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Pyro-Electric Infrared Sensor-Based Intrusion Detection and Reporting System

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ABSTRACT

Mitigating the incidence of burglary, kidnapping and armed robbery in every society is a serious concern world-wide today. Adequate and prompt information about unlawful entry into places of special interest are required in order to effectively safeguard lives and valuable properties. The proposed intrusion detection system utilizes pyro-electric infra-red (PIR) sensor to detect unauthorised entry into an area or premises and thereafter communicate this to the security personnel via GSM module. The proposed design is built around a microcontroller which primarily performs the entire signal processing functions. The developed system is found to produce good results, with 6m and 1cm, as maximum and minimum detection distance respectively for 110° and 70° sectorial detection range. The minimum and maximum timeout for the buzzer are measured to be 2.5 and 250 seconds respectively. Improved security is ensured in areas where the device deployed.

Keywords: Intrusion, Detection, Infrared, GSM module, PIR sensor

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1. INTRODUCTION

Intrusion system is a security system designed to detect unauthorized entry into a building or premises. Some security systems serve a single purpose such as burglary protection; combination systems provide both fire and intrusion protection. Intrusion alarm systems range from small, self-contained noisemakers, to complicated, multi-area systems with computer monitoring and control. Motion sensors constitute an important part of most intrusion systems, which help in alerting security personnel, especially in situations where no obvious break-in has occurred. Motion sensors/detectors are electronic devices that sense movement and thereafter trigger an alarm. Many of these sensors operate in total darkness, without an intruder becoming aware that an alarm has been triggered. Motion sensors are usually employed to protect indoor areas, where the conditions can be more closely controlled [1].

Basically, three technologies are used in practice for motion detection; they are Passive InfraRed (PIR), ultrasonic and audible. Both ultrasonic and microwave sensors detect in a similar manner and they do not require a direct line of sight of a motion source like PIR sensors. They will however detect a slight movement which can lead to false and nuisance tripping, such as a draught moving a piece of paper or movement beyond a glass partition, window or door [2]. PIR sensors have been widely applied for various applications especially in the building of smart environments, such as healthcare, smart energy system and security.

In [1], an occupancy and indoor environment quality sensing method is presented. The method is based on a suite of sensors which employs PIR sensor. In addition, as a way of reducing the standby power consumption of lighting devices, an ambient light sensor and lighting duration modules based on a PIR sensor, has been demonstrated [3]. Many researchers have devoted great deal of efforts to developing localized technology for indoor human tracking using PIR sensors. These include development of motion tracking system capable of detecting human motion in one of the 15 cells in a 1.6 square metre area using four PIR detectors [4], and human tracking device utilizing cluster of PIR sensors and Fresnel lens arrays [5]. In [5], three-dimensional simulation of human tracking based on the binary output of the PIR sensors is demonstrated.

Recently, Sun *et al*. [6] propose an identification system that is based on binary PIR sensor network for multi-target and complex scenario identification. Most of the previous research into human identification using PIR sensor exploited the digital on-off output signals of PIR sensors with visibility modulation while the analog output signals of PIR is not used. Moreover, it is worth investigating, the suitability of analog output signals of PIR sensors for identifying subjects, as in the research on classifying the walking direction, speed and the distance of the body from the sensor.

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To the best of our knowledge, there is no published literature investigating human identification based on the analog output signals of PIR sensors and machine learning algorithms. This capability of PIR sensor for occupancy and motion detection provided the motivation for its use in this work for detection of intruder in a restricted area. The main objective of this work is to develop a PIR-based intrusion detecting and reporting system, which is suitable for deployment in homes, offices, laboratories, industries and any other places of interest that need to be monitored for unauthorized access. The device works through sensing of black body radiation and triggers alarm when intruder is detected and at the same time sends pre-defined short message through GSM network to a pre-defined phone number.

2. PROBLEM STATEMENT

Lack of a proper security system in homes and offices often results in loss of lives and property. As a means of safeguarding against theft, crime, fire, etc. a powerful security system is required not only to detect but also pre-empt hazards. Considering the inadequate security measures put in place by the government in our society, it is found to be extremely difficult to curb crimes to the barest level, without the use of security system, put in place privately by individuals in their places of interest. Setting up a good security system involving Closed Circuit Television (CCTV) requires huge investment. This is usually not within the reach of average individuals and the need for effective security measures cannot be over-emphasized. Attempt to saddle a middle course motivates this work to develop a low cost but effective intrusion detecting and reporting system that utilizes a PIR sensor and existing GSM infrastructures.

3. MATERIALS AND METHOD

The simple block diagram of the developed PIR-based intrusion detection and reporting system is shown in the Fig. 1. The proposed intrusion detecting and reporting system has the following units: PIR sensor, power supply unit, control unit, GSM module, alarm unit and mobile station. The design exercise involves two phases: hardware and software phases. The former is concerned with the design and selection of needed hardware and electronic components, while the latter involves writing instruction codes to the microcontroller, which drives the entire intrusion detecting and reporting system.

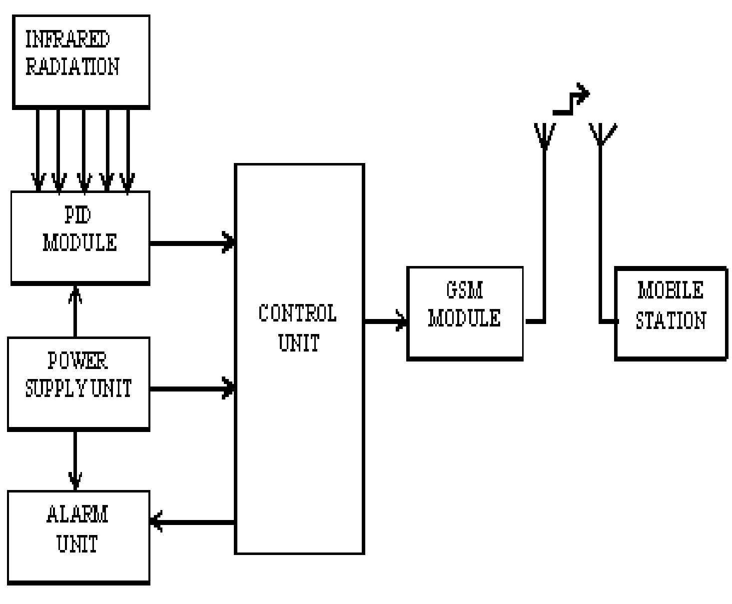

Fig. 1: Block diagram of the PIR-based intrusion detecting and reporting system

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3.1 Hardware Phase

Control unit: At heart of the developed intrusion detecting and reporting system is the control unit, which consists of PIC16F628A microcontroller as the master circuit and two other circuits – crystal oscillator and LM393 comparator- as slaves. PIC16F628A is an 18-pin, flash-based and 8-bit microcontroller. The following pins are utilized in the PIC16F628A while implementing this work: PIN 4 (V_{pp}) is used as the programming voltage input port, through which 5V dc is supplied to the microcontroller; PIN 7 (RX/DT), is employed as the port for data transmission between the microcontroller and the GSM module; PIN 8 (TX/CK), as the communication port between the PIC16F628A and the LM393 comparator; PIN 13 (RB7), as the alarm port; PINS 15 and 16 (CLKIN and CLKOUT PORTS) are ports where crystal oscillator input and output are connected; and PIN 17 (AN0) is the analog comparator input port, which receives analog signal from the PIR sensor in form of electrical voltage.

Crystal oscillator generates clock signal and provides frequency stability to the PIC16F628A microcontroller. As earlier stated, crystal oscillator terminals are connected to the PIN 15 and PIN 16 of the micro controller to drive the device. Two capacitors C_1 and C_2, constitute the load capacitance of the crystal and for smoothening of the clock pulses. Generally, the load capacitance, stray capacitance and smoothening capacitance are related by:

$$C_L = \frac{C_1 C_2}{C_1 + C_2} + C_s \qquad (1)$$

C_L is the optimum load capacitance for a given crystal as specified by the crystal oscillator manufacturer. C_S is the stray capacitance on the printed board circuit; typically a value of 5.5pF is specified [7].

Suppose $C_1 = C_2$, equation (1) reduces to

$$C_L = 0.5C_1 + C_s \qquad (2)$$

with $C_L = 22pF$ and $C_s = 5.5pF$, as specified [7], the value of $C_1 = 33pF$.

LM393, a dual comparator, which consists of two independent voltage comparators, designed to operate from a single power supply over a wide range of voltage is employed in the design. This is due to the need for data transformation between the PIC16F628A operating voltage range and that of GSM modem. The voltage range of GSM modem is between 0 to 3V while that of PIC16F628A is from 0 to 5V.

Sensor: The sensor has to be physically compatible with its intended applications. There are few factors for considerations while selecting a sensor [8], [9]. They include operating range, which is concerned with maintaining the range requirement and good resolution, sensitivity level to allow sufficient output signal, frequency response which must be flat over the entire desired range, environment compatibility (which involves temperature, corrosive fluids and pressure, shocks, interaction, size and mounting restrictions), ruggedness and electrical parameters.

According to Stefan-Boltzmann law, the relationship between the temperature of the sensor surface T_s and that of object T_O within the sensor's field of view is given by

$$T_O = \sqrt[4]{\left(T_s^4 - \frac{P}{\sigma A e_O e_S}\right)} \qquad (3)$$

Where
P is the net power radiated by the object, A is the area, e_O and e_S are the emissivity of the object and the sensor, respectively, and $\sigma = 5.669 \times 10^{-8} Wm^{-2}K^{-4}$ is the Stefan-Boltzmann constant.

A PIR sensor is employed in this work. Most PIR modules come with three-pin connections at the side or bottom; these are the 'V_{cc}', 'OUT', and 'GROUND'. The major task here involves the setting and configuration of the module to suit the desire application. The PIR sensor can be configured to work in non-triggering mode or re-triggering mode. The mode configuration is realised via the use of jumper, on the upper edge of the PIR sensor [10]. If the jumper is set to L-position, the PIR works in non-triggering mode while re-triggering mode is achieved when the jumper is at H-position. The implication of the mode selection has a significant effect on the operation of the buzzer. When the jumper is set on H-position, the buzzer is sound continuously once triggered while it operates intermittently when the jumper is at L-position. For the purpose of this work the PIR module is configured to operate in re-triggering mode.

In addition to that, sensitivity and the timeout of the PIR sensor are equally configured. Two potentiometers are provided in PIR module for calibration of timeout and sensitivity level. These potentiometers are labelled in Fig. 2; one is marked TX for time and the other, SX for sensitivity. The potentiometer identify as SX facilitates the adjustment of sensitivity of the sensor as application demands. The value of timeout T_{out} determines how long the buzzer sounds to alert the neighbour following detection of movement. This is easily adjusted via use of the potentiometer label as TX

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GSM Module: The GSM module accepts GSM network operator Subscriber Identity Module (SIM) card and functions like a mobile station having its own unique phone number [11]. With the use of GSM module, varieties of embedded applications such as SMS control, data transfer, remote control and logging are easily developed. The GSM module utilizes in this work is built around the dual band 900/1800MHz cellular engine. The GSM module interface operates on the Universal Synchronous Asynchronous Receiver Transmitter (USART), which is also known as a Serial Communications Interface (SCI). The USART is configured to operate in full duplex asynchronous mode at a baud rate of 115.2kbps. The antenna has the following specifications: frequency 890-910 MHz for transmits (TR); 935-960MHz for receive (RX), impedance of 50Ω, voltage standing wave ratio (VSWR) of 1.7:1 (TR), 1.9:1 (RX) and 1W carrier wave power.

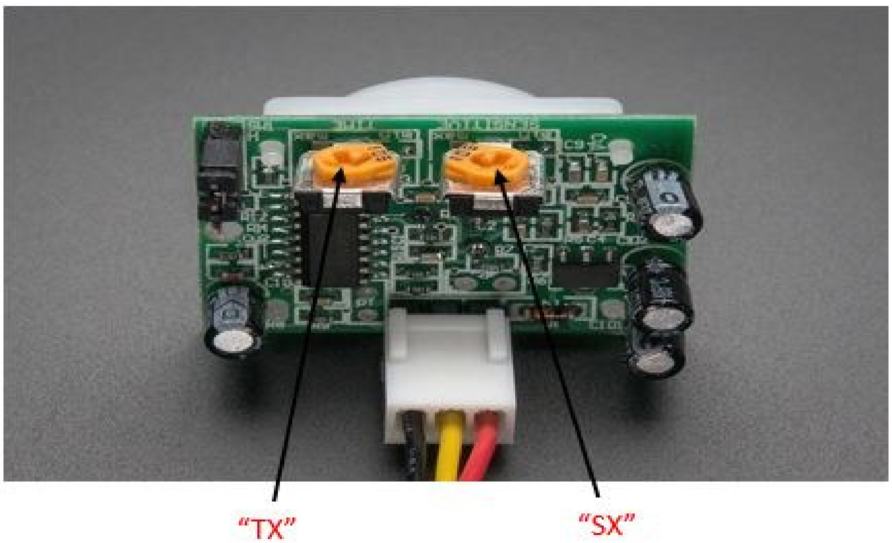

Fig. 2: Potentiometers for timing and sensitivity adjustments in PIR module

Alarm unit: This is a generic name for the device, which gives audible, visual or other forms of signal to alert and create awareness about a problem or an abnormality. In this work, a buzzer is employed to alert the occupant or neighbours, when there is an event of intrusion or unauthorized movement. When power ON the proposed intrusion detecting and reporting system, the PIR sensor takes 60 seconds to initialise and stabilize its temperature to that of the environment i.e. its field of view. Then it beeps to indicate that it is ready and operational. *Power supply unit*: The entire intrusion detection and reporting system is powered by a 5V dc source. This is readily available in modular form.

3.2 Software Phase

The software phase involves programming of the PIC16F628A microcontroller. The firmware of PIC16F628A is developed in assembly language and compiled using MPLAB assembler.

Fig. 3 illustrates the complete circuit diagram of the developed PIR-based intrusion detecting and reporting system.

3.3 Implementation

The developed PIR-based intrusion detecting and reporting system is implemented by assembling components in line with the circuit diagram presented in Fig. 3. The PIC16F628A has the written assembly code firmware assembled on it via the use of MPLAB. The entire construction is powered by a 5V dc source.

The various views of the completed developed system are shown in Fig. 4.

3.4 Operation principle

When power on, the intrusion detecting and reporting system takes about 60 seconds for the PIR sensor to stabilize itself to the temperature of the environment. When this is done, the system signifies with a beep sound. In the event that a radiating objects, be it human-being or animal passes in front of the location where the intrusion detecting and reporting system is deployed, a sudden change in temperature is detected by the PIR sensor. This is due to the black body radiation releases by human-being or animal, which manifests in the form of voltage difference in the PIR sensor ports. This voltage difference signal is communicated to the PIR sensor to the PIC16F28A through pin 17.

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The microcontroller triggers alarm, after processing the received signal from the PIR sensor, through its pin 13. The buzzer continues to sound as long as the object is within the field view of the PIR sensor. If the object leaves immediately after the alarm begins to sound, the alarm stops. This causes the intrusion detecting and reporting system to reset and wait for another 60 seconds. In the event of having an object in a stationary position within the field of view of the PIR sensor for more than 10 seconds, PIC16F28A unit sends a predefined message, 'Intruder Detected', through its pin 7 at a baud rate of 115.2kb/s to the RXD pin of the GSM module as well as a predefined recipient's telephone number. The GSM module uses this information to establish communication between the predefined recipient mobile phone and the developed system via the SIM card in the GSM module.

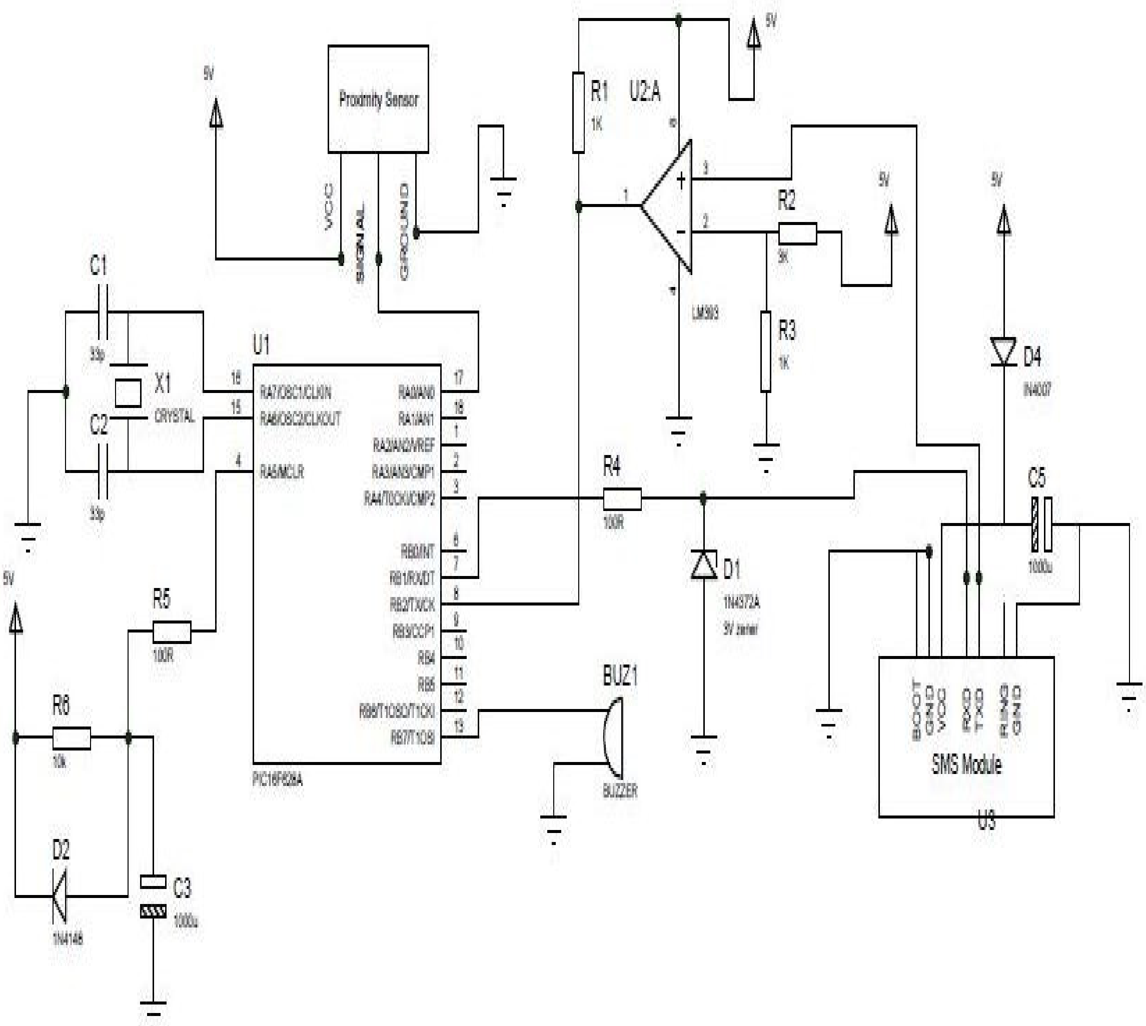

Fig. 3: Overall schematic diagram of the PIR-based intrusion alarm system

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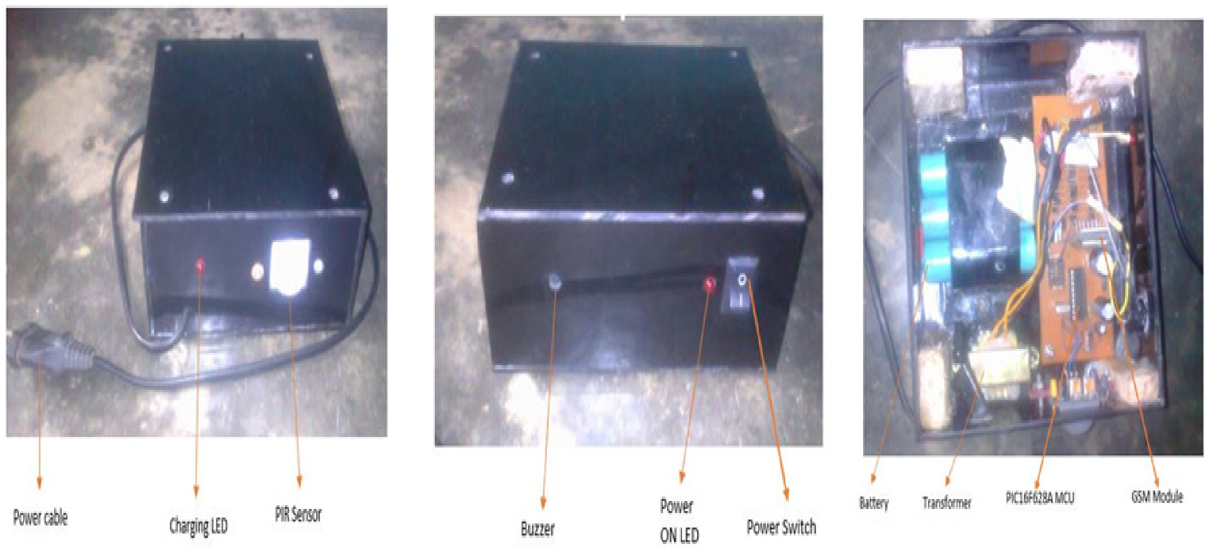

(a) (b) (c)

Fig. 4: Different views of the PIR-based intrusion detecting system (a) front (b) side (c) plain

4. TESTS AND DISCUSSION

Four different tests are carried out on the developed intrusion detecting and reporting system to ascertain its level of compliance with the design objectives. *Minimum and maximum distance detection test*: After the implementation, the minimum and maximum ranges for detection are determined. This is done by adjusting the sensitivity knob "SX" in the PIR module. It is established that the maximum distance for detection is 6m for $110^o \times 70^o$ sector (with respect to the horizontal plane) detection range. This occurs when the knob of the SX is completely turned counter-clockwisely, the position which corresponds to a resistance of 0Ω. On the other hand, when the knob is fully turned clockwisely, the minimum distance for detection is found to be 1cm away from the PIR sensor, corresponding to a resistance of 1MΩ on the potentiometer. Furthermore, the timeout for the buzzer, when it is triggered, is also determined using the knob TX. It is established that 2.5 seconds and 250 seconds, respectively, are the minimum and maximum timeout for the buzzer.

Detection test: The test is carried out at Applied Electricity Laboratory, Federal University of Agriculture, Abeokuta. The developed intrusion detecting and reporting system is deployed in one corner adjacent to main entrance of the laboratory. A full grown up man is ushered into the field of view of the sensor. After 10 seconds has elapsed, the buzzer is activated and sounds alarm. The sound is continuous for as long as the subject is still within the field of view of the PIR sensor. At about 33 seconds short message 'INTRUDER DETECTED' is received on the pre-defined phone number in the microcontroller.

Alarm test: The alarm time duration test is carried out on the developed device after the construction. The intrusion detecting system stabilizes the temperature of its sensor to that of the environment, with a beep as indicator of the system readiness on power ON.

Three individuals and a dog are involved. In each case, as soon as the sensor observed a temperature difference in the environment; this variation is sent to the microcontroller as voltage input for appropriate signal processing. Consequently, the alarm is triggered ON when any black body radiating object has stayed within field of view of the sensor for 10 seconds. It is established via the conducted test that the time to trigger of the developed device 10 seconds.

Message delivery and delivery time test: Though, it is a function of the quality of service provided by the telecom service operator's network, it is vital to ascertain which of the operator offers better services in the area where the intrusion alarm system is to be deployed. The ability of the GSM module to send short message to a predefined phone number is demonstrated.

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The test is conducted at the Electronic Laboratory of the Federal University of Agriculture, Abeokuta. The developed intrusion system is mounted as done for human and pet detection test. Intrusion is initiated via ushering of a grown up man and later ushering of a dog.

The device responds in each case after 10 seconds by activating the buzzer to alert the neighbour as expected. Subsequently, the device through GSM module sends a short message "INTRUDER DETECTED" to a predefined phone number.

Through this test it is found that the developed device is able to communicate effectively with the pre-defined phone number i.e. relay the information from the signal processing module of the PIR-based intrusion detecting system to a pre-defined user phone number. The time taken by different communication networks to deliver the sent message is also recorded. The SIM card in the GSM modem is changed in turn while carrying out this test. The duration of each test is a function of the time taken for message delivery. The readings obtained for three different networks out of the four available in FUNAAB are presented in Table 1.

Table 1: Delivery time of short messages sent by GSM module

Network Provider	Delivery Time (s)	Average delivery time (s)
A	10.05 8.17 10.50	9.57
B	8.51 50.00 48.00	35.5
C	60.00 40.75 40.91	47.22

It can be inferred from Table 1 that, as at the time of conducting the message delivery time test on the proposed intrusion detecting and reporting system in FUNAAB permanent site, the communication network A performed better than the other two. The implication of this result is that periodically, the user should check and ascertain the average message delivery time in order to decide the preferred SIM card to be inserted in the GSM module.

5. CONCLUSION AND FUTURE WORK

In this work, a PIR-based intrusion detection and reporting system using GSM module is developed. The developed system works by sensing the intruder heat radiation and converting such radiation into electrical signal for the microcontroller to act on. A PIR sensor does the heat sensing and conversion into electrical signal. This electrical signal constitutes the input required by the microcontroller to trigger the alarm and also activate the GSM module to send a short message to a pre-defined mobile number programmed in the microcontroller. The developed system has maximum and minimum detection distance of 6m and 1cm, respectively, within the sectorial coverage of 110° x 70° (sector with respect to horizontal plane). In the event that the alarm is triggered, 2.5 and 250 seconds, respectively, are the minimum and maximum timeout for the buzzer. This timeout is adjustable via the use of provided potentiometer in the PIR module. The developed device has the potential of checking the menace of burglars and improvement in the security of the areas where it is deployed. Array of PIR sensors can be used in order to eliminate the issue of 'dead-spots' that is possible with a single sensor element deployment. In addition, there is need to extend the sensing range of the device to enhance performance. Furthermore, the device can also be configured for smoke and fire detection as the radiation from flame can be easily detected by PIR sensor.

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