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# Enhancing Home Protection System Using FPGA

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**ABSTRACT**

With the rapid growth of technology and the growing popularity of smart homes, it is critical to implement solid security measures. This paper presents an approach to enhance home protection by designing and implementing a Smart Home Security Access System using FPGA. The proposed systems incorporate a range of security elements to ensure household safety such as user authentication, access control and using variety of sensors. Smart home security access systems provide enhanced security solutions to address issues such as theft, intrusion, gas leakage and potential fire incidents. Consequently, this project aims to design and construct a smart system the incorporates a digital security entry for automatic door locking. The systems feature a magnetic door lock system at the entrance, PIR motion sensor to detect irregular movement, temperature sensor to measure high temperature within the house as well as gas sensor to detect the presence and concentration of hazardous gases and vapors. These sensors are connected through Arduino Uno and transmit through analog signals to DE-115 FPGA Board. The process data is then displayed on LED at FPGA and Seven Segment Display as an indication status of the password entered and the condition of the sensors.

## 1. Introduction

The increasing threats of burglary and theft in recent years, along with the vulnerabilities of traditional security systems have made smart home security products more popular [1]. The rise of smart home technology which incorporates integrated digital systems like FPGAs, has opened extensive possibilities for various applications. FPGAs offer significant potential in developing fully functional and reliable smart home products, driven by innovation and market demand.

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Statistical reviews have shown that houses without security systems are more prone to break-ins compared to those equipped with security alarms [2]. These cases clearly demonstrate the effectiveness of security systems in reducing intrusion incidents. Consequently, it has become imperative to develop and enhance existing security systems with smart technology to safeguard people, residents, and their properties [3].

Many traditional security systems have limited surveillance coverage, leaving blind spots where potential intruders can go undetected. This poses a significant risk, especially in peaceful neighborhoods with spacious gardens and private surroundings that may attract burglars [4]. Burglars often exploit obvious flaws in residential security, such as dim lighting, overgrown plants that can be used for cover, and unsecured doors and windows [5]. It is crucial to address this limitation strategically by placing the sensors to ensure doors and windows are securely locked and add an additional layer of protection. The protection can be automatic lock for doors and automatic lights at the windows when the abnormal motion presence at abnormal time at dim and targeted place.

Traditional security systems can be enhanced with smart fire detection and prevention features. Dangerous gas detectors and heat sensors can be integrated into the system to provide early warnings of fire hazards. When triggered, the system can automatically alert homeowners and emergency services, while also activating measures to prevent the spread of fire, such as shutting off electrical appliances and activating fire suppression systems [6]. Carbon monoxide can be dangerous gases produced by malfunctioning or improperly vented combustion appliances such as furnaces, boilers, water heaters, gas stoves, and fireplaces. If these home appliances do not receive enough oxygen for complete combustion or if there is a problem with the exhaust venting, carbon monoxide can be released into the surrounding air that has an impact on health condition [7].

Beyond intruders and disasters, conventional security may not provide early warnings for various hazards due to the delays and not real time [8]. By implementing smart home protection systems, residents can take necessary precautions to protect their property and loved ones. Early warning systems can also detect environmental factors like gas leaks or fire disasters, providing timely alerts and preventing further damage [9].

Smart home systems available in the market nowadays are expensive and high maintenance. Therefore, Arduino and FPGA are used to resolve these problems. Arduino has low power consumption and an easily programable interface compared to another microcontroller. It is relatively cheap components and supports basic analogue circuit interface [10], [11]. The fundamental advantage of an FPGA over the same discrete circuit or Application Specific Integrated Circuit (ASIC) is the ability to readily modify its functionality once a product has been created.

This project combines security features using Arduino sensors and the DE 2-115 FPGA Board. It detects door security, irregular motion, and fire incidents in a smart home. If any input is detected, the sensor activates an alert for the owner and nearby individuals. The ALTERA DE 2-115 Board displays affected inputs on the seven-segment display, allowing the owner to identify the issue and seek assistance without exposing themselves to danger.

## 2. Theorical background

Home protection systems use a combination of hardware, software, and communication technologies to provide real-time surveillance, alerts, and response mechanisms for home safety. FPGA can indeed be a crucial component in a smart home security system. FPGA are versatile integrated circuits that can be programmed to perform specific tasks, making them valuable for implementing various functionalities in security systems, including access control, monitoring, and data processing. To ensure reliable and secure operation, home security protection systems often use encryption algorithms to protect sensitive information and communications, where FPGA can be

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used to implement these algorithms which providing high performance and low power consumption compared to microcontroller-based solutions.

In these scenarios, the system potentially emits an alert and notifies the user. Maximizing home security can reduce the effort, time, and electrical power required to support children and the elderly at home [16]. When a sensor activates, the buzzer warns of home danger. If intruders are spotted, siren alarms make a loud sound and flashlights to alert homeowners and the neighborhoods [21]. Faulty electrical systems, careless smoking, and cooking equipment contribute to fires [22]. To detect these, sensors for high temperature (usually set at 58°c) and carbon monoxide gas are employed. Recent improvements allow detectors to activate at a lower temperature (47°c), providing more time to evacuate [23]. Gas detectors measure the concentration of carbon monoxide in the environment.

Carbon monoxide (CO) is a fatal, colorless, and odorless gas that can affect health. Symptoms, such as headache, exhaustion, and vomiting, become more obvious when CO levels rise and stay over 70 ppm. At 100 ppm, within 90 minutes or fewer, gas detectors must emit a full alarm to alert the owner that high concentration of CO happen to avoid disorientation, paralysis, and death are all conceivable with prolonged CO concentrations [24]. To make it as a home with smart high security system, the motion sensor and temperature sensor are used. PIR Motion sensor used to detect the movement around the house even in dim light. While temperature sensor detects high temperature upper than 47°C. Hence, a password-protected door lock system is also used to make the house more secure. In this project, a smart home security system will be constructed using FPGA using Verilog HDL. FPGA is now commonly used nowadays due to its ability to fully functional toward the smart home product [12].

## 3. Methodology

In this project, the protection consist of three parts which are password-protection door security, motion detection outside the house, fire prevention and gas leakage detection in the house as shown in Figure 1.

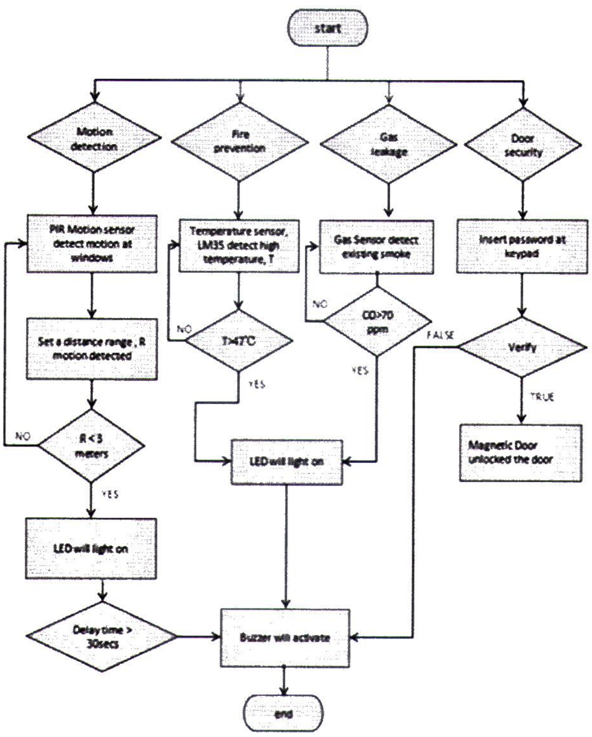


Figure 1: Flowchart of the sensors at the Arduino

Motion detection utilizes PIR Motion Sensors, LED lights, and a buzzer to identify the presence of an intruder near windows. When the PIR motion sensor detects human movement beyond a range of 7 meters, it indicates a normal condition, and therefore the LED lights and buzzer remain inactive. However, if the PIR motion sensor detects movement within a range less than 3 meters, the LED lights activate to inform the household of human presence. The buzzer also turns on if the PIR sensor remains activated for more than 30 seconds, warning the intruder to leave the window.

Fire prevention involves the use of a temperature sensor and a buzzer to monitor the temperature. If the temperature sensor detects a high temperature exceeding 47°C, the LED lights and buzzer activate to alert the user of a fire inside the house. To detect gas leakage from home equipment, a gas sensor and buzzer are employed. When the gas sensor detects the presence of CO gas with a concentration of around 100 ppm in the surrounding environment, the LED lights and buzzer activate to notify the household, prompting them to take appropriate action. Door security is achieved through a keypad, magnetic door sensor, and a buzzer. The keypad allows the user to input a passcode to unlock the door. If the correct password is entered, the magnetic door sensor disengages the circuit connection, enabling the door to open. In the case of three consecutive incorrect password attempts, the magnetic door locks, and the buzzer activates, alerting the user to an attempted entry. The buzzer continues until the correct password is re-entered by the user.

Figure 2 presents a detailed block diagram illustrating the power supply configuration for the FPGA Board. The main objective of this board is to effectively compute and process signals that traverse from the input to the output stages. Within this system, the input signal originates from sensors connected to the Arduino microcontroller.

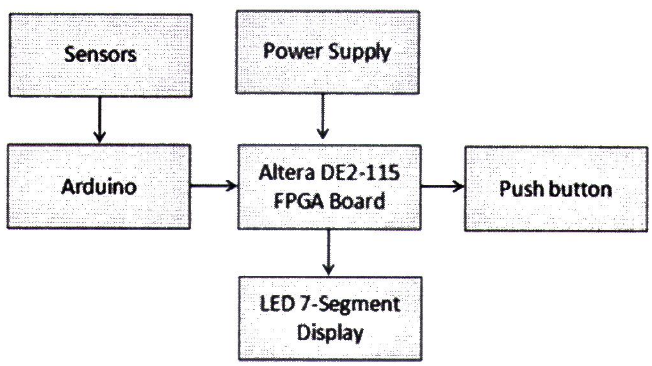


Figure 2: Block diagram from arduino uno to the FPGA board

The signal processing process begins with the input stage, where all the sensors relate to the Arduino to capture essential data. Then, the input signal in this system is collected through sensors attached to the Arduino. The output signal was then transmitted towards LED 7 segment display and LED red at the FPGA board. Furthermore, the FPGA Board includes a push button that functions as a switch, allowing the user to perform a reset operation. When the push button is pressed, a command is issued to reset all linked sensors as well as the LED 7 segment display.

Figure 4 shows a modelling project of the Arduino Uno board, aimed at demonstrating the connection of various sensors to the board's different pins. The Arduino Uno provides a range of pins that support digital and analog inputs, serial interface and PWM (Pulse Width Modulation) outputs, allowing for versatile sensor integration. The architecture of modelling design in the figure has been simulated using Thinkercad, a freely available software.

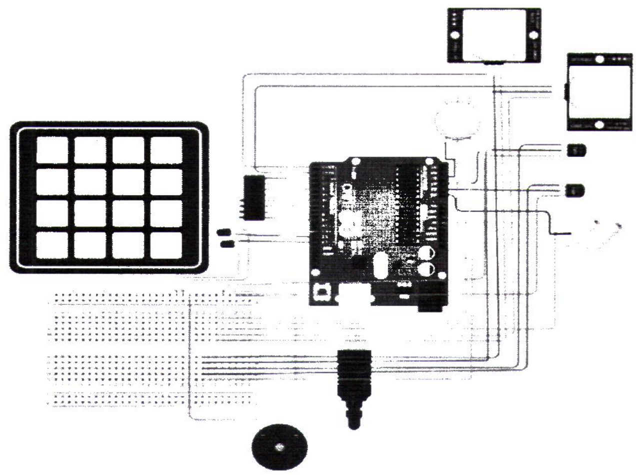

Figure 3: Thinkercad simulation at the arduino uno

## 3. Results

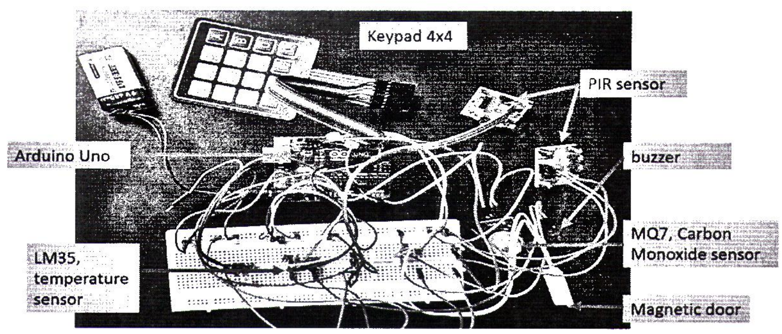


Figure 4: Home protection system at Arduino.

Figure 5 represents the connections of various sensors to the Arduino. These sensors include a keypad, PIR motion sensor, temperature sensor (LM35), and carbon monoxide sensor. Additionally, there are output sensors such as a buzzer, LED, and a magnetic lock door connected to the Arduino Uno.

The keypad is a 4x4 keypad and is connected to the Arduino Uno using digital pins. The keypad serves as an input device that allows the user to enter a password that has been set. The Arduino Uno reads the keystrokes from the keypad connected to the designated digital pins. This input can be used for security purposes to enter an access code or performing specific actions based on the keypad inputs password. On the other hand, magnetic door serves as an output device for the keypad. Its main function is to secure or release access to a door or gate based on control signals received from the Arduino Uno.

PIR motion sensor detects motion within its range. When it senses any movement, it sends a signal to the Arduino. By connecting LEDs to input pins, the board can control the illumination of these LEDs based on the signals received from the PIR motion sensor. When motion is detected, the Arduino Uno activates the LEDs, causing them to turn on, providing a visible indication of the detected motion and enabling security-related actions. LM35 temperature sensor is used to measure the temperature of the environment it is placed in. It generates an analog output signal that is proportional to the temperature reading. When the temperature exceeds 47°C, the Arduino Uno activates the output sensor. As a result, the buzzer starts producing sound, thereby alerting the residents to indicate the presence of a high temperature condition.

The carbon monoxide sensor, MQ7 is connected to the input pin allowing the board to receive voltage readings corresponding to the detected carbon monoxide concentration. When the carbon monoxide concentration surpasses a certain threshold or reaches a dangerous level which is upper than 100ppm, the Arduino Uno can activate the buzzer to generate an audible alarm or alert. This serves as a warning to the residents or users of the system about the presence of high levels of carbon monoxide, enabling them to take necessary precautions or evacuate the area if required.

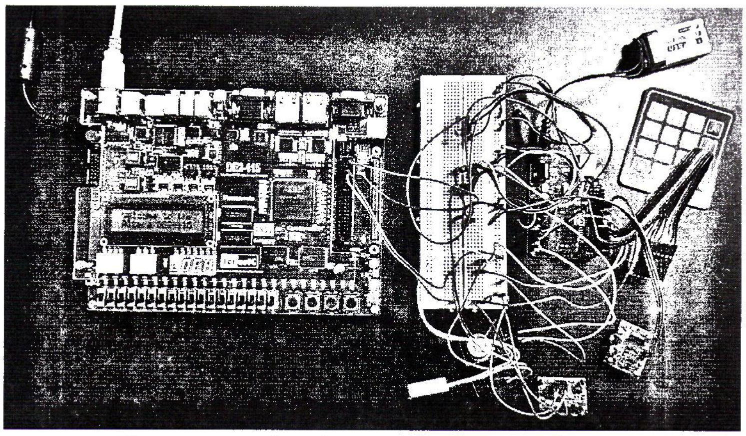

Figure 5: Interface between Arduino and FPGA

Figure 6 shows a complete interface between Arduino and the FPGA for home protection system. This interface facilitates the connection of output sensors from the Arduino to the GPIO (General Purpose Input/Output) on the DE2-115 board. The output sensors from the Arduino Uno are represented by their respective pins. These output sensors can include devices such as the magnetic lock door, PIR motion sensor, temperature sensor, and carbon monoxide sensor. Each of these sensors has specific pins on the Arduino Uno to control their functionality.

The system monitors various parameters, including high temperature, carbon monoxide concentration, abnormal motion presence, and the security lock door. The output signals indicate the status of these parameters and are represented by the activation of specific LEDs on the board. To monitor the temperature, the LM35 temperature sensor connected to the Arduino Uno detects the temperature level in its surroundings. When the temperature exceeds 47°C, the output signal is sent to the FPGA board to activate LED at the FPGA, visually indicating the presence of high temperature. Similarly, the system also monitors the concentration of carbon monoxide in the surrounding environment. If the carbon monoxide level exceeds 100 parts per million (ppm), the output signal is sent to the FPGA board. In response, LED red lights from 4 to LED red 7 are activated, providing a clear indication of the high carbon monoxide concentration. The smart home security system is further equipped with a PIR motion sensor to detect any abnormal motion. When the motion sensor detects any unusual movement, it triggers an output signal that is received by the FPGA board. As a result, LED red lights from 8 to LED red 11 are activated, indicating the presence of abnormal motion.

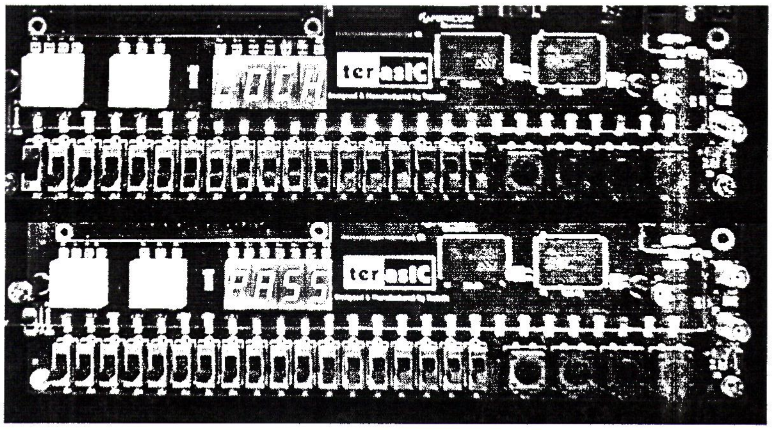

Figure 6: Result at the DE2-115 board

To monitor security lock door, it will display on the LED 7-segment as "LOCK" or "PASS" as shown in Figure 7. When a user enters an incorrect password on the keypad, the LED 7-segment display will continuously show "LOCK". This indicates that the door remains locked due to the erroneous password input. The continuous display of "LOCK" serves as a reminder to the user that the correct password needs to be entered to gain access. On the other hand, when the user successfully enters the correct password on the keypad, the LED 7-segment display switches to show "PASS". This indicates that the door is now unlocked, allowing the user to gain access to the secured area.

## 4. Discussion

The analysis aims to evaluate the effectiveness and functionality of a smart home security system in addressing the concerns related to intruders and fire incidents. Figure 8 shows the simulation output from Quartus Prime lite which equivalent when downloaded into FPGA.

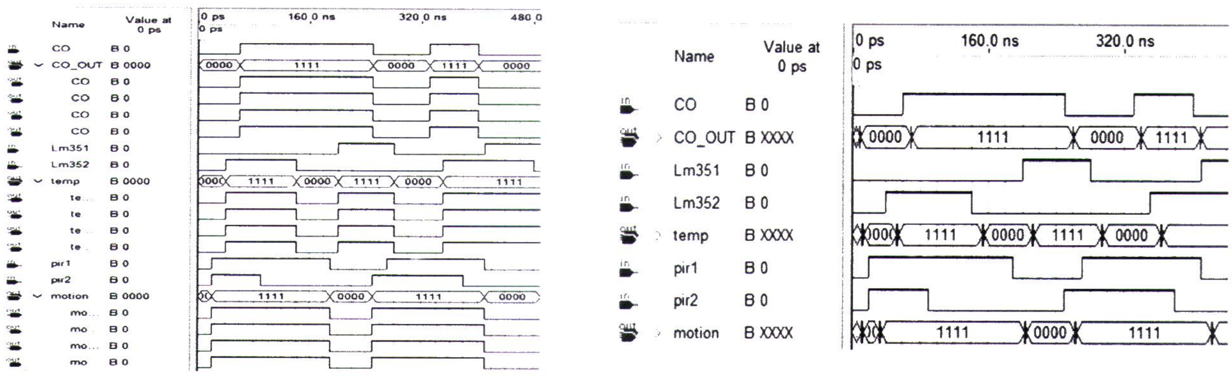


Figure 7:Output from Quartus Simulation.

The waveform captures the implementation of the FPGA in response to various inputs related to carbon monoxide detection, temperature sensing, and motion detection. For the input CO which is indicating as an input in detecting concentration of carbon monoxide in the surrounding, the output to show the changes at the carbon monoxide sensor. When input detecting is low, carbon monoxide not existence in the surrounding, output will be 0. Hence when the input is high which is carbon monoxide existing, the output will represent as 1. Moving on to the temperature sensor inputs, there are two signals denoted as LM351 and LM352. In conditions either one or both temperature sensors detect a high temperature, the output signal will be set to high. On the other hand, when both temperature sensors indicate a low temperature condition, the output signal will be set to low.

Lastly, for the motion sensor detection, the input signals pir1 and pir2 indicate the presence of abnormal motion in the sensed area. If either one or both motion sensors detect abnormal motion, the output signal will display 1. However, if there is no abnormal motion detected or both motion sensors indicate a low condition, the output signal will be set to 0. In FPGA board, even though there is delay but time taken to delay for the signals is nearly to real time due to the architecture and design of FPGAs, the delay incurred during signal propagation is significantly reduced compared to other computing platforms. This low delay ensures that the output of the FPGA can be generated quickly and efficiently, allowing for real-time processing of data. The ability of FPGAs to run in real-time is especially beneficial in applications that require rapid response and high-speed processing.

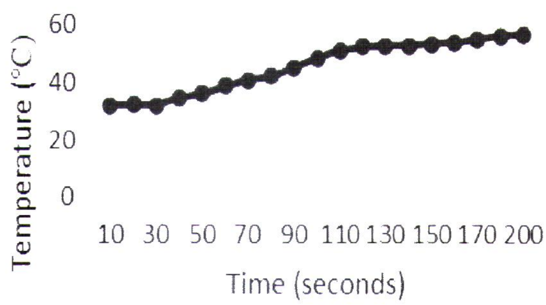


Figure 9:Graph about temperature with time

Figure 9 shows graph of the temperature with the time in seconds according to reading from the serial monitor. The temperature is observed increase linearly with time. This indicates that as time progresses, the temperature reading obtained from the LM35 temperature sensor rises steadily. The LM35 temperature sensor is designed to detect changes in temperature and provide corresponding readings. In this case, as the temperature changes in the surroundings, the LM35 sensor automatically senses these variations and outputs the temperature readings.

LM35 sensor requires less than 70 seconds to detect high temperature above the threshold value, 47°C to detect the presence of fire in the surrounding area. This implies that the sensor is sensitive enough to rapidly respond to significant increases in temperature associated with a fire event. Once the LM35 sensor detects such a change, it can promptly alert the residents or users. The instantly detection of a fire through the LM35 sensor allows residents to have more time to evacuate and escape from the house safely. By providing early warning, the sensor gives individuals valuable time to take necessary precautions and exit the premises, potentially minimizing the risk of harm or damage caused by the fire.

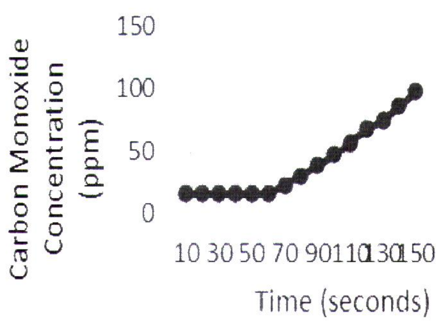


Figure 10: Graph about carbon monoxide concentration with time

Figure 10 shows the graph of the carbon monoxide (CO) concentration in the surrounding environment when there is a presence of this gas. The graph demonstrates that the carbon monoxide concentration increases rapidly when it is present. The graph begins with a baseline concentration of 16ppm, indicating the normal or background level of carbon monoxide in the environment. As time progresses, the graph shows a steep rise in the carbon monoxide concentration. Within less than 60 seconds, the concentration reaches a threshold value of 70ppm. This rapid increase suggests that there is a significant source of carbon monoxide nearby, potentially posing a danger to human health and safety. At this point, it is crucial for residents or individuals in the area to evacuate and seek fresh air immediately and implement appropriate safety measures.

The threshold value of the carbon monoxide concentration can be varied according to specific regulations, standards, and guidelines set by relevant organizations and authorities. Typically, it is recommended to evacuate the premises, ensure proper ventilation, and contact the relevant authorities or emergency services for assistance. Carbon monoxide is a toxic gas that is odourless and colourless, making it particularly dangerous as it can go undetected without proper monitoring.

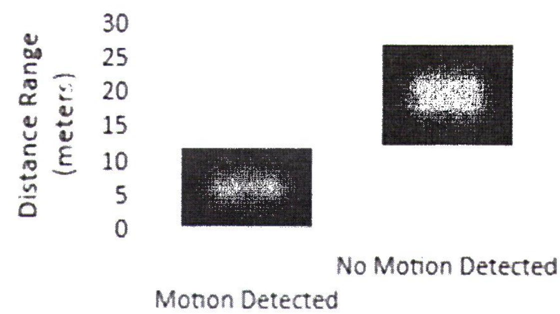


Figure 11: Graph of the PIR sensor in detecting distance range.

Figure 11 shows the graph of the pir motion sensor in detecting motion based on the distance. It operates based on the detection of changes in infrared radiation emitted by objects within its field of view. When an object moves within the detection range of the PIR sensor, it causes a change in the infrared radiation pattern and triggering the sensor to respond. From the graph, it can conclude that, the PIR motion sensor can reliably detect motion within a distance that is less than 12 meters. Therefore, when the distance exceeds 12 meters, the motion detection system may no longer reliably register or detect motion. This means that the sensor is optimized to detect movements occurring within a relatively short range. As an object moves closer to the PIR sensor within detecting area, the sensor detects the change in infrared radiation and responds by generating an output signal.

Once the PIR motion sensor detects motion that is considered abnormal or unexpected within its detection range, it sends a signal to the system controlling the output LED. This signal triggers the LED to turn on, creating a visible indication that something out of the ordinary has been detected. By utilizing the output LED as an alert mechanism, the residents are immediately made aware of the presence of abnormal motion and can make a response accordingly.

## 5. Conclusions

In this paper, an enhanced home protection system has been with a highly efficient cost-effective system. Integrating sensors that are interfaced with an FPGA increases efficiency in terms of its ability to change its functionality even after the design has been embedded. Through the integration of advanced technologies such as sensors, alarms, smart home security systems are capable for detecting and alerting users to potential threats. Motion sensors, door security mechanisms, and high-temperature sensors enable the system to detect intruders and fire hazards at an early stage. The activation of a siren alarm accompanied by flashing lights helps draw attention to the situation, both within the home and in the surrounding neighbourhood. Furthermore, the inclusion of a gas detector for carbon monoxide (CO) monitoring is essential in preventing health risks. By promptly detecting high CO concentrations, the system ensures timely evacuation and necessary precautions to avoid potential fatalities or health complications.

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