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Development of Voice-Instructed Smart Fire Alarm Using Arduino and IoT Functionality

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Fires can destroy and cause significant damage to property and human life. Fires break out unexpectedly, anywhere, and at any time, and it is essential to get accurate information on fire causes to minimize casualties. Therefore, it is imperative to set an alarm appropriately. Traditional fire alarms sound simply noisy without much guiding detail. Sometimes, building occupants even escape toward the flames. In this study, an intelligent Arduino system was created for a verbal guide with more precise information. It informed the location, sources of fire, and seriousness while alarming the fire department through the email alert system. The self-surveyed scoring tests demonstrated that our voice-instructed smart fire system was significantly informative and superior in the aspects of audibility, intelligibility, reliability, and acceptability, compared to the traditional fire alarm systems. At the same time, further study might be necessary to develop more effective fire alarms.

Keywords: Fire alarm; fire safety system; IoT functionality; voice-instructed system.

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1. INTRODUCTION

Fires usually cause serious property damage and leave deep emotional scars on the victims [1]. In addition, fires can set out at any place and at any time with no predictable signs. So, it is essential to thoroughly study the most common causes and establish any methodologies to prevent them from occurring [2].

The importance of fire safety in the workplace cannot be emphasized, as fires can have horrendous consequences for businesses, employees, and visitors [3,4]. National Fire Protection Association (NFPA) published that US fire departments have dispatched for an average of 4,440 fires in office properties annually between 2017 and 2021 [5]. And, the National Safety Council revealed their data that workplace fires cost an estimated $2.4 billion in property damage in 2022. In 2022, there were 140,000 fires from non-residential places, based on the NFPA report [6]. The worn-off electrical malfunctions, heating equipment, cooking equipment, intentional fires, and burning materials are the leading culprits of workplace fires, according to the NFPA [7].

These statistics underscore the graveness of fire safety in occupational places. A comprehensive fire safety plan fully covers prevention, detection, and response measures is important for mitigating the risks of workplace fires [8]. By establishing fire safety protocols, conducting regular inspections and maintenance, and providing ongoing employee training, businesses can significantly safeguard fire prevention and minimize their impact if they do occur [9].

In designing a fire system for a building, it is necessary to have a clear understanding of the relevant design standards, the legal framework concerning building safety legislation, and an efficient knowledge of product application theory [10,11]. The following system design process is executed to present a reasonable description of comprehensive knowledge areas essential for the optimal design of a fire alarm system.

Due to the complicated attributes of regal regulation and system standards relating to fire alarm system design, the system is not intended to be comprehensive to all aspects of fire alarm system but rather a very useful source of background information to which further application-specific detailed information can be added from other sources as required.

The reason for having a fire alarm system relies on the premises in question and the legal requirements [12]. Any local firefighter officer may need a fire alarm system directly from the occupancy building. Typically, a fire alarm system's legal codes and conditions are designed to protect life [13]. Generally, fire alarm systems should be equipped to warrant the safety of occupants in buildings and to make a safe way for their evacuation or refuge for a sudden fire or accidental emergency [14]. Secondly, it must provide the fire department with an early notification of a fire in a building and guide them to the contents of risk [15]. Thirdly, the fire alarm system must minimize the loss of property that may have significant price value, and the insurers either require a fire detection system or may give motivations for use [16]. Fourthly, most fire systems are to reduce building destruction; the building may not be used for long periods when some appliances are still powered, and some responsible parties demand to confirm that if anything goes risky, the firefighter from the department should come to the scene on time [17]. Frequently, fire detection and alarm systems are utilized to remove the weak points of structural fire protection and to give special coverage for items of high value [18]. Fifthly, it may be created to reduce the amount of business loss, and finally, it is designed to reduce the risk to the public who attend unfamiliar properties [19].

It is often an obligatory requirement of the Building Regulation Items. Whatever the cause, an automatic fire detection and alarm device usually consists of a network of manual call points, smoke, and heat detectors, and alarm warning elements across the area covered [20]. Once activated, the systems initiate signals to the fire alarm panel, activating audio and visual devices, including lights and sounders. The alarm system may transmit its signal to an off-site monitoring headquarters of fire controls [21].

Noisy testing periods at random fire drill repetitions and durations do not help the building occupants to tell the difference between testing and real alarms [22]. Most occupants recognize the annoying sound of the fire alarm as an emergency danger. Still, they need more trust in the fire alarm system. One of the main reasons for the lack of confidence originates from the fact that fire alarms have become perceived as a nuisance or unwanted system [23]. Even the signals during regular system testing are treated as unnecessary events to the general building occupants. When a fire alarm is triggered, the occupants intend to obtain any simple information for the alarm quickly, and further, they determine whether to evacuate or ignore it [24]. Residents are not much threatened in fire situations if they do not feel heat or are seen with a burning flame. Their reactions are mainly dependent on interpreting the information they have received. The whole decision process is a series of constant evaluations on the part of the occupants, some of which can be wrong information. It takes a long time for them to realize the actual situation. Therefore, the actions of the building occupants in fires can be easily disorganized. Traditional fire alarm systems use audible tones with flashing strobe lights on the walls to announce the fire's imminent danger to the building occupants [25]. The message should contain several essential elements for more efficient fire management to inform the occupants, reduce response time, and enforce evacuation procedures to ensure safety. These should include the fire's severity and location, type of fire, and instructions to escape the hazardous situation. It is usually difficult to find research that has examined actual message information to identify the best way to inform the building occupants. The problem comes from the fact that each building and fire seem identical. However, messaging for fire alarms becomes further complicated by the demand to provide additional information to the occupants depending on their location relative to the fire, their training, and their physical and mental capabilities. Most fire codes adopt a messaging system that alerts the occupants on the fire floor, floor above, and floor below. They may be guided to leave the building or move to three or four stories below their present floor. The fire alarm system should help decide which floors get the message based on the origin of the fire alarm device [26]. Other systems offer more channels to announce another message to other occupants, warn them of the fire, and guide them to different areas. The firefighters are trained to make decisions and broadcast appropriate messages to reduce the likelihood of error. The fire information should be collected from diverse sources such as security sensors, CCTV, and energy management systems [27].

The National Electrical Manufacturers Association (NEMA) is funding a research project at NIST that examines the possibility of applying multiple sensors to indicate to fire department personnel the origin and real-time progress of fire [28]. The system could be installed with sensor data in a model to assess optimal responses in various hazardous conditions. Giving the building occupants confidence in the emergency message is essential for a functioning fire alarm system not to cause anyone to become a victim. So, messaging and communication strategies should work with confidence by providing truthful and reliable information. When any fire alarm system blasts out by false activations with no actual fire, most occupants will disregard any future alarm. In addition to minimizing false alarms, methodologies should be employed to enhance alarm system accuracy and occupant confidence [29]. One possibility to build high trust may be to ensure the building occupants that follow-up measures should be taken soon after any false alarm is made. If the system has manual voice capability, any staff in charge can immediately bring the correct message after the false alarm. These days, multiple user-friendly messaging systems have been investigated using voice, text, or video to assist the building occupants in agreeing with the fire alarms. Correct and forthright communications with the anxious occupants are essential for building the messaging system's confidence. So, reliable messaging procedures need well-integrated coordination among the leading teams, including the fire service department [30]. The fire service department is the most critical user of our system.

The conditions of stairs, elevators, and cross-connect corridors affect the choice, wording, and delivery of messages to residents. Fire alarm systems may not do everything necessary to ensure all occupants are correctly informed. Careful planning, design, installation, implementation, testing, messaging, and communication systems can win the building occupants' positive interest in shortening the response time [31]. Multiple attempts have been made for the smart alarm systems to be investigated [32,33,34]. However, each system has its own advantages and disadvantages. This study was designed to create an Arduino voice-guiding fire alarm to enhance the spread of fire information to the occupants with much detailed instructed functionality. This new alarm system can be more effective in guiding people out of danger and is more user-friendly than any others sold on the current market. Most fire alarm systems are located in various rooms of the building. The present system mainly detects fire with multiple sensors of temperature, flame, and carbon dioxide sensors spread throughout the building and activates with a voice recorded in the system.

2. METHODS AND MATERIALS

2.1 Electric's Parts Specifications and Functions

2.1.1 Adafruit audio FX soundboard

This module was equipped with WAV/OGG Trigger with 16 MB Flash and was purchased from Amazon.com. It was designed for people who wanted to make props, costumes, toys, and other small portable projects. It can be used as a complete stand-alone; it just needs a 3- to 5.5VDC battery. No microcontroller was required, but it could be combined with Arduino. It had a built-in mass storage USB with 16 MB storage. High-quality sound - decoding hardware handled any bit/sample rate and mono or stereo.

This board has 11 Triggers, and it can be connected to up to 11 buttons or switches, with which each one could trigger audio files to play. Headphones, powered speakers, and wire-up amplifiers make loud sounds when plugged into the stereo line. Five different types of triggers could be covered for many projects without programming. Depending on the devices used, the audio played in other ways. Triggers include basic, hold looping, latch loop, play next, and play Random. Audio files, mp3, m3a, wav, and ogg should be converted from m3a to wav and eventually to ogg. The soundboard was designed to be simple. It did not have the polyphonic ability and couldn't play MP3s. The following voices were recorded to be activated by the conditions of fire; 1. Fire Fire, 2. Basement Basement, 3. Minor Fire Now, 4. Moderate Fire Now, 5. Fire! Evacuate right now, 6. Organic Volatile Fire, 7. High Carbon Monoxide! 8. Gas leaking! Gas leaking!, 9. Family Room, 10. Second-floor, 11. Kitchen.

2.1.2 Flame sensor

The Infrared Phototransistor included in the kit is PT334-6B. It is susceptible to infrared light. The flame usually emits a lot of infrared light, so we can use the PT334- 6B to detect the flame. The Buzzer could sound for the following circuit if a flame was near the PT334-6B. PT334-6B silicon phototransistor. The phototransistor is housed in a dark diffused package and has high sensitivity to infrared radiation. A potentiometer on the click board allows precise setting of the detection threshold, which, when reached, will send an interrupt to the target board MCU through the mikroBUS INT pin. The click board also has an analogue output for continuous infrared level measurement. The board requires a power supply of 3.3 or 5V.

2.1.3 MQ-5 LPG gas city sensor module

The MQ-5 sensor could detect liquefied methane, coal, and LPG dioxide gas. Its input voltage was DC5V, and power consumption as current was 150mA. Its digital output was the TTL digital 0 and 1, correctly, 0.1 and 5V, while the analog output (A0)) was 0.1-0 .3 V, relative to pollution. The maximum concentration was designated to be a voltage of about 4V. After the sensor was powered, approximately 20 seconds was needed to warm up, by which its measured data was stable; the heat sensor was a normal mechanism because the internal heating wire, if hot, was not normal. A highly sensitive MQ-5 gas sensor is employed to create an environment in which the combustible gas sensor, the conductivity sensor with increasing concentration of combustible gases in air increases. A simple circuit converts the modification in conductivity of the gas level against the output signal. MQ-5 gas sensors of high butane, propane, and methane sensitivity can be better considered. This sensor can detect various combustible gases, for example, natural gas. MQ-5 is a low-cost sensor for multiple applications. How to calibrate?

2.1.4 MQ-7 for carbon monoxide sensor

Carbon monoxide (CO) is sneaky odorless, colorless, and tasteless gas. Nobody can have idea of staying in the air of high CO level besides the fact that they would start to feel horrible. The most notorious symptoms of CO poisoning are headache, nausea, dizziness, fatigue, vomiting, and a feeling of being exhaused. Neurological signs can be listed as confusion, disorientation, visual blurriness, syncope, and convusions.

Carbon monoxide is generated from the incomplete oxidation of carbon-containing chemicals. CO is created when there is defficient amount of oxygen to produce carbon dioxide (CO), in cases that cooking on a stove or operating an gasoline engine in an confined space. On the other hand, under the high oxygen level, such as atmospheric concentrations, carbon monoxide burns with a blue flame, producing carbon dioxide. So, enclosed spaces with partial oxidation of carbon products create the danger of carbon monoxide production in homes or working areas.

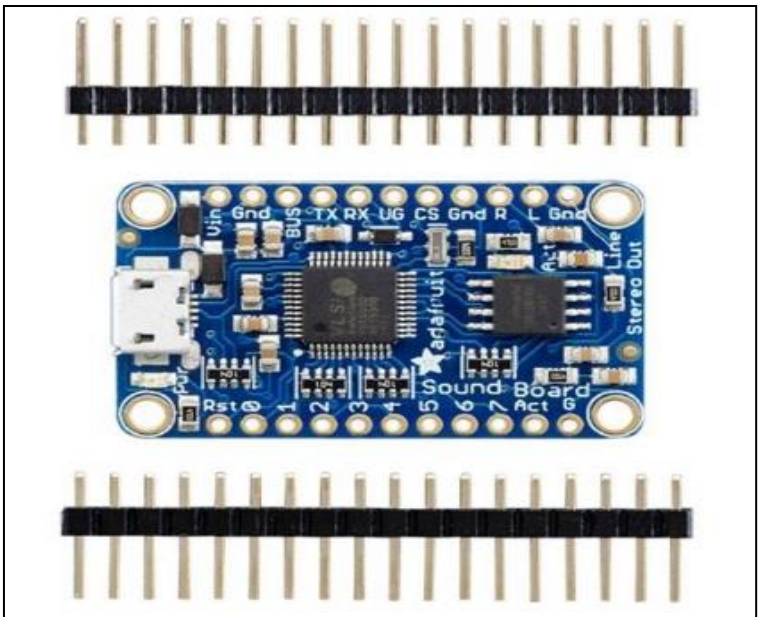

Fig. 1. Presents the FX soundboard

2.1.5 SGP30 for volatile sensor

The SGP30 sensor meausures with the top-notched metal oxide gas sensor method that facilitates it to react a fast response time less than 10 seconds. This implies that the sensor can present real-time air quality concentration, which can be utilized to detect and monitor changes in air quality. One of the critical specifications of the SGP30 sensor is its tiny dimension of 5mm x 5mm x 1.5mm which supported the measurement easy to be assembled into small sizes of devices that are readily installed in the portable air quality monitors, relatively small home devices, and wearable technology with smart functionality.

The SGP30 sensor functions with comprehensive temperature spectrum of -40 °C to 85 °C, facilitating it to operate in various environments. It can detect multiple VOCs, including formaldehyde, acetone, and benzene. The SGP30 sensor requires a calibration process to ensure accurate and reliable measurements that should be worked for an integrated calibration modality. The SGP30 sensor is coordinated with many microcontrollers using an I2C interface, that allows for easy integration into a range of different devices and appliances. The sensor records a power consumption of smaller than 10 µA while in its resting mode. Operating current consumption of the SGP30 sensor is still low. Its measurement current is 48 mA. And, the actual measurement duration is less than 20 ms, while its sleep current becomes up to 10 µA. It measures that the default I2C address of the Sensirion SGP30 gas sensor is used at 0x58 (7-bit address) or 0xB0 (8-bit address). TVOC can be measured from 0 to 60000 ppb, while CO2 can be from 400 to 60000 ppm with a sampling rate of 1Hz. Supply voltage falls from 1.62 to 1.98 v, while power-up time is 0.4 to 0.6 ms, the same as soft reset time.

2.1.6 DHT 22 Temperature and humidity

The humidity-sensing element consists of two electrodes with a moisture-holding material layered in between. The sensor detects the resistance between the electrodes, which changes depending on the air's moisture. The sensor has a small IC at the back that senses and conveys the analog signal. It also maintains the calibration coefficients and does the analog-to-digital conversion. When the datasheet of the DHTxx sensors is seen, it can be noticed that they measure the air's relative humidity (RH) dffierent from any absolute humidity. The absolute humidity presents the amount of water vapor in the air as expressed in g/m^3. In contrast, the relative humidity does take temperature level into its calculation.

Relative humidity is presented as the ratio of the water vapor in the air to the amount of water vapor the air can be saturated at a particular temperature. Therefore, warm air can keep more water than cold air. This implies that the relative

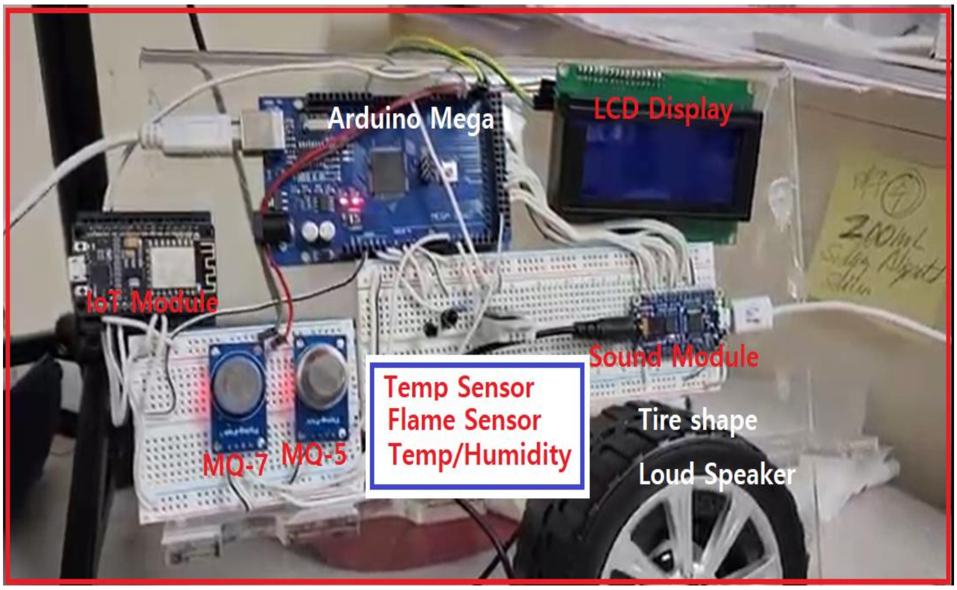

Fig. 2. Presents the assembled smart fire alarm for our study

humidity in cool air should be higher than that in warm air for the same amount of water vapor in the atmosphere. Hundred percent relative humidity means that the air is completely saturated and is at its dewpoint.

2.1.7 IoT functionality with ESP-8266

The ESP8266 is composed of a low-cost Wi-Fi microchip, and built-in TCP/IP networking protocol, and microcontroller ability, manufactured by Espressif Systems in Shanghai, China. The chip was famous in the English-speaking creator community in August 2014 via the ESP-01. This tiny device facilitates microcontrollers to work with a Wi-Fi network and make TCP/IP functionalities with Hayes-style commands. Almost no English-language documentation was prepared on the chip and the commands it accepted.

2.2 Our Assembly with Microcontroller Arduino Mega

The Arduino Mega 2560 is categorized to a microcontroller board based on the ATmega 2560. It is equipped with powerful 54 digital input/output pins. Among the pins, 15 can be used for PWM outputs, while 16 analog inputs, 4 UARTs , a 16 MHz crystal oscillator, a power jack, a USB connection, an ICSP header, and a reset button that supports multiple shields and accessories. It is ready for everything to support the microcontroller. It has the functionality of being connectable to a computer with a USB cable or power it with the power supply of an AC-to-DC adapter and battery to get booted. The Mega 2560 board has the high compatibility with most shields targeted for the Arduino Uno and the former boards Duemilanove and Diecimila as seen in Fig. 2.

2.3 Data Analysis and Report

All the data was summarized as mean and standard deviation. All the calibration values were typed into Microsoft Excel and plotted accordingly. Using the trendline functionality in the software, regression analysis was performed. Most study was performed with six trials. Student's t test was executed using online t-test calculator as unpaired analysis ($P<0.05$).

3. RESULTS AND DISCUSSION

3.1 LM 35 Temperature Sensor Calibration

The LM35 series presents precision integrated-circuit temperature devices with a linear output voltage dependent on change of the centigrade temperature. The temperature sensor was calibrated as described above. Fig. 3 shows the analog output from the LM35 sensor was highly correlated with the temperature from the mercury thermometer. The equation was used for triggering the system at a specific threshold temperature.

3.2 Flame Sensor Calibration

The Infrared Phototransistor included in the kit is PT334-6B. It is susceptible to infrared light. The flame usually emits a lot of infrared light, so we can use the PT334- 6B to detect the flame. The Buzzer will make a sound for the following circuit if a flame is near the PT334-6B. The sensor was calibrated as described. Fig. 4 illustrates the calibration curve of the flame sensor concerning the increase in distance. And it showed a highly linear relationship between the analog output and the distance. The data was used for coding to set up an alarming triggering level.

3.3 MQ-5 Gas Sensor Calibration

Nowadays, natural gases are omnipresent. Natural gases are highly manageable to transport safely and supply energy for various tasks in both household and industrial use. However, it also raises a significant risk of fire if not handled carefully. This is where the MQ-5 combustible gas sensor should be applied. The MQ-5 combustible gas sensor can detect LPG, H2, CH4, and CO. So, the MQ-5 sensor should be attached to an Arduino to investigate what happens when gases are moved closer to it. Fig. 5 shows the dramatic increase in analog output immediately after the sensor was covered with a butane-gas-filled beaker.

3.4 MQ-7 Gas Sensor Calibration

The MQ-7 Gas Sensor is a popular sensor applied to quantify the presence of carbon monoxide (CO) gas in the air. This article explore using this sensor with an Arduino to display the gas level on an LCD. Carbon monoxide is notorious for being a colorless and odorless gas that is life-threatening and further fatal if inhaled in high concentrations. The incomplete fossil fuel combustion produces CO. Fig. 6 demonstrates the sudden increase of analog output values as soon as the CO sources were detected.

3.5 SGP30 Volatile Concentration Sensor Calibration

SGP30 was very sensitive sensors that could sense the TVOC from volatile liquids such as alcohol. As seen in Fig. 7, SGP30 was able to measure the alcohol when it evaporated near distance, while the magnitude of TVOC was the function of distance.

3.6 Self-Survey Questionnaire Grading System

3.6.1 Audibility questionnaire grading system

The VIFAS, Pray Crate, and Andyssey Models were thoroughly evaluated against each other and graded on a scale of 1 for the category audibility. As seen in Fig. 8, the mean audibility score from First Alert was significantly higher than that from VIFAS ($P<0.05$) because the VIFAS system is now installed with a PC speaker created only for prototyping purposes. Later, a more advanced speaker system will be added. The bar graph of survey score in audibility among the fire alarm systems the bar graph of survey score in intelligibility among the fire alarm systems which caused the algorithm to output -2 or a class B Self Survey Evaluation of Audible Alarm The VIFAS, Pray Crate, and Andyssey Models were tested against each other, rated on a scale of 1-10 on the category audibility. As seen in Fig. 8, the mean audibility score from Pray Crate and Andyssey was significantly higher than that from VIFAS ($P<0.05$) because the VIFAS system is now installed with a PC speaker created only for prototyping purposes. Later, a more advanced speaker system was added.

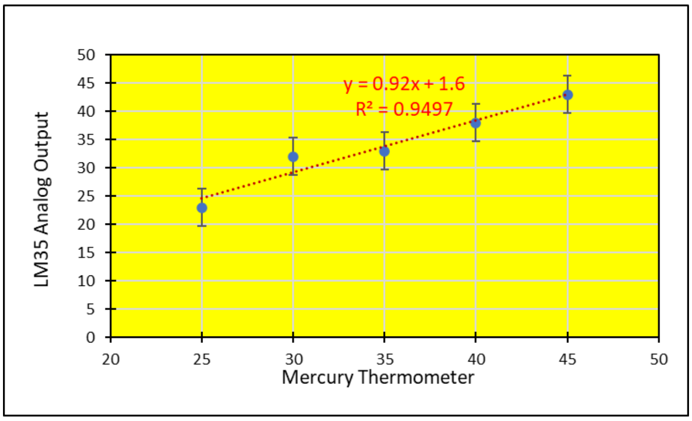

Fig. 3. Shows the high linearity of the analog output with a mercury thermometer

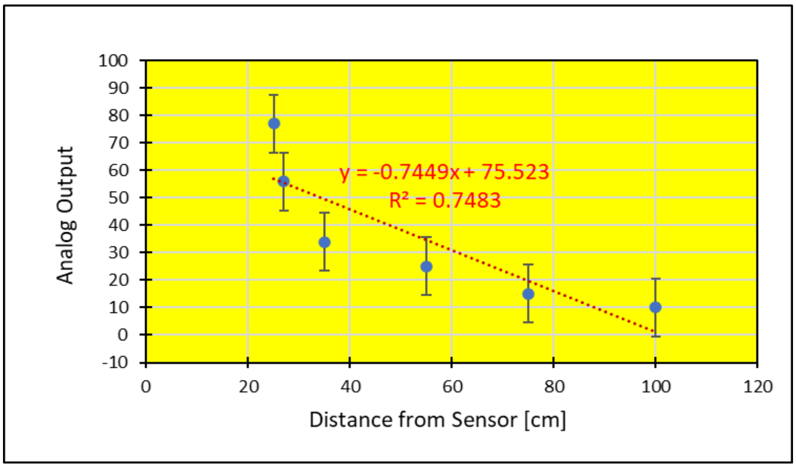

Fig. 4. presents the analog output from a flame sensor concerning the distance of the flame

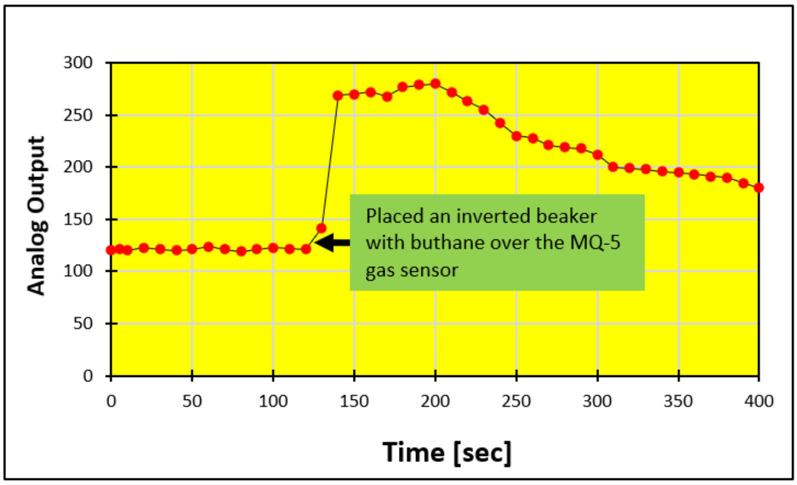

Fig. 5. Presents the analog output profiles from the MQ-5 gas sensor when covered with an overturned beaker with puffs of butane gas

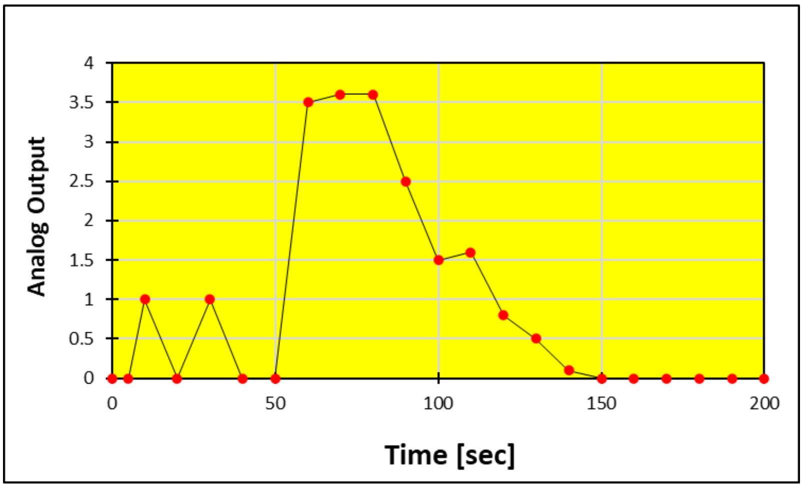

Fig. 6. presents the analog output profiles from the MQ-7 gas sensor when covered with an overturned beaker with burning pieces of paper towel

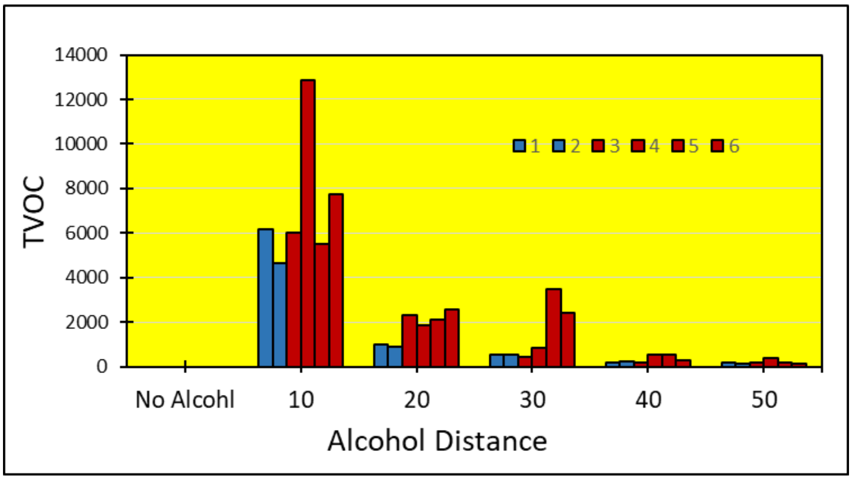

Fig. 7. presents the TVOC analog output for the alcohol distance. Legends: Distance unit; cm, The number of the box legends in the figure: Number of trials

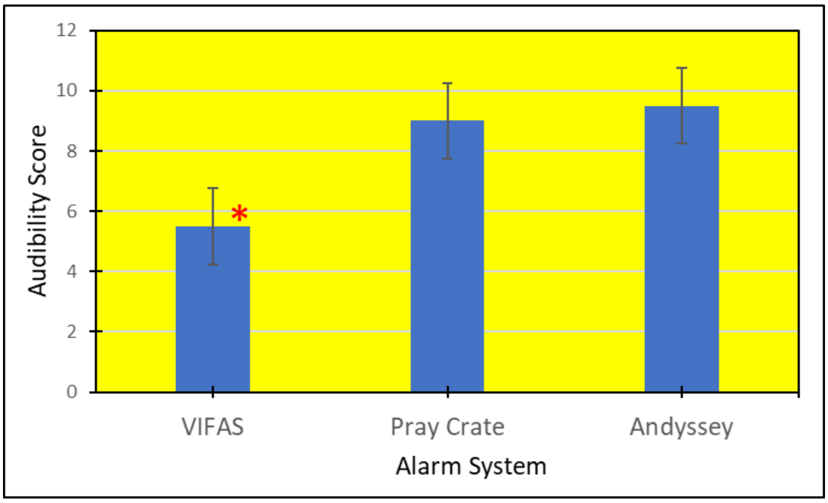

Fig. 8. presents the audibility scores obtained from the developer

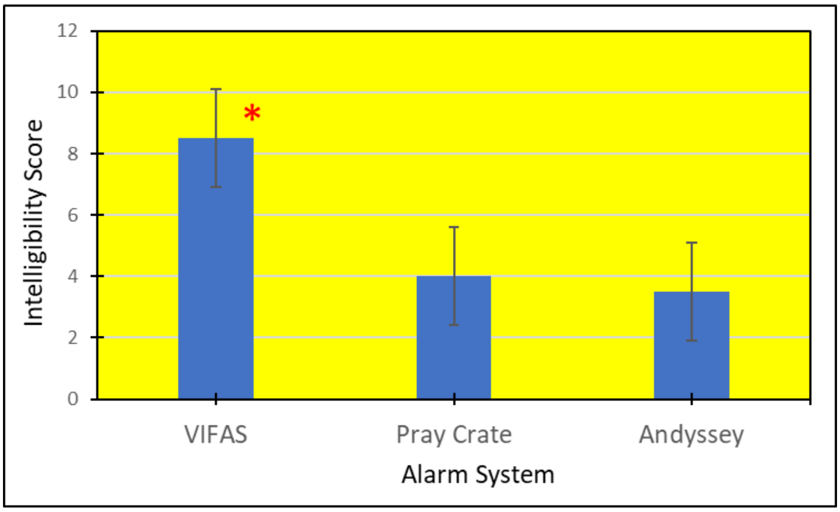

Fig. 9. Presents the intelligibility scores obtained from the developer

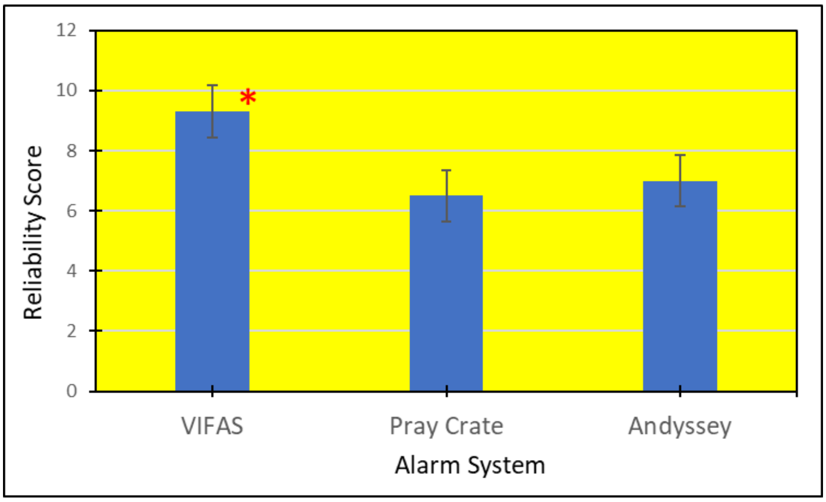

Fig. 10. Presents the reliability scores obtained from the developer

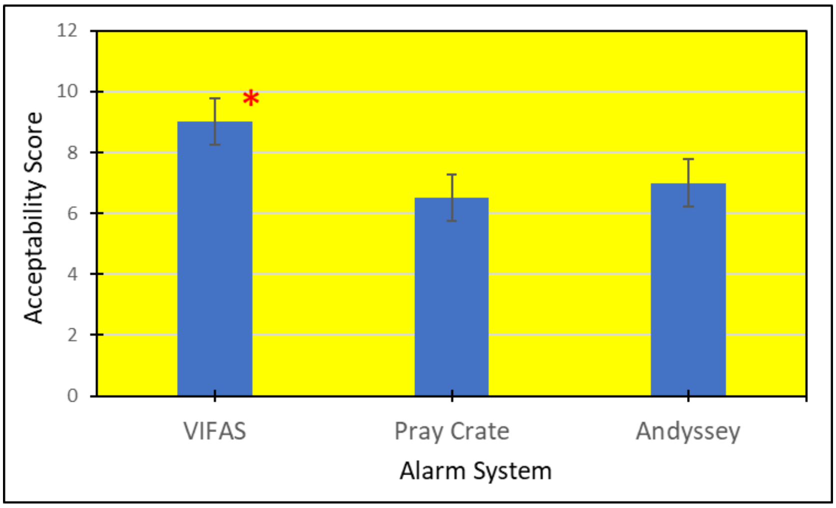

Fig. 11. Presents the acceptability scores obtained from the developer

3.6.2 Intelligibility self questionnaire grading system

The VIFAS, Pray Crate, and Andyssey Models were blasted against each other, and their intelligibility was graded on five graduations from 1 to 10. Intelligibility is an essential property of a fire alarm system since it should be the most favorable if any building occupant can be recognized immediately after a fire alarm blasts off. As seen in Fig. 9, the mean intelligibility from VIFAS was statistically higher than that from Pray Crate, and Andyssey ($P<0.05$), which was naturally understandable from our VIFAS system since our system informs users of the type of fire and location verbally with detailed information, compared to the other two models which only notify that there was a fire broke out.

3.6.3 Reliability self-questionnaire grading system

The VIFAS, Pray Crate, and Andyssey Models blasted off alarm sounds against each other, scoring 1 to 5, depending on the reliability. Fig. 10 is illustrated as a bar graph of the questionnaire survey score in Audibility. Fire alarm models were tested against each other and rated on a scale of 1-10 on the category reliability. This is an essential quality of a fire alarm because the fire information should be recognized immediately after it blasts off. As seen in Fig. 10, the reliability from VIFAS was statistically higher than that from Pray Crate, and Andyssey ($P<0.05$), which is reasonable from our VIFAS system since our system informs users of the type of fire and location compared to the other two models which only notify The VIFAS, Pray Crate, and Andyssey Models were tested against each other, rated on a scale of 1-10 on the category reliability. As seen in Fig. 10, the mean reliability score was significantly greater VIFAS than that from Pray Crate, and Andyssey (P<0.05). This is an essential element since a fire alarm system should output accurate data 100% of the time to mitigate false positives or, even worse, false negatives, meaning the alarm does not go off in the case.

3.6.4 Acceptability questionnaire scores

The VIFAS, Pray Crate, and Andyssey models tested against each other and rated the category acceptability on a scale of 1. The user should trust the alarm, have a sense of security, and react quickly to the initial siren. Compared to the other two models, the VIFAS scored much higher in acceptability, meaning this alarm was trusted and directed to the user more effectively before the firefighters arrived on the scene. The bar graph of survey score in audibility among the fire alarm systems the bar graph of survey score in acceptability among the fire alarm systems as in Fig. 11.

4. CONCLUSIONS

Fires are not easy to predict in advance, and they cause much devastation and result in serious damage to property and even human death. Fires can break out without prior notice at any place and at any time. So, it is inevitable to blast an alarm system appropriately with accurate information to extinguish early. Traditional fire alarms sound noisy with little guiding information. And, sometimes, casualties even could be occurred when the victims escape toward the flames. In this study, an intelligent Arduino system was created for a verbal guide with more detailed information. It informed the location, sources of fire, and seriousness while alarming the fire department through the email alert system. Self-surveyed scores demonstrated a significantly informative and safe system in the aspects of audibility, intelligibility, reliability, and acceptability, and further study might be fine-tuned to be a more effective fire alarm.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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