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Research article

Towards preventing the false alarms in indoor physical intrusion detector system and the incorporation of intruder immobilizer system

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ABSTRACT

Indoor physical intrusion detector systems are rendered ineffective and inefficient if the frequency of false alarms is high. The sensor technology deployed and the sensor architecture implemented determines the sensitivity of the intrusion alarm systems and the rate of false alarms. Here we report the development of an innovative smart reliable, easily deployable, indoor physical intrusion detector and intruder immobilizer system for security applications. The developed device implements two ultrasonic sensors positioned strategically apart and combined by AND logic gate to detect only intruders and preventing false triggers. A gas canister containing lachrymatory agents is connected to the circuit in such a manner that a solenoid switch activates the discharging of the gas upon the enabling of the circuit when an intruder is detected. Through this arrangement, the intruder is rendered immobile and harmless before apprehension. The device also activates an alarm simultaneously to alert the users. The developed device creates a secured environment and is suitable for homes, apartments, banks, warehouses, supermarkets especially in low income countries of Africa.

1. Introduction

There is a huge demand for a secured and safe environment as the world faces the harsh economic situations arising from the post COVID-19 pandemic quagmire and the climate change. As our evolving world is confronted with severe challenges of growing poverty levels with people from many low income countries of Sub Saharan Africa desperately struggling to survive, security is a crucial issue which needs to be established in order to discourage and reduce crime [1]. The locations susceptible to burglars and intruders are the homes, banks, warehouses, factories and other indoor facilities which may provide forced succor for the criminals and the impoverished [2]. Several security application technologies have been implemented in safeguarding the environment such as the surveillance cameras, closed circuit television (CCTV) monitors, security door locks, taut wire fence system, Micro phonic sensor cable, burglar alarm systems, etc. [3].

The major challenge with burglar alarm systems is with the high levels of false alarms [4]. Most users of burglar alarm devices do not respond to the alarms owing to the incessant alarms triggered by moving objects within the environment leading to false alarms. A

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case study of an international bank in Nigeria with 1391 branches reveals that only 22 branches are currently using the burglar alarm systems while the other branches disabled theirs due to the malfunctioning of the device which manifests as false alarms. The 22 bank branches relocated the alarm section of the burglar alarm device to their security post to manage the noise emanating from the false alarms. Preventing the false alarms generated by the burglar alarm system will enhance its effectiveness and efficiency.

Another challenge with the application of burglar alarm system is in the approach towards the apprehension of the detected burglar [5]. The sudden sounding of the alarm at the detection of a burglar may provoke the suspects into being aggressive and so can be harmful and dangerous to apprehend. There is a need to immobilize the burglar and render the suspect incapacitated before arrest.

This paper focuses on preventing the false alarms in indoor physical intrusion detector system and the incorporation of intruder immobilizer system. It emphasizes on developing a reliable and economically viable intrusion alarm system that possesses the capability of rendering the intruder immobile and harmless before apprehension. The ultrasonic sensor technology is preferred because of the following reasons [6,7]. The ultrasonic waves are invisible and therefore difficult to detect by an intruder; the device is more compact with both transmitter and receiver on the same chip; it is tunable to deliver very low false alarms. A comparison of the estimated rate of false alarms generated while using only one type of sensor component solely in an intrusion alarm device is presented in Fig. 1.

The ultrasonic sensor generates the lowest false alarm when deployed solely in intrusion alarm systems as shown in Fig. 1.

There are other security intrusion detector systems used to secure the environment such as the fiber optic cable, glass break detectors, micro phonic systems, inertia sensors, taut wire fence systems etc. [9]. They are usually mounted outdoors on the perimeter fence or barriers to detect any attack on the structure by an intruder.

2. Materials and methods

The main components of the developed device are the power supply unit, the microcontroller unit, the intruder detector unit comprising of two ultrasonic sensors T_1 and T_2, the alarm unit, and the intruder immobilizer unit. The block diagram of the Physical Intrusion Detector and Intruder Immobilizer device is described in Fig. 2. The operation of the system is illustrated in the flowchart in Fig. 3.

2.1. The algorithm for the flowchart

Step 1: Start
Step 2: Create a variable to indicate if ultrasonic sensor 1 or 2 is blocked. If Yes go to step 3, if No go to step 1
Step 3: Create a variable to indicate if ultrasonic sensor 1 and 2 are blocked. If Yes go to step 4, if No go to step 1
Step 4: Activate the alarm system and immobilizer system
Step 5: End

2.2. Ethical approval and compliance with experiments on humans

All the participants for the validation of the developed physical intrusion detector and intruder immobilizer system were briefed on the background and details of the experiment. The ultrasonic waves are sound waves with frequencies above human audible range of 20 KHz. The generated ultrasonic waves are not harmful and have no health hazard. Each of the participants executed a consent form indicating their consent and awareness of the experiment protocols. The University of Lagos, Nigeria Research Management Office reviewed the research protocols and granted an ethical approval for the research to be conducted. The participants are not to be exposed to tear gas in the course of the validation of the developed device. The authors hereby state as follows.

- In this research, all methods were carried out in accordance with relevant guidelines and regulations.

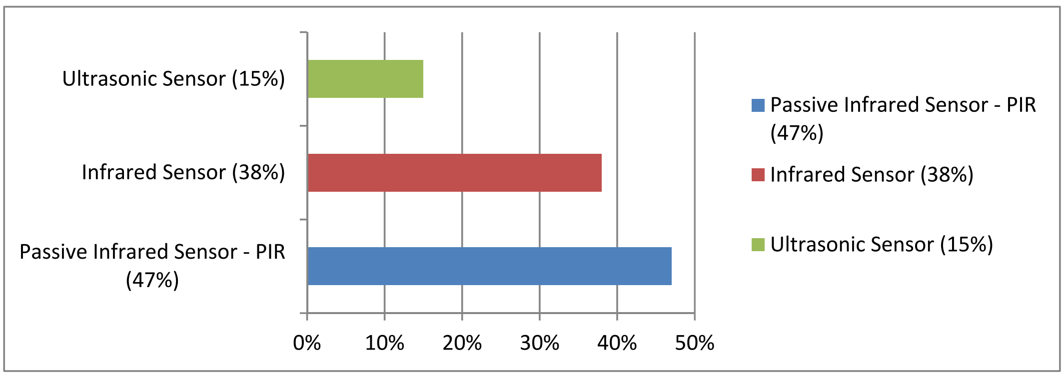

Fig. 1. Estimated rate of false alarms introduced while using only one type of sensor component solely in an intrusion alarm system [8].

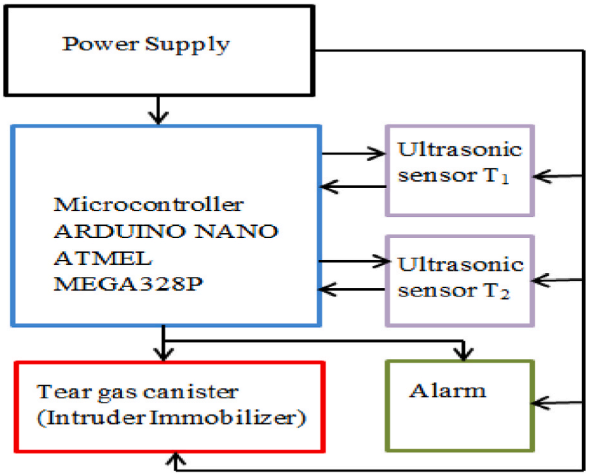

Fig. 2. Block diagram of the Physical Intrusion Detector and Intruder Immobilizer Security Device.

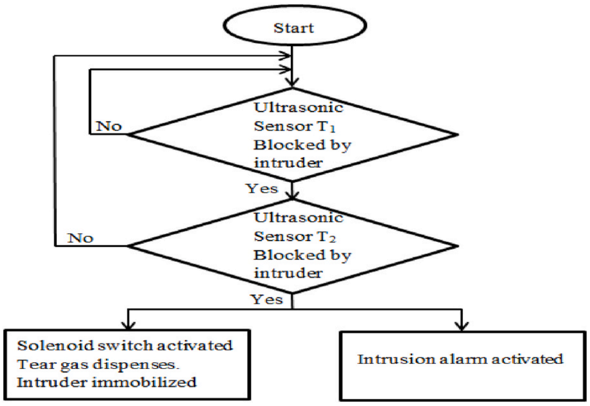

Fig. 3. Flowchart illustrating the operation of the Physical Intrusion Detector and Intruder Immobilizer Security Device.

- All experimental protocols were approved by Research Management Office, University of Lagos, Nigeria (NHREC/07/02/2022A).
- Informed written consent was obtained from all subjects that participated in the validation of the developed device.

2.3. Component structure of the developed device

The physical intrusion detector and intruder immobilizer security device functions deploying two ultrasonic sensors positioned at 0.2 m vertically apart and 0.05 m horizontally apart. The bottom ultrasonic sensor is located at 0.8 m vertical height from the ground. In this architecture the ultrasonic sensors can detect only human thereby eliminating the false triggers by any other objects. This is achieved by using an AND logic gate to combine the action of the two ultrasonic sensors as shown in the flowchart in Fig. 3. In the flowchart, when only one ultrasonic sensor is blocked by an object, the device will not activate the immobilizer and the alarm system. This algorithm prevents the false alarms generated by rodents and other moving objects. The immobilizer and the alarm system will be triggered ON only when the two ultrasonic sensors are blocked the same time. The algorithm of the flowchart is presented in subhead 2.1. Adopting this sensor architecture, it is almost impossible for any human to pass the location without blocking the two transmitted ultrasonic beams the same time. The positioning of the ultrasonic sensors is illustrated in Fig. 4A. Notice that the coloured background conceals the ultrasonic surface so that it cannot be easily identified by an intruder.

The immobilizer unit consists of a 227 g teargas cartridge bottle with the canister nozzle controlled by a mechanical switch activated by a solenoid. When the circuit receives pulse from the microcontroller, the switch compresses the cap of the canister spraying teargas from the nozzle. The intruder immobilizer unit is described in Fig. 4B. The teargas is made with lachrymatory agents which renders the intruder weak and immobile. In that condition, it will be safe to apprehend the intruder without resistance. The common lachrymatory agents used for immobilization includes Nonivamide, Phenacyl chloride, Bromoacetone, Xylyl bromide, 2-chlorobenzalmalononitrile, Bromobenzylcyanide, etc. [10].

The alarm system is positioned close to the security post or any other location where it can easily alert the occupants of the presence of an intruder. The intrusion alarm is enabled simultaneously with the immobilizer system as shown in the flow chat. A buzzer

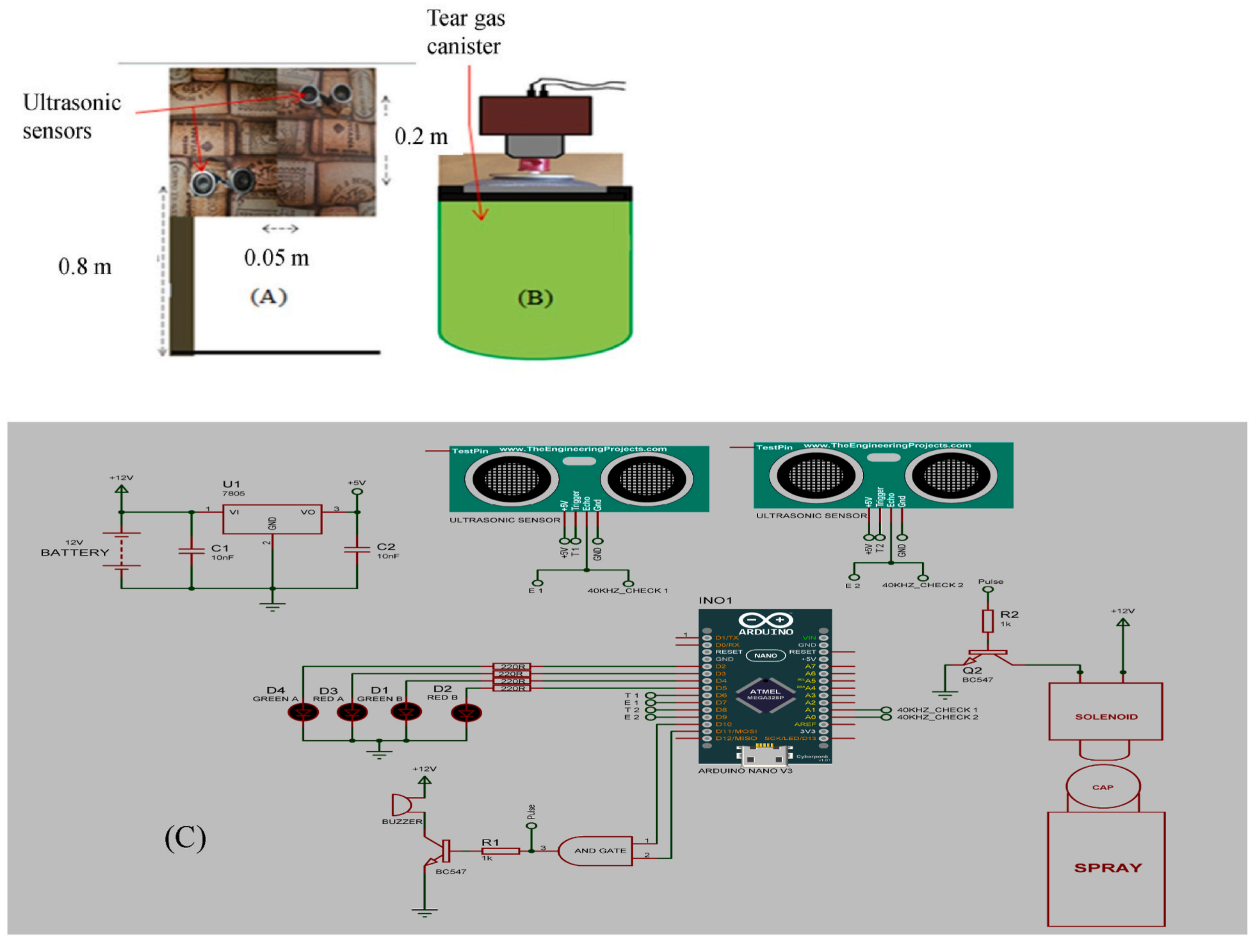

Fig. 4. (A) Describes the positioning of the ultrasonic sensors on multicolored background wallpaper. (B) Illustrates the tear gas cartridge revealing the dispensing system of the mechanical switch. (C) The electronic circuit design of the physical intrusion and intruder immobilizer security system.

connected in the circuit generates the warning alarm. The circuit board for the developed device is packaged in a metal case. It is good to conceal the metal box behind any wall drawer or painting and now extend the wires for the connection of the two ultrasonic sensors, the immobilizer unit, and the alarm system to their appropriate locations. The circuit diagram of the physical intrusion detector and intruder immobilizer security system is presented in Fig. 4C.

The effectiveness of security intrusion alarm systems depends on the installation technique. If an intruder can identify the location of the spot where the device is positioned, then it increases the chances of maneuvering the device without being detected [11]. In order to conceal the device, it is ideal to position the ultrasonic sensors at a background that is multicolored in a manner that it will blend with the patterns on the wall. The use of designed wallpapers at such locations will go a long way in achieving that with the connection wires hidden under the wallpapers. Also, the circuit panel of the device can be packaged in a toy shape to deceive any intruder. A similar dummy device may be positioned in other locations to deceive an intruder.

2.4. Power supply to the device

Electric power supply is scarce, unstable and unreliable in most countries of Sub-Saharan Africa. The intrusion alarm system cannot function without electric power source. A 12 V 7.2 AH Direct current (DC) rechargeable battery was used in the developed product to ensure that there is no power outage. The battery can be recharged through the national power grid, fossil fuel power generator, solar power, or any available stable power source. It is projected that the battery if fully charged, will last for 24 h before fully drained. A battery bank with lithium ion batteries will be provided for locations where electricity supply is not available. The power supply unit is shown in the circuit diagram in Fig. 4C.

In locations where there is a reliable and stable alternating current (AC) source, a rectifier circuit consisting of two pairs of diodes in a bridge configuration and a filter circuit using capacitors and resistors in pie circuit is used for the conversion to a direct current (DC). Usually AC voltage from the mains is 220 V, so a transformer is needed to step it down to 12 V before the rectification [12]. The rectification circuit is not required if a solar cell is used since it delivers a DC current. The DC to DC converter is used to convert the direct current from the solar module from one voltage level to the desired 12 V.

2.5. The intruder detection system

The major challenge with intrusion alarm system is in reducing the false alarms while ensuring that the device detects any intruder. Two ultrasonic sensors combined with AND logic gate were implemented as shown in Fig. 4A. The staggering of the two ultrasonic sensors by varying the distance between them both vertically and horizontally limits the chances of false alarms while enhancing the performance of the device in detecting intruders. The webvpython was used to create the virtual 3D animations of human and cats. By adjusting the position of the two ultrasonic sensors in the x, y, z coordinates, the ideal position that detected only humans were determined. In the deployed sensor architecture, it is almost impossible for an intruder to pass undetected. The HC-SR04 ultrasonic sensor operates on 5 V and can detect distance up to 13 feet making it suitable for the developed device [13]. The transmitter and receiver are embedded on same chip making it very easy to install with reduced space and wiring connection compared to other technologies like infrared sensors that requires the spacing of the receiver and transmitter.

The deployed HC-SR04 ultrasonic sensor comes with four pins, the voltage common collector (VCC), Trigger, Echo, and Ground. By interfacing the two ultrasonic sensors with Arduino, it delivers 8 pulse pattern ultrasonic waves each when enabled. In the active state the two ultrasonic sensors transmits sonic signals which reflects back part of the emitted waves upon impact with a surface and is received by the receiver. Initially the distance between each ultrasonic sensor and the wall is calculated bearing in mind that the generated ultrasonic wave signal undergoes twice the covered distance in making the to and fro movement from transmitter to wall and to receiver. The relationship between the speed and time of the generated signal is described in equations (1) and (2) [14].

$$\text{Speed} = \frac{Distance}{time} \tag{1}$$

$$\text{Distance} = (Speed \times time) \tag{2}$$

The rated speed of the acoustic waves emitted by the ultrasonic sensor is about 330 m/s so the distance is derived from the time taken between the transmitted signals and the received signals [15]. The actual distance is obtained by dividing the given distance by two since the signal reflects back to origin. The wall described here is the barrier or boundaries at each end of the protected space where the ultrasonic waves transmits uninterrupted before reflection. The detected distance is programmed in the microcontroller as a reference point. Any reduction of the distance due to obstruction of the transmitted ultrasonic waves by an obstacle will be detected immediately [16]. However the pulse will only be transmitted to activate the alarm and the tear gas switch when both ultrasonic sensors are simultaneously blocked. In the implemented logic, the device cannot generate false trigger from birds, rats or any rodents within the protected space.

In the adopted two ultrasonic sensors architecture in AND combinational logic gate, any faulty ultrasonic sensor will lead to false negatives. In order to promptly identify a faulty ultrasonic sensor, a pair of light emitting diodes (LED), one green and one red are connected to each ultrasonic sensor as shown in the circuit diagram in Fig. 4 C. The diodes are labeled D1_green, D2_red, D3_red, D4_green connected through 220Ω resistor to the microcontroller. The green LEDs, D1 and D4 turns on when the two ultrasonic sensors are functioning in good condition delivering 40 kHz frequency and the red LEDs remain off. But the red LEDs D2 and D3 will be triggered on immediately any of the ultrasonic sensors is malfunctioning. The corresponding red LED connected to the malfunctioning ultrasonic sensor will switch on while the green LED will turn off. So a red LED On indicates a faulty ultrasonic sensor connected to the red LED.

The configuration of the red LEDs was set by first taking samples of the ultrasonic pulse frequency delivered by the ultrasonic sensor which is 40 kHz, then, it was fed into the analogue input of the Arduino A_0, and A_1 to read the signal. The transmitted signal from each of the ultrasonic sensors is compared with the stored frequency of 40 kHz through the comparator of the microcontroller. The digital output of the microcontroller D_2,D_3,D_4,D_5 are connected to the LEDs such that when the frequencies match 40 kHz, the green LED is On but when the frequency is below or above 40 kHz, the red LED is turned On. A faulty ultrasonic sensor will not transmit pulse at 40 kHz and so lead to a mismatch which will cause the comparator of the microcontroller to trigger the red LED On. In this system configuration, a faulty ultrasonic sensor can easily be identified and therefore eliminate any false negative associated to a faulty sensor.

It is important to note that once any of the red LED's switches On, the device performance is interrupted due to the AND gate logic that was implemented. The developed device is easily serviceable since the fault can be detected promptly and even traced to the particular ultrasonic sensor that is malfunctioning. So the maintenance is simple and projected to take less than 1 h.

Alternatively, additional two ultrasonic sensors can be introduced as standby creating a system backup plan. The device can toggle to the standby ultrasonic sensors once a fault is detected. While this may be attractive for some users, it will increase the cost; introduce more components and wiring requirements.

2.6. The microcontroller of the device

Intrusion alarm systems are miniaturized to make them more difficult to be noticed by intruders. Here we implement the Arduino Nano V3 because of its smallest dimensions and pin headers that allow for easy attachment onto a circuit board [17]. The Arduino Nano board based on microcontroller ATmega328 was used to interface the two ultrasonic sensors with the tear gas dispenser switch and the alarm system. The Arduino Nano is equipped with 30 input/output headers, in a Dual in-line package 30 like configuration as shown in Fig. 4C. The microcontroller was programmed using the Arduino software integrated development environment (IDE).

The code and programming of the microcontroller is available upon request via email from the corresponding author.

2.7. The tear gas discharging system

There are two ingredients required in making tear gasses namely a lachrymatory agent and a medium to cause it to be speedily and widely dispersed in air. The tear gas is contained in a 650 ml canister with the mechanical switch that activates the spray positioned on top of the nozzle cap. Upon activation of the solenoid switch, the load depresses the nozzle cap and discharges the tear gas as illustrated in Fig. 4B. In order to achieve wider diffusion of the tear gas in the protected space, it is ideal that the canister is placed at the edge of the room with the nozzle pointing out to spray to cover the entire space.

Tear gas has a low flammability and when subjected to an ignition source such as a naked flame or an electrical spark, most common tear gasses will only catch on fire if they are prior exposed to high temperatures [18]. Even when the tear gas concentration on air is in contact with flames, it will only cause a moment of fire that is unlikely to be sustained for more than a few seconds. There is no risk of setting the protected space on fire when the tear gas is discharged into the air.

2.8. The intrusion alarm

The buzzer in the intrusion alarm circuit delivers the alarm whenever the two ultrasonic sensors transmitted waves are blocked simultaneously. It is ideal to place the buzzer in a location where the intruder will not hear the sound because the target is to alert the security guards or the occupants of the house, not the intruder [19]. This paper reports an approach towards eliminating the false alarms associated with intrusion alarm systems.

2.8.1. Sensors and systems installation and configurations

The installation of the two ultrasonic sensors in the ideal positions identified to eliminate false alarms is described in Fig. 5. The arduino board is packaged in a rectangular metallic box measuring length 0.2 m, height 0.15 m, and thickness 0.03 m with the buzzer mounted at the top. The 12 V 7.2 AH DC battery is isolated outside the circuit board to prevent the heating of the device. The connection of all the components is as shown in the circuit diagram in Fig. 4C. The tear gas canister is located at a spot where the spray nozzle projects outwards inside the room in such a manner that it will speedily reach an intruder.

2.8.2. Cost of the developed physical intrusion detector and intruder immobilizer system for security application

All the components deployed in the construction of the developed device were procured locally in Lagos, Nigeria. The cost of the developed device is presented in Table 1. The electronic components were procured from HUB 360, A7 Oshodi street, Shop Number EU2 9 and 10, Lagos, Nigeria. The choice of the chemical agents deployed in tear gas depends on the environmental conditions, the susceptibility of the location to intruders, and the cost of the available materials. The developed device is cheap at USD 61.03.

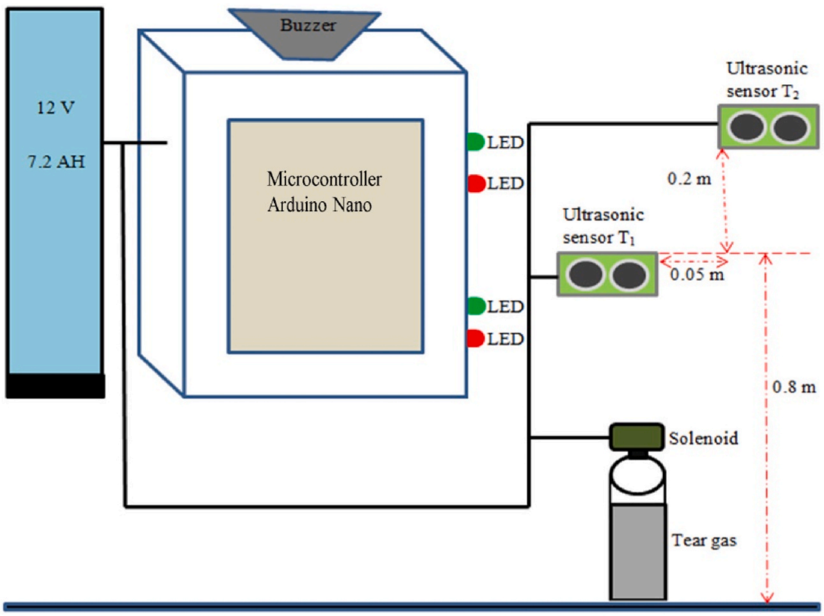

Fig. 5. Sensors and systems installation and configurations.

Table 1
Costing of the physical intrusion detector and intruder immobilizer system.

Item	Quantity	Unit cost ($) USD	Cost ($) USD
Ultrasonic sensor (HC–SR04) China	2	5.99	11.98
Arduino Nano V3 board (China) ATmega328 microcontroller	1	12.05	12.05
Solenoid switch (China)	1	5.99	5.99
12 V DC Rechargeable battery (Germany)	1	10.00	10.00
Plastic Casing for Packaging the device (China)		5.57	5.57
PCB board (China)	1	0.5	0.5
Buzzer - Huawei (China)	1	2.5	2.5
Wire and other accessories		5.00	5.00
Light emitting diodes (China)	4	0.1	0.4
Resistors 220Ω (China)	4	0.1	0.4
Capacitors 10 nF (China)	2	0.99	1.98
NPN transistors BC547 (Texas)	2	1.25	2.50
Resistors 1 kΩ (China)	2	0.5	1.0
IC 7805 (Korea)	1	0.8	0.8
Tear gas cartridge	1	0.36	0.36
Total			**$61.03**

2.8.3. Determination of the ideal position for the two ultrasonic sensors

Confusion matrix was used to analyze the performance of the developed intrusion detector device to identify the best sensor architecture that eliminates false alarms. The confusion matrix was developed based on True Negative, True Positive, False Positive, and False Negative [20–23].

- True Negative: represents the number of times the device correctly recognized objects that blocked the ultrasonic waves as non-human and therefore alarm was not activated.
- True Positive: represents the number of times the device correctly recognized human and activated the alarm.
- False Positive: represents the number of times the device wrongly recognized other objects as human and activated the alarm.
- False Negative: represents the number of times the device failed to detect human that passed the protected environment.

Computer based graphics simulations augmented reality deploying webvpython were used to demonstrate the following scenarios in a virtual room in order to determine the ideal position for the placement of the two ultrasonic sensors to prevent false alarms.

Two ultrasonic sensors were used for each trial test with one always positioned at a level 0.8 m vertical height from the ground while the vertical (y-axis) and horizontal (x-axis) distance of the second ultrasonic sensor is varied with respect to the lower one.

Five graphically simulated people with different heights were sampled in the trial test; 0.9 m, 1.2 m, 1.5 m, 1.8 m, and 1.9 m. Each human with different height was programmed to pass the location of the two ultrasonic sensors to test if the size would block the two sensors simultaneously in the virtual environment.

Five graphically simulated cats of height 0.15m were programmed to be moving randomly in the virtual room to test if the ultrasonic sensors will trigger false alarms.

3. Results

The outcome of the test is presented in Table 2.

The webvpython 3.2 version was used in the creation of real-time navigable 3D animations of humans and cats implemented in the identification of the ideal positions for the two ultrasonic sensors. The distance between the two ultrasonic sensors were adjusted in the

Table 2
Trial test of the Intrusion Detector Alarm System using virtual computer simulation.

Two ultrasonic sensors spacing with the lower sensor 0.8 m from ground	True Negative	True Positive	False Positive	False Negative
Vertical spacing = 0.2 m; Horizontal spacing = zero.	3	5	2	0
Vertical spacing = zero; Horizontal = 0.05 m.	2	4	3	1
Vertical spacing = 0.2 m; Horizontal = 0.05 m.	5	5	0	0
Vertical spacing = 0.3 m; Horizontal = 0.1 m.	5	3	0	2

x-axis, y-axis and z-axis during each trial with a focus on achieving a position that will detect only humans while still eliminating false negatives. It was observed that placing the two ultrasonic sensors at vertical spacing of 0.2 m and horizontal spacing of 0.05 m did not produce any false alarms after ten trials. The device also detected all the simulated intruders of different heights using that sensor architecture.

The developed device is very effective and efficient in the detection of intruders based on the computer animations. Placing both ultrasonic sensors at the same horizontal level and then separated vertically at 0.2 m produced some False Positives. It was possible for the cats to block the two ultrasonic sensors since they were aligned vertically with the lower one directly under the higher one. That also reduced the number of True Negatives from 5 to 3.

Placing the two ultrasonic sensors at the same vertical level with a horizontal spacing of 0.05m produced some False Positive alarms because it was easy for the cats to block the two ultrasonic sensors the same time. Again it reduced the number of True Negatives from 5 to 2.

Furthermore, placing the two ultrasonic sensors at a horizontal height 0.1 m apart and vertical height of 0.3 m apart reduced the True Positives because it was possible for an intruder to maneuver the sensors without interrupting the transmitted waves simultaneously. The fact that the distance between the two ultrasonic sensors increased, eliminated the chances of the rat blocking the two sensors at the same time so there was no False Positive alarms. The machine learning confusion matrix is presented in Table 2.

4. Discussion

The obtained results of the trial test indicates that the false alarms can be eliminated by using two ultrasonic sensors and spacing them apart to achieve a very reliable sensor architecture. Existing intrusion alarm systems implements Global System for Mobile Communications (GSM) modules which malfunctions whenever there is an unstable telecommunication network [24]. Most wireless communication intrusion alarm systems are not attractive for low income countries of Sub Saharan Africa where electricity is scarce and unavailable.

The intrusion detector systems that rely on surveillance cameras depend on the physical monitoring of the device to spot intruders. Distraction of personnel monitoring the surveillance area can allow intruders undetected. The surveillance camera that uses motion sensors deploys passive infrared sensors on the field of view of the protected area. Passive infrared sensors generate a lot of false positive alarms making them ineffective and unreliable for intrusion detector systems [25]. The PIR sensors have a short detection range due to its very limited field of view.

Some intrusion alarm systems incorporate solar panels as a source of electric power for the device. While this is good as a stable source of power for the device, it malfunctions as soon as the solar panels are contaminated and stained with dust. Also, the solar panel needs to be exposed to sunlight making the device easily noticeable by an intruder. Rechargeable batteries are the best solutions for intrusion alarm systems.

Cost is a very important consideration for low income countries of Africa which determines whether an economic product is affordable by the masses. The developed intrusion detector system is cheap at USD 61.03. A comparison of the cost of some of the existing intrusion alarm systems and their technologies is presented in Table 3.

4.1. Field test of the developed device

The developed physical intrusion detector and intruder immobilizer system was installed in a store room in Lagos measuring 8 m length and 5.5 m width. The store is usually locked in the night at 7 p.m. after close of work. The ultrasonic sensors for the intrusion detector system were mounted with the dimensions as specified in Fig. 4A. The immobilizer circuit was disabled and the alarm buzzer was wired to the security post.

The device was switched On and then the store door was left open for an intruder. Five people of different sizes who completed the ethical consent forms participated in the trial test. The intrusion alarm triggered On within 2 s each time an intruder blocked the two ultrasonic sensors the same time. The trial test was repeated ten times for each person. It was observed that when only one ultrasonic

Table 3
A comparison of the cost of some of the available intrusion alarm systems and their sensor technologies.

Intrusion alarm system	Operation
Eyesyte intelligent alarm system. Unit cost is $79.99.	It implements Wi-Fi and GSM system for transmission of signals. It fails if the telecommunication network is unstable. The intrusion detector system uses Passive Infrared sensors (PIR) which generates high level of false alarms.
Zsmart alarm system kit. Unit cost is $117.88.	The device uses PIR sensors. It is very expensive and complex to install.
Solar powered motion sensor alarm. Unit cost is $115.99.	It incorporates solar panels in the intrusion device as the power source. The intrusion detector system uses PIR sensors.
Infrared perimeter intrusion Unit cost is $150.44	The device is used for outdoor environments. It uses infrared sensors which generates high levels of false alarms. It is very expensive.
Anti-theft home security burglar alarm system. Unit cost is $105.	It uses ultrasonic sensors combined with PIR sensor technology. It is expensive.
Hik Vision Ax-Hub intruder alarm kit. Unit cost is $182.99.	The device uses closed circuit television system for surveillance. It also records 24 h. The sensor technology implements PIR sensors. It is very expensive.

sensor was blocked, the alarm did not sound showing that positive alarm will only be triggered if the object size is within the range of that of a human.

The intruder immobilizer system was enabled and wired with the teargas canister positioned outside the room facing away in a place that it cannot be inhaled during the trial test. The entire surrounding was evacuated to ensure that no animals or humans were within the location of the teargas discharger outside to ensure the safety of everyone. The test was conducted with full human manikin positioned to interrupt the two ultrasonic sensors before the device was switched on. It was observed that the teargas switch activated the spraying of the teargas within 2 s the device was switched on. Both the alarm and the teargas were triggered the same time the sensors detected the manikin.

Although the immobilizer unit performed well by spraying the teargas immediately the manikin was detected, the dispersing of the teargas can be made faster and more distributed by mounting the teargas canister on top of a rotating electric motor rotor. Thus the canister nozzle can turn around while spraying the teargas. Adopting the technique will increase size, cost and electric power consumption of the device.

4.1.1. Related works

Most of the existing indoor security systems only detect and alert the users of an intrusion [26]. An intruder may overpower the security guards and harm the occupants of the building. Intrusion alarms sometimes trigger false alarms. When the rate of false alarms is high, it becomes very disturbing and makes the security system inefficient [27]. The effectiveness and efficiency of the intrusion alarm depends on the deployed sensor technology [28].

The infrared sensor technology delivers very high rate of false alarms as the beams are easily interrupted by objects in motion. It requires a transmitter and receiver during operations. The transmitter generates the infrared beam which is continuously transmitted and then received by the receiver. Any interruption of the infrared signal between the transmitter and receiver will activate the alarm. Usually an array of infrared beam at strategic positions to form a fence prevents an intruder from passing undetected by the system. The limitation of the infrared intrusion alarm system is that the infrared beams can easily be seen using night-vision goggles or infrared cameras [29].

An improved version is the passive infrared (PIR) motion sensor. The PIR implements Pyroelectric materials which generates charges in response to change in temperature to detect any moving object within the field of view [30]. Usually there is a reference electrode on the PIR which determines the ambient temperature. Any approaching object within the field of view of the PIR will cause a change in temperature which is detected as a moving hot or cold spot and thus activates the intruder alarm. The sensitivity of the device is manipulated and programed to enable it detect only humans. All Pyroelectric materials are also piezoelectric, making them susceptible to mechanical vibrations which generate false alarms [31]. However, the fact that the circuit only becomes active when the PIR senses an object in motion reduces the power consumption of the entire circuit.

The ultrasonic sensor uses the change in the frequency of generated ultrasonic waves to detect an intruder [32]. The transmitter and receiver are located in the same chip in a configuration that enables any obstruction of the transmitted ultrasonic waves to alter the distance and transit time of the reflected waves which is then decoded by the receiver. The false alarm triggers can be reduced by using an array of ultrasonic sensors which are combined with And logic gate such that they can only detect objects about the size of human. The ultrasonic waves are sound waves which cannot be seen and so will be difficult for an intruder to identify the position of device unlike the infrared system. The fact that ultrasonic waves are not visible makes it the preferred choice for the developed intrusion detector system.

4.2. The novelty in the physical intrusion detector and intruder immobilizer system

The novelty of this product is in the ultrasonic sensor architecture deployed which eliminated the false alarms, the incorporation of an intruder immobilizer system, and the implementation of ultrasonic waves in the detection of an intruder. The positioning of the two ultrasonic sensors at dimensions to detect only objects with the size of human prevented the false alarms which is a major challenge with intrusion alarms. A more complex and expensive approach towards eliminating the false alarms is by combining the technology with a facial pattern recognition system. But the exposure and vulnerability to privacy invasions will be high and also the product may not be affordable for most people in low income countries of Africa.

The intruder immobilizer system makes it safe to apprehend an intruder. It is very dangerous to get in contact with an intruder since the person may be armed. Applying teargas to render the intruder immobile is safer for the occupants of the secured environment.

The choice of ultrasonic wave sensors for the detection of the intruder is also unique. Most intrusion alarm systems deploy PIR sensors which although is more sensitive but it delivers high levels of false alarms. Considering the implemented sensor architecture using two ultrasonic sensors, the developed device was effective and efficient in the detection of intruders.

4.2.1. The limitations of this research

The scope of this work does not cover the formation and health assessment of the impact of lachrymatory agents used for teargas. Teargas could be very harmful to health if consumed in high quantities at a very close range. It is therefore the recommendation of this study that more research should be done towards developing safer chemical agents in the most environmentally friendly manner to be deployed for the immobilizer system. Human manikin was used to validate the operation of the immobilizer system to ensure safety.

4.2.2. The immediate impact of this research

The immediate impact will be an upsurge in the number of users of the intrusion alarm system leading to a more secured environment that will further discourage crime. The incorporated intruder immobilizer unit in the intrusion alarm system will extend its application to intrusion prevention. Also, the increase in the demand for the product will create more market and returns on investment for all the stakeholders. There will be job creation along the supply and production chain.

Most people are discouraged from using intrusion alarm systems because of the various limitations such as; the possibility of privacy violations associated with the camera surveillance systems; the nuisance of frequent false alarms; the unavailability of a stable electric power source for the device; and the high cost of the available intrusion alarms making it unaffordable. The available intrusion alarm systems are unattractive, complex, and unreliable. This research product demonstrates superiority to the existing products by overcoming these limitations.

4.2.3. *Contributions of the present work*

This work combines Intrusion Detection System (IDS) with Intrusion Prevention System (IPS), an aspect lacking in previously published literature on physical intrusion alarm systems. The developed intrusion system immobilizes any detected intruder making the intruder not harmful before apprehension. Also, the implemented strategy of determining the ideal positioning of the ultrasonic sensors prevented the false alarms.

Most advanced intrusion alarm technologies implement multiple sensor architecture which includes surveillance cameras, passive infrared sensors, microwave sensors and other sensors that function with Wi-Fi and internet facilities. Although the outcome appears effective, it presents significant drawbacks in vulnerability to hacking, reduced battery life, limited scalability, over reliance on power, and other challenges such as susceptibility to interference from other electronic appliances. Recent intrusion alarm systems incorporate voice control systems termed Alexa-enabled devices. Again they depend on security cameras. The issue of privacy violation is very critical with surveillance camera enabled methods for intrusion alarm. Security cameras offer surveillance capabilities such as remote monitoring and recording. The problem manifests if the recorded data is hacked or fraudulently intercepted and used against the people in the covered location [33–35]. The developed intrusion alarm system does not use cameras and does not rely on wifi or internet, it is very effective and efficient in operation and affordable for low income countries of Africa.

4.2.4. *Future work*

The next phase of this work is the development of the lachrymatory agent used for the immobilizer unit. The formation of the chemical, the health assessment, and the speed of dispersion of the agent with consideration to the concentration to room space volume ratio, are the projected components of the next phase.

5. Conclusion

A physical intrusion detector and intruder immobilizer system has been developed to meet the current limitations of the existing technology of intrusion alarm systems with a focus on making it affordable for low income countries of Sub-Saharan Africa. The global dwindling economy associated with the climate change and post Covid-19 pandemic have created a surge in crimes especially burglaries [36]. The development of effective security monitoring devices will not only combat crime but also discourage it.

In this research work, care was taken to deliberately and intentionally adopt the following design approach; minimize the number of implemented electronic components to optimize electric power consumption and cost, eliminate dependence on internet and telecommunication to enhance reliability of the device and make it functional even with unstable network, and then to strategically implement a very simple and efficient sensor architecture affordable for low income countries of Africa where there is lack of advanced facilities and repair outlets to support state of the art technologies. Most of the advanced intrusion alarm systems deploy security cameras which are considered highly invasive to the privacy of the people within the coverage area.

The physical intrusion detector and intruder immobilizer is very marketable because of its unique features of immobilizing the intruder enabling the person to be easily apprehended. There is a huge market for intrusion alarm systems in Africa [37]. Investing in the commercialization of the developed innovative product will create excellent return on investment for all the stakeholders considering the enormous market in Africa and the very low cost of the device.

CRediT authorship contribution statement

Uzoma Ifeanyi Oduah: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daniel Oluwole:** Writing – review & editing, Writing – original draft, Validation, Software, Resources, Formal analysis, Data curation. **Samuel Olamilekan Johnson:** Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation.

Additional information

The microcontroller source code and any other information can be obtained from the corresponding author via email.

Data availability

All data generated are included in the paper.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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