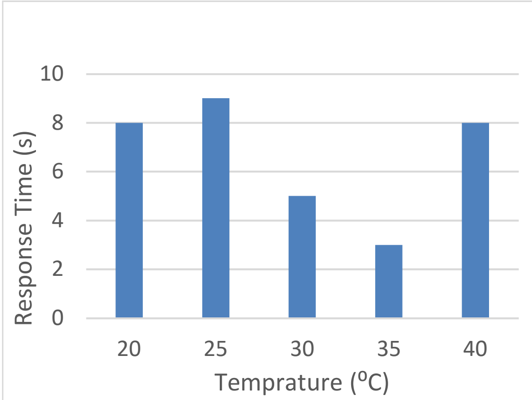

Fig 13: response time of the temperature Sensors

Result for humidity

The humidity sensor was primarily used to obtain the results of the humidity presented in Table 4 and Fig. 12. This value was further displayed on the LCD screen and the corresponding response time was also recorded using a stop watch.

Table 6: Accuracy and response time of Humidity sensor

Humidity (g.m-3)	Status	Response time (s)
15	LOW	00:00:07
20	NORMAL	00:00:04
25	NORMAL	00:00:05
30	NORMAL	00:00:06
35	HIGH	00:00:03
40	HIGH	00:00:08

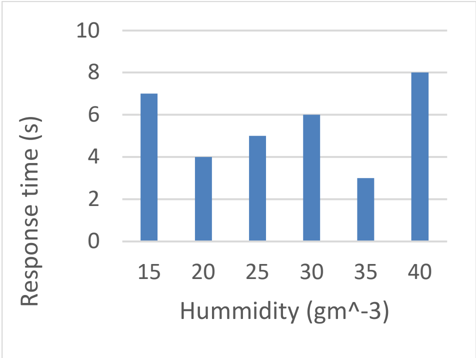

Fig 15: response time of the Humidity

Result for gas detection

The MQ-2 gas detector was the component used in the fire detection system of this work. The value of the gas was given by the detector and the status was displayed on the LCD as shown in Table 5 and Fig. 13. The time taken for the LCD to display the gas detector data was also recorded using a stopwatch.

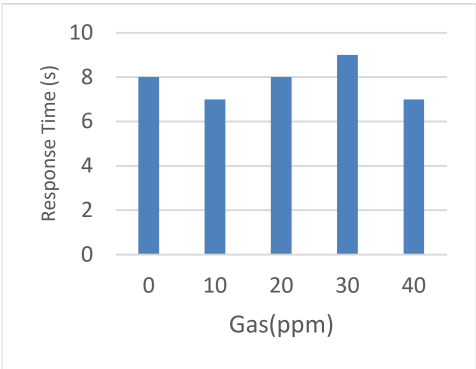

Fig 16: response time of the gas Sensors

Table 7: Accuracy and response time of gas sensor.

Gas detector (ppm)	Status	Response time (s)
0	No gas detected	00:00:08
10	No gas detected	00:00:07
20	No gas detected	00:00:08
30	No gas detected	00:00:09
40	No gas detected	00:00:07
50	Gas detected	00:00:06

DISCUSSION OF RESULT

The performance evaluation tests shown in Tables 5, 6 and 7 for the system revealed that the accuracy of the system was consistently high for all tests, demonstrating the reliable detection capability of the system. Also, the response time of the system was quite good, indicating its ability to detect changes in the environment in a timely manner. The range of the system was found to be quite large, ensuring wide coverage of the environment and finally the system was found to have good connectivity to the Internet, making it easily accessible. The results obtained from the performance evaluation tests showed that the system has excellent capabilities. The system was found to be accurate, have a fast response time, have low power consumption, have a large range and have good connectivity to the Internet. These features ensure reliable and convenient operation of the system, allowing the safety manager to detect environmental changes quickly and efficiently. Finally, RAMD analysis was carryout on the system.

CONCLUSION

The research presented in this paper has demonstrated the effectiveness of a microcontroller-based IoT system for detecting temperature and humidity, gas leakage, and light intensity. Through the integration of an IoT-based wireless communication system, data can be collected and stored on the cloud, which provides an accessible way for further analysis. Additionally, the ability to adjust and modify the parameters of the system to customize its performance makes it more user-friendly and powerful. The findings from this research suggest that a microcontroller-based IoT system can effectively serve as a versatile detector and is highly suitable for smart home, commercial and industrial applications. In conclusion, this system can provide an efficient and cost-effective way of detecting and monitoring environmental parameters. The integration of various sensors, reliable communication protocols and easy-to-use hardware makes the system attractive to use in various applications. Additionally, its expandability to multiple detectors, makes it even more powerful. With this, it is hoped that this technology can contribute to the realization of an ever-safer and smarter factory and work environment. The RAMD analysis would help to evaluate long term and short-term cost effectiveness of the system from the reliability and maintainability results.

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