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Development of IoT-Based Home Security Monitoring and Management Systems to Support Smart City Ecosystems

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Abstract

The safety of the house and its contents is an essential need and must be maintained to avoid unwanted things. This is because of the increasing prevalence of criminal acts of theft in houses that their owners are abandoning. Along with the development of the times and the increase in technology, a home security device is needed to obtain accurate information, where homeowners can access and get reports about the house's condition in real-time. To overcome these problems, it is necessary to have a tool that can monitor the house's condition and inform the house's state at any time. The device used in designing this security system, namely the Esp32-Cam microcontroller, will automatically send photos to Telegram, and the buzzer alarm and LED flash will be turned on; if this thief gets closer to the front door of the house, then the ultrasonic waves will also be activated.

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A. Introduction

As population growth and urbanization increase, crime rates in some areas may increase. This includes theft, robbery, or other crimes in the home environment. The safety of the house and its contents is an essential need and must be maintained to avoid unwanted things when the homeowner leaves the house for a long time. Along with the development of the times and the increase in technology, a home security device is needed to obtain accurate information, where homeowners can access and get reports about the condition of the house in real-time and ease of access that does not interfere with the activities of homeowners in the event of theft. One of them is by applying the Internet of Things (IoT)-based Smarthome concept to the home. So, the Smarthome system will be needed for good home management, and many aspects are included. In addition to the safety aspect, the smartphone offers energy savings and complete control over what happens in the home. An Internet of Things (IoT)-based smart home used for home security will be beneficial for keeping an eye on people who will infiltrate the house when they escape surveillance [1].

To overcome these problems, it is necessary to have a tool that can monitor the house's condition and inform the house's state at any time. This research considers designing IoT-Based Smart City Prototype Design (Home Building Security Management Case Study). The device used in developing this security system is the Esp32-Cam microcontroller [2]. In that research, every captured image is sent continuously via telegram so that it becomes ineffective and also if an incident occurs, no alarm indicates there is a theft. For this reason, in this proposed system, there are some improvements from research that has been done in [2] by adding an alarm that can provide an early indication that a stranger has entered the house to be known by the surrounding neighbors. And also photo capture if recording objects captured by the camera is stored for use when investigative purposes of the authorities only. The manufacture of this theft detection device is equipped with an alarm system as a notification to provide a notification message by issuing a warning sound. This system also has an infrared (PIR) passive Sensor, which aims to detect humans in the house when the security system is activated. In addition, it uses the ultrasonic Sensor HC-SR04 to detect human distance.

B. Research Method

This research uses several stages, including literature review, system planning, system testing, and analysis and conclusions. The following are the stages of this research:

1. Literature Review

A literature study has been conducted by reading and understanding various journals and books related to this research. Some of the literature studied is related to home security issues and IoT devices used in devices, such as NodeMCU ESP32 Cam, sensors, and ultrasonic waves to detect movement and provide photo or image notifications on Telegram, to the literature on software development. The problems raised in this study and some solutions several researchers have offered are obtained from this preliminary study. Several studies have been carried out previously.

In 2022, Fauziah Fanny, Nadia Amalia Putri, Neha Poetri Setiawati, and Dwi Hartanti from the Department of Informatics Engineering, Duta Bangsa University conducted research on Microcontroller-Based Security Systems Using Infrared Motion Sensors (PIR) [3].

In 2021, Jhonny Hendra Cipta Pangaribuan, Indra Gunawan, Heru Satria T, Sumarno, Ika Okta Kirana from the Department of Informatics Engineering AMIK and STIKOM Tunas Bangsa Pematangsiantar conducted research on the Design of Anti-Theft Alarms for Motorized Vehicles in Parking Positions Using PIR (Passive Infrared) Sensors. Receiver) and Vibration Sensor Based on Arduino Uno R3 [4].

In 2023, Ardiansyah, Aldi Febryan, Adriani, and Rahmania from the Department of Electrical Engineering, Faculty of Engineering, Muhammadiyah University of Makassar conducted research on the Design and Development of a Telegram-Based Home Security System Using Esp 32 Cam [5].

2. System Planning

The system design involves several key steps:

Block Diagram System

The system planning in working on this research is done based on the diagram blocks that have been created, as shown in Figure 1 below:

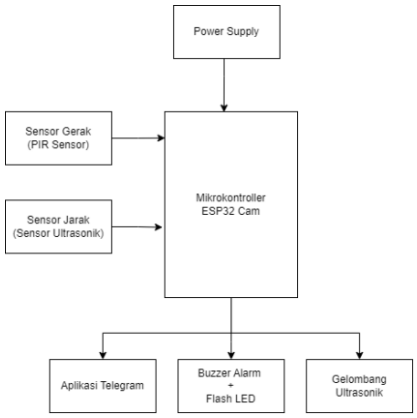

Figure 1. Block Diagram Illustration

Based on the block diagram above explaining the overall picture of the system made in this research, the PIR sensor block functions to detect movement in front of the house; the Sensor can read human movement if the distance from the Sensor is less than 7 meters towards the door. This aims to be the first information sent directly to the homeowner's cellphone via a telegram bot in the form of an image. With the output, there is a buzzer alarm sound if there is movement. Then, the block of the Ultrasonic Sensor (distance) functions to detect the distance between the criminal and the distance of house door; if it gets closer, the second output will be activated, namely the ultrasonic wave emitted by the PCT-4000 speaker, where the frequency will be set at a value of 8-10kHz. In addition to the third output ultrasonic wave, the very bright LED Flash will continue to flash if the perpetrator's position is still near the house door [6].

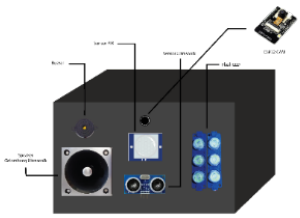

Figure 2. Prototype Hardware Design

In this research, a tool was made for the home building security system using PIR sensors, ultrasonic sensors, ESP32 Cams, and ultrasonic waves [7]. The monitoring system of this tool uses the NodeMCU ESP32 Cam as the data transmission and is displayed in the Telegram Bot application. The monitoring system of this tool is carried out automatically on the Arduino when there is movement in a house, and notifications are sent to the smartphone if there is a movement by sending messages and pictures of the situation in front of the house. The stages of making this tool are making a box system and electronic hardware for the monitoring system and creating a system connected to a telegram bot with the homeowner's smartphone.

3. System Testing

Tests were carried out to evaluate the performance of hardware components such as the PIR Sensor and HC-SR04 Ultrasonic Sensor. Testing also includes integrating Telegram Bots to ensure notifications and other functions operate correctly.

4. Analysis

Test results are analyzed to assess system performance, sensor detection accuracy, and notification speed in Bot Telegram. The conclusion is based on an analysis to evaluate the success of the designed prototype.

Table 1. Main Device Specifications Used

No	Identity	*Type*	*Main Specifications*
1	ESP 32 CAM	AI-Thinker	2MP Camera, Supports wifi 802.11 b/g/n, Bluetooth v4.2, GPIO, UART, SPI, ADC, SD card slot, Max Resolution: UXGA (1600x1200).
2	PIR sensors	HC-SR501	Voltage 3.3 VDC - 5 VDC, Dimensions 32.2 mm x 24.3 mm x 25.4 mm, Sensor Angle < 120 degrees.
3	Ultrasonic Sensor	HC-SR04	Voltage 5V DC, Static current < 2mA, Detectable distance 2cm – 450cm (4.5m)
4	Audio Generator	Ne555	Operating Voltage +5V to +18V, Source/Sink Current 200 mA, eight pins available.

5	Speaker PCT4000	Piezo-Electric Super Horn Tweeter	Continuous Peak Program Power 75 Watt, Efficiency 92 dB/1 Watt at 1 m, Frequency Response 3.000 Hz – 40.000 Hz.

C. Result and Discussion

After planning and manufacturing the tool, this research will have several tests. The test was carried out in several stages. The first test is carried out separately, followed by the test as a whole or an integrated system and the data transmission time test.

1. Ultrasonic Sensor Testing

Testing involves measuring distances using ultrasonic sensors at various distances, such as 10 cm, 20 cm, 30 cm, and more, verified with a manual measuring device to ensure accuracy. The stability and response speed of the system is tested by changing the distance quickly to see if the system can respond consistently and on time. The expected result is that the LED flash and ultrasonic waves are activated only at a distance of less than 30 cm and remain off if the distance is more significant, thus ensuring that the system functions according to the program already created [8].

Figure 3. Ultrasonic Sensor Testing

The following is a comparison table of the sensitivity of Ultrasonic sensors with digital meters:

Table 2. Testing of Ultrasonic Sensors with Digital Meters

Experiment to	Ultrasonic Sensor	Digital Meter
1	60 cm	62 cm
2	95 cm	96 cm
3	156 cm	157 cm
4	164 cm	166 cm
5	200 cm	202 cm
6	247 cm	244 cm

Based on experimental data, ultrasonic sensors show accurate measurement results compared to digital meters as a reference tool, with a small difference of

1 to 3 cm. In the first to fifth experiments, the Sensor consistently produced slightly lower values than the reference tool, while in the sixth experiment, the sensor measurement yield was higher. This relatively small difference indicates that ultrasonic sensors have good accuracy and precision for distance measurement. However, they are slightly affected by environmental factors such as measurement angle, object surface, or ambient conditions.

2. PIR Sensor Testing

PIR sensors generally have an effective reading range of up to 5 meters. Still, PIR sensors have a range of reading distances and angles that vary depending on the characteristics of the Sensor. Testing this Sensor to find out if it can work when detecting the presence of humans so that it can sound like a buzzer to maintain the state of the house. PIR sensors can work well and detect movement with an object distance of 2 meters from the Sensor. The following are the results of the PIR sensor distance test with human objects [9].

Table 3. Front PIR Sensor Distance Measurement

Data Retrieval to	Object sensor distance (Meters)	Buzzer State
1	0,5	Turn on
2	1	Turn on
3	1,5	Turn on
4	2	Turn on
5	8	It does not light up
6	9	It does not light up
7	10	It does not light up

From the results of the above measurements, it can be concluded that all directional parts of the PIR sensor can work well and detect movement with the object being as far away as 7 meters from the Sensor. This is shown by the response of the Buzzer that lights up and sends an image on Telegram because of the signal transmission from the PIR sensor. If the PIR sensor detects human movement with a maximum distance of 7 meters, the Buzzer will turn on. If the distance between the PIR sensor and human movement exceeds 7 meters, the Buzzer will not turn on because the Sensor cannot reach it, so this device will not detect movement with a distance of more than 7 meters.

Figure 4. PIR Sensor Testing

3. System Integrated Testing

This integrated system test is used to determine the reliability of the system that has been made. The overall system test displays the Ultrasonic Sensor and PIR sensor results input, LED, and Buzzer as output [10]. This test is carried out with a PIR sensor detecting whether there is human movement or not. The sensors that will be used to detect movement are PIR (motion) sensors and ultrasonic sensors (distance). Then, the LED will light up, and the ultrasonic wave speaker will be active [11].

Table 2. Integrated System Test Results

Conditions Met	Telegram Notifications	Ultrasonic Sensor (m)	Flash LED And ultrasonic waves	Buzzer
Motion detected	Text and Images	1	Active	Turn on
	Text and Images	1.2	Active	Turn on
	Text and Images	1.5	Active	Turn on
	Text and Images	2.3	Inactive	Turn on
	Text and Images	2.4	Inactive	Turn on
No Motion Detected	No Notifications	1	Active	Off
	No Notifications	1.2	Active	Off
	No Notifications	1.5	Active	Off
	No Notifications	2.3	Inactive	Off
	No Notifications	2.4	Inactive	Off

The test is carried out by observing the sensor output under the condition that the system has been integrated between hardware and software [12]. The output of the sensor data reading will be displayed through the Telegram Bot that has been created, and when the reading from the Sensor is at the set point, it will send a notification in the form of text and images on Telegram [13]. When motion is detected, the Buzzer will light up for 5 seconds, and the ultrasonic Sensor will light up when reading the value below 2 meters. The LED flash and Ultrasonic Wave will light up. When no motion is detected, the PIR sensor does not send notifications on Telegram, and the Buzzer also turns off [14].

4. Application Testing

This system test is carried out based on system testing in several conditions that have been created. The results of the information the tool reads are then sent to the Telegram Bot, which the user will later receive. If the PIR sensor reads the gesture On Telegram, it will send the text "Motion Detected" and an image in real time [15].

Figure 5. Telegram Display Detected Motion

D. Conclusion

The home security system using the esp32 cam effectively detects human movement and sends real-time images of the situation, thereby preventing theft with ultrasonic wave output and LED flash. This research shows that ultrasonic waves can create an uncomfortable environment for criminals, thereby increasing home security. Using ultrasonic waves as a crime prevention method is relatively safe and environmentally friendly. Ultrasonic waves are not harmful to humans, animals, or plants, so that they can be used effectively without adverse side effects. The Sensor emits sound waves, which are reflected by objects in front of it and are received and processed to determine the distance between the Sensor and the object. A home security system using ultrasonic waves in the event of a theft at home can be an efficient and cost-effective alternative to smart home control methods.

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