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Smart Door Locking System for Children Using HC-SR04 and IoT Technology

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A B S T R A C T

The increasing incidence of minors accessing hazardous indoor areas—such as staircases, balconies, and rooms with sharp objects—raises serious safety concerns, often due to insufficient parental supervision. This study proposes an Internet of Things (IoT)-based automatic door lock system to enhance child safety in home environments. The system integrates dual ultrasonic sensors for distance and height detection, a KY-037 sound sensor, and an ESP32-CAM for real-time video monitoring, all accessible via a web interface. A key novelty lies in the integration of multi-sensor spatial awareness with live surveillance, enabling automated control and proactive safety features. Tested on ten children aged 4 to 6 years, the system achieved a 90% success rate in locking the door when a child under 120 cm approached within 1 meter, with an average response time of approximately 2 seconds. A sound-based alarm is also triggered when noise levels exceed 120 decibels, serving as an emergency alert. However, a 10% false negative rate was observed when children were detected at distances of 1.3 to 1.5 meters, suggesting the need for further sensor calibration. Overall, the system demonstrates strong potential as a scalable and cost-effective smart home safety solution, combining automation, real-time monitoring, and child-specific access control. Future work should focus on improving detection accuracy and extending functionality for multi-object scenarios.

INTRODUCTION

In this modern era, many families face challenges in guarding children's safety in the environment at home, especially when they become more active and have a sense of curiosity about big tofu. Children, specifically toddlers and preschoolers, tend to be energetic and happy to explore various corners of the home. The desire for natural tofu often makes them unaware of possible dangers threatening their safety. Previously, over the past 4 years, many cases of injuries that occurred in children under age 6 years happened in the home. Sixty-seven thousand children experience accidents, and 43,000 of them happen to children under 6 years old. A lot occurs in the kitchen, the stairs, or the outside room [1].

Several research cases show that children are often at risk of leaving the room without supervision, which can place them in dangerous situations, such as going up the stairs, balconies, outdoor areas, or rooms containing sharp objects. The causes of the occurrence are the lack of busy parental supervision with tasks, House stairs, or activities [2]. Research by Focardi et al. [2] also highlighted that increased parental stress and workload during the COVID-19 pandemic exacerbated the lack of supervision of children, thereby increasing the potential for children to leave the room unsupervised and enter hazardous areas, such as balconies or stairs. Therefore, developing an automated system based on the Internet of Things (IoT) is a relevant approach to address this problem.

In research [3], a solenoid lock locks the door automatically with a detection face. In [4], an ultrasonic sensor detects movement at a distance of 1.6 meters from the sensor. [5] Sound sensors measure noise and display it on an LCD in a room. [6] ESP32 CAM records video and can be monitored using a Telegram application.

Researchers [3] have conducted a study about the automatic use detection of a keyless door system in a room. The system will monitor the people who enter the home and detect compatible faces, and the system will open the door automatically when it recognizes the face. This study focuses on developing and evaluating an IoT-based automatic door lock system to prevent children from accessing dangerous areas within the home, such as stairs and balconies [37]. By integrating sensors, microcontrollers, and wireless communication, the system aims to provide a proactive and reliable solution for minimizing the risk of accidents and injuries among young children [38]. This study contributes to the growing body of literature on technology-driven child safety interventions, offering insights into the potential of IoT to create safer and more secure living spaces for families.

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This research focuses on designing an automatic door lock system utilizing IoT technology. The system aims to minimize accidents in enclosed spaces by automatically locking the door when an ultrasonic sensor detects the presence of a child under 100 cm in height approaching the door. The door will unlock once the child moves at least 1.3 meters away from it.

Additionally, the system is equipped with a monitoring feature that can be accessed through a special link on a website. This significantly enhances the safety of the child in the room, as parents can monitor their children in real-time. The system can also provide video footage of activities taking place in the room.

This study adopts a novel approach by combining the HC-SR04 ultrasonic sensor, the KY-037 sound sensor, and the ESP32-CAM camera, all controlled by the ESP32 microcontroller, to create an IoT-based automatic door locking system. The system can detect the presence of children based on their height and noise, and visually monitor their activities in real-time. This integration results in a system that is not only reactive to the presence of children in danger-prone areas but also provides parents with visual monitoring access through a web interface. By referring to the strengths and limitations of previous studies, this study aims to refine the smart lock concept with a system that is more responsive, lightweight, and easily accessible. It has the potential for widespread implementation in ordinary household environments without sophisticated infrastructure.

METHOD

The methodology of this study consists of four parts: hardware preparation, software preparation, system testing, and data collection, as illustrated in Figure 1.

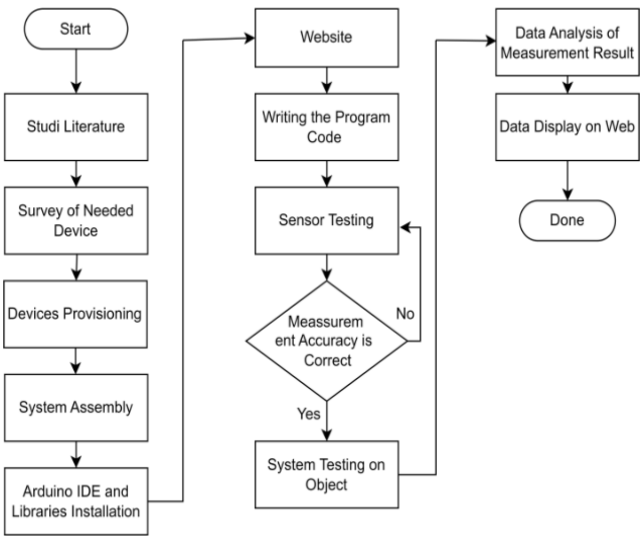

Figure 1. Methods Used

Hardware Arrangement

This study uses three types of sensors to support the implementation of the designed system. The first is the HC-SR04 ultrasonic sensor, which functions to detect the presence of children based on both distance and height parameters [7]. Two HC-SR04 sensors are installed at different vertical positions—approximately 80 cm and 120 cm—to enable object height estimation [8]. These sensors operate by emitting ultrasonic waves and measuring the time taken for the echo to return, allowing the system to calculate distance with an average error rate of 2% [9]. When the system detects an object under 120 cm in height and within 1 meter of the door, the ESP32 microcontroller activates a solenoid lock, securing the door automatically.

The second sensor used is the KY-037 sound detection sensor, which is responsible for monitoring the ambient noise level around the door area [10]. If the sound detected exceeds the threshold of 120 decibels, the sensor sends a digital signal to the ESP32 microcontroller. In response, the system triggers a buzzer alarm as an early warning mechanism in potentially hazardous situations [11][12]. This functionality adds an additional layer of safety by responding not only to physical proximity but also to abnormal sound activity.

The third component is the ESP32-CAM, a variant of the standard ESP32 microcontroller equipped with a built-in camera. Unlike the ESP32 that controls sensors and actuators, the ESP32-CAM is specifically designed for real-time video monitoring [13]. This module connects to an internal Wi-Fi network and transmits images to Firebase. The image data is then rendered into live video streams on an HTML interface using JavaScript [14], allowing parents or caregivers to remotely monitor children's activity within the room.

All sensor and actuator modules are integrated into a unified system architecture. The ESP32 microcontroller acts as the central control unit for sensor readings and actuator responses, while the ESP32-CAM operates in parallel to provide real-time visual data. This dual-microcontroller configuration ensures a clear separation of control and monitoring functions, improving performance and system responsiveness. A schematic representation of the interconnected devices is shown in Figure 2, illustrating the flow of data from the sensors to the web-based user interface in a seamless and real-time manner.

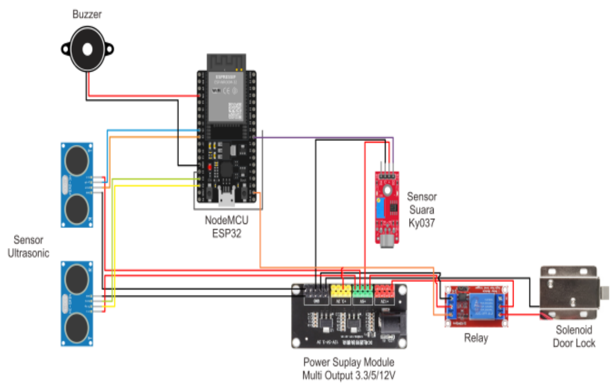

Figure 1. System Block Diagram

Software Arrangement

This study uses the Arduino IDE as a software application for writing system programs. Before writing the program, installing and utilizing specific libraries for the components used, including the HC-SR04 ultrasonic sensor, KY-037 sound sensor, buzzer, and solenoid lock, is necessary. Each sensor will produce data in

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numbers or characters, which will be transmitted to Firebase in real-time. Firebase will then forward the data to the website using JavaScript as the website's backend. The received data will subsequently be processed by JavaScript into real-time images displayed on HTML pages, resulting in a video-like stream. The buzzer operates using "HIGH" and "LOW" signal logic based on input detected by the KY-037 sound sensor, while the relay functions to switch "ON" and "OFF" when the detected height is below or above 100 cm.

The website's system includes door status and video monitoring. The door status display will be differentiated based on color and image, namely " red " for the condition door locked and " green " for the condition door in normal or open state. Users can also lock or open the door automatically using the website's button.

Data collection

This evaluation involved a sample of ten typically developing children enrolled in the FKIP USK Kindergarten in Banda Aceh. The sample consisted of five girls and five boys, aged between 4 and 6 years. The three primary variables measured in the study were distance, height, and voice frequency.

Measurements of distance and height were obtained using ultrasonic sensors integrated into the research device. Voice frequency was measured using a KY-037 sound sensor, which was also installed on the same device. To ensure data accuracy, measurements were conducted in three repetitions for each child, with each session lasting one minute.

Prior to testing the complete system on the subjects, preliminary trials were carried out to assess the accuracy and precision of each sensor used. The accuracy of the ultrasonic sensor was evaluated by comparing its readings to manual measurements taken with a measuring tape. The accuracy rate was then calculated using Equation (1) [26]:

$$\text{Sensor Performance} = \left| \frac{Sensor\ Value\ X - Value\ Y}{Sensor\ Value\ X} \right| \times 100\% \quad (1)$$

RESULTS AND DISCUSSION

Design Results System

In this section, this will display results from a series of tools that have been made that are as high as 2 meters and consist of an ultrasonic sensor, KY037 sound sensor, ESP32 CAM, relay, solenoid lock, and ESP32. Figures 3 and 4 show channel system tools and assembled tools.

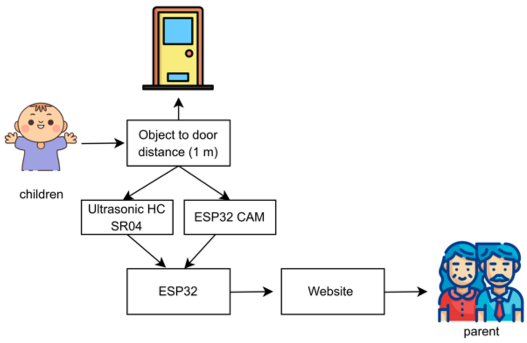

Figure 3. Tool System Flow

According to [15], ultrasonic sensors are utilized to detect the height and distance of objects relative to the door. These sensors operate by emitting sound waves and measuring the time it takes for the waves to return after reflecting off an object [7][16]. In this system, two ultrasonic sensors are installed at different heights to facilitate more accurate height detection. Additionally, the ESP32-CAM is employed as a visual sensor capable of recording video footage of children's activities within the room. The recorded data can also be monitored via a custom-built website platform.

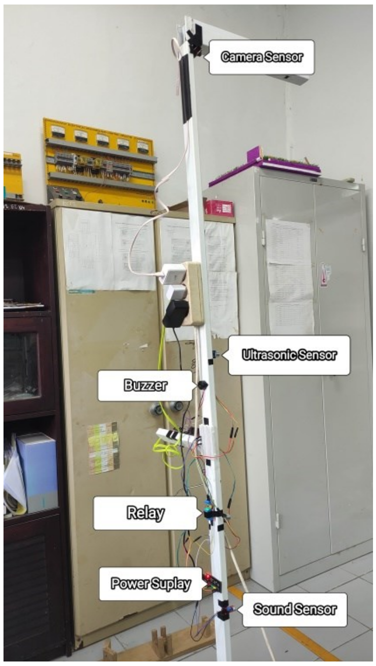

Figure 4. Overview

Based on Figure 4, the device is assembled on an iron pole, which serves as the structural support connecting each sensor to the ESP32 microcontroller. The ESP32 functions as the central controller that manages the performance of the entire system. This design facilitates ease of use and enhances the portability of the device.

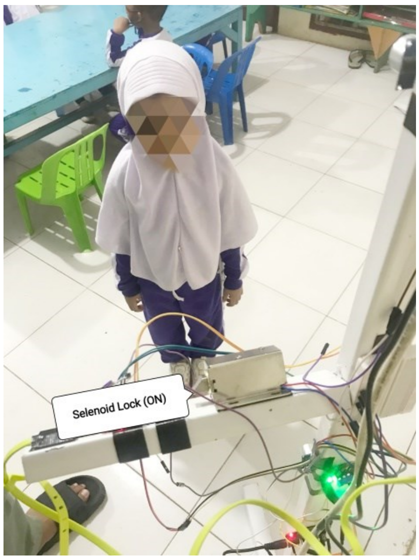

Figure 5. Tool Testing Image

Figure 5 illustrates the functionality of the device once it is connected to a power source. The two ultrasonic sensors are mounted at different heights on the supporting pole, with the first sensor positioned at 80 cm and the second at 120 cm. The ESP32-CAM is strategically placed on the pole to ensure optimal recording of the room's conditions. Each sensor collects measurement data, which is then processed by the ESP32 microcontroller. The resulting video footage and door status information are subsequently displayed on the associated website platform.

Hardware Testing

Testing HC-SR04 Ultrasonic Sensor Accuracy

Distance and height measurements are obtained using ultrasonic sensors. These sensors operate by emitting sound waves through a transmitter and receiving the reflected waves via a receiver after they bounce off an object. When the wave returns to the sensor, the time taken for the round trip is measured. This time interval is then used to calculate the distance between the sensor and the object.

Table 1. Ultrasonic Sensor Accuracy Results

No.	Observation	Measuring Tape (cm)	Ultrasonic Sensor (cm)	% Error
1.	Child 1	110	115	4.5
2.	Child 2	187	190	1.6
3.	Child 3	95	102	7.4
4.	Child 4	247	251	1.7
5.	Child 5	130	134	3.1
6.	Child 6	143	145	1.4
7.	Child 7	87	91	4.6
8.	Child 8	91	98	7.7
9.	Child 9	116	121	4.4
10.	Child 10	73	74	1.4

Testing KY037 Sound Sensor Accuracy

KY037 sound sensor detects voice with a change intensity voice around, then produces analog or digital signals that the ESP32 microcontroller can receive. When the sound is detected to be more than 120 decibels, the sensor output will be HIGH, and the buzzer will sound. However, when the sound detected is less than or equal to 120 decibels, the sensor output will be LOW, and the buzzer will remain silent.

Table 2. KY037 Sound Sensor Accuracy Results

Trial To	Sound Level (dB)	Digital Status KY037
1	121-135	HIGH
2	< 66	LOW

Based on Table 4, it can be observed that when the sound level exceeds 120 decibels, the digital output of the KY-037 sound sensor changes to HIGH, triggering the buzzer to turn ON. Conversely, when the sound level falls below the threshold, the sensor output switches to LOW, and the buzzer turns OFF.

Software Testing

The testing of the developed website system aims to verify whether the configured data stream functions properly. The results of the testing are illustrated in Figure 5. As shown in Figure 6, the website system operates effectively, displaying both door status and live video monitoring. The door can be opened and locked via the website interface, indicating that the system functions as intended. The door status display updates in real time to reflect the actual condition of the door.

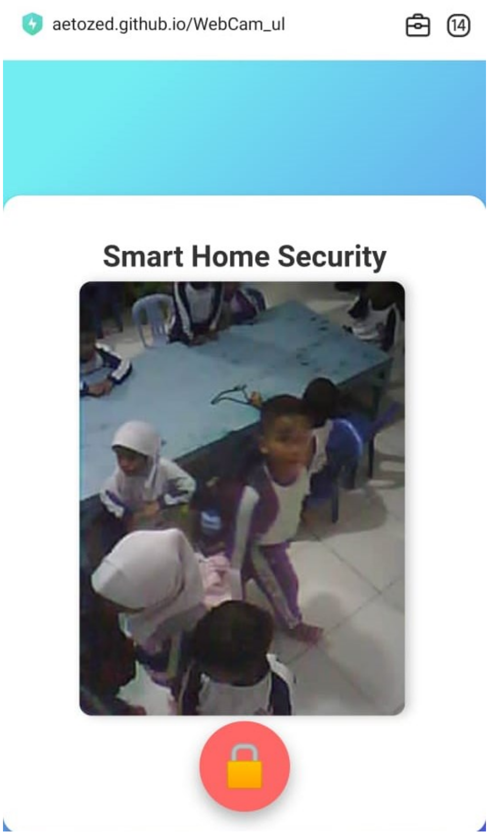

Figure 6. Display on the website

The test was conducted in a kindergarten setting with children of varying heights. Each test was repeated three times, with each session lasting one minute. The first child tested had a height of 76 cm, as measured manually using a measuring tape. When the child approached the door, the system was activated, triggering the solenoid lock to engage and automatically lock the door. Conversely, when the child moved away from the door, the system responded by unlocking the door automatically.

Table 3. Test Results Overall System

Test	Distance (m)	Ultrasonic Sensor	ESP32-Cam	Status	Response Time (s)
1	1	ON	Detected	LOCKED	1.9-2.32
2	1.5	OFF	Detected	OPEN	-
3	1	ON	Detected	LOCKED	2,62
4	1	ON	Detected	LOCKED	2,90
5	1	ON	Detected	LOCKED	1,85
6	1	ON	Detected	LOCKED	2,32
7	1.5	OFF	Detected	OPEN	-
8	1	ON	Detected	LOCKED	1.92
9	1	ON	Detected	LOCKED	2.21
10	1	ON	Detected	LOCKED	2.12

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In contrast, when an adult approached the door to exit the room, the system did not activate, allowing the door to remain open and enabling the adult to exit freely. Throughout both scenarios, the ESP32-CAM continued to operate, allowing users to monitor children's activities in real time within the room.

Based on Table 3, it can be observed that at a distance of 1 meter, the ultrasonic sensor responds accurately and consistently in detecting objects. This enables the door to be locked automatically with a response time of less than one second. However, at a distance of 1.5 meters, the sensor fails to detect objects, resulting in the door remaining unlocked.

Automatic Door Lock Result Analysis

This section discusses the implementation of the system to enhance the safety of children within a room. As previously described, the system was tested on ten children of varying genders and heights. The device measures distance and height while simultaneously recording room activity. The resulting data are transmitted to the ESP32 microcontroller and subsequently forwarded to a user-accessible website. As shown in Attachment 1, testing was conducted on ten children, with each subject tested three times for durations of less than one minute. These tests aimed to evaluate the accuracy of the sensors. The results indicate that when a child is shorter than 100 cm and within a 1-meter distance from the door, the system automatically locks the door. Conversely, when the child moves beyond 1.3 meters, the door unlocks. Additionally, the website features manual controls that allow parents to remotely lock or unlock the door. Based on these findings, it can be concluded that the IoT-based automatic door locking system functions effectively, as it is capable of detecting distance, height, and providing real-time video monitoring of the child in the room.

The observed error percentage in ultrasonic sensor measurements can be attributed to several factors. Environmental conditions—such as temperature and humidity—may alter the speed of sound, resulting in measurement inaccuracies. Obstacles along the sensor path may cause signal reflections that distort readings, while ambient noise can interfere with echo detection. Furthermore, the sensor's technical limitations, including its beam angle and minimum detection range, also contribute to measurement errors. Compared to previous studies [13], this study found an error range between 1.4% and 7.7%, which is consistent with existing research that reports accuracy ranges of 2% to 5%. This suggests that under optimal conditions, the system performs comparably; however, in less controlled environments, the likelihood of increased error is higher. These inaccuracies may impact the reliability of the automatic door lock system—false negatives could pose safety risks by failing to engage the lock, whereas false positives may lead to unnecessary locking. Therefore, ensuring high sensor accuracy is essential for system reliability and user confidence, emphasizing the need for careful calibration and potentially integrating additional sensors.

Table 4 presents a comparative analysis between this study and several related works that utilize different models and techniques for child monitoring and door automation systems. The comparison highlights key differences in sensor types, system architecture, accuracy levels, and functionalities implemented. This evaluation provides contextual insight into how the proposed system performs relative to existing studies, particularly in terms of accuracy, responsiveness, and the integration of real-time video monitoring. Overall, the findings suggest that the proposed IoT-based approach offers competitive performance while providing additional features such as real-time surveillance and distance-height dual detection

Table 4. Benchmarking

Authors	Features	Accuracy
G. Surla, et. al. [3]	Solenoid lock, Raspberry Pi, Haar Cascade Classifier	This system produces a door lock system using facial detection.
Andreas, et.al. [5]	Sound Sensor KY037,Wemos D1R1,LCD	The design of this tool is capable of measuring the noise level, which is displayed on the LCD.
Proposed method	Ultrasonic Sensor HC-SR04, Sound Sensor KY037, ESP32 CAM	This system can detect distance and height and record children's activities in real time. It shows an accuracy of under 8%, and an average response time of two seconds to lock the door when the child approaches a dangerous area.

CONCLUSION

This study demonstrated the effectiveness of an IoT-based automatic door locking system in enhancing child safety. With a 90% success rate in detection and a fast response time averaging 2 seconds, the system shows promising results for domestic use. A key novelty of this research lies in the integration of dual ultrasonic sensors for both distance and height detection, combined with real-time video surveillance using ESP32-CAM—an approach not commonly found in previous studies. However, detection inaccuracies at certain distances highlight the need for sensor calibration. The inclusion of a sound-based alarm further strengthens the safety function. Future research should focus on improving multi-object detection and evaluating performance in complex environments to ensure broader applicability.

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APPENDICES

Observation	Measuring Tape (cm)	Ultrasonic Sensor (cm)
Child 1	110	115
	110	117
	110	113
Child 2	187	192
	187	190
	187	189
Child 3	95	103
	95	105
	95	99
Child 4	247	250
	247	253
	247	249
Child 5	130	137
	130	135
	130	129
Child 6	143	141
	143	148
	143	150
Child 7	87	91

	87	93
	87	89
Child 8	91	102
	91	98
	91	95
Child 9	116	120
	116	125
	116	118
Child 10	73	69
	73	77
	73	75

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