

Toolbox Monitoring System

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ABSTRACT

This study develops and tests a wireless toolbox monitoring system designed to improve efficiency and security in tool management. The system uses infrared sensors to detect the presence of tools in the toolbox, then wirelessly transmits data to a server that stores the information in a database. Testing demonstrated that the system significantly reduces the time required by operators to check and locate tools, ensuring that tools are always available when needed. Additionally, the system enhances tool management security by providing automated real-time monitoring, which helps minimize the risk of tool loss. The database not only serves as a central data repository but also as a reporting tool for technicians to manage tool maintenance and replacement. Overall, the system has proven effective in accurately detecting tool presence, transmitting data wirelessly, and storing information in the database, supporting operational efficiency and informed decision-making for tool maintenance.

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1. INTRODUCTION

The toolbox in a workshop setting serves as a storage and organizational unit for tools used during practical sessions. It promotes an orderly and safe working environment for students while making it easier for them to locate the necessary tools. However, these toolboxes often face issues such as tool loss, which can disrupt the learning and working processes within the workshop. The loss of tools not only results in financial costs but also hampers productivity and operational efficiency [1]. To address tool loss and improve tool management, a wireless-enabled toolbox solution can be employed. This system upgrades the traditional toolbox with modern technology, incorporating sensors, hardware, and wireless connectivity that allow it to connect to a network and communicate with devices such as smartphones or computers [2]. A key feature of this monitoring system is its ability to automatically track the tools inside; every stored tool is detected and logged, enabling users to easily identify which tools are available or currently on loan. The system also accurately records borrowing and return data, allowing for easy tracking of accountability for each tool [3].

This study develops a wireless toolbox monitoring system that utilizes infrared sensors to identify the presence of tools within the toolbox. Infrared sensors are a type of optical sensor frequently used to detect the movement or presence of objects positioned in front of them. These sensors consist of two primary components: an infrared (IR) light emitter and a light receiver. The components are compactly arranged so that the infrared light source and the sensor/detector face the same direction. This configuration enables the detection of approaching objects by sensing the reflection of the emitted infrared beam off the object's surface [4].

The system is powered by an ESP32 microcontroller, which collects data from the sensors and transmits it wirelessly to a web-based server. The collected data is stored in a database and displayed via a web interface, allowing users to monitor tool status in real-time. The ESP32 is a robust and versatile microcontroller widely used in the development of various electronic projects and wireless devices [5]; it is responsible for gathering data from each infrared sensor and wirelessly transmitting that information to the web-based server using efficient communication protocols such as MQTT or HTTP. The server then stores the received data in a

database designed to maintain structured tool records that are accessible at any time. Implementing this system is expected to enhance accuracy and efficiency in tool management while simultaneously reducing the risk of tool loss or theft. Beyond facilitating smooth operations, the system contributes significantly to improving overall operational efficiency within industrial environments.

2. METHOD

The method employed in this study is Research and Development (R&D). The research phase involves a literature review concerning the technologies and components to be utilized in this toolbox monitoring system. This review encompasses an analysis of the use of infrared sensors and RFID in object detection applications [6]. Additionally, previous research on IoT implementation and the ESP32 microcontroller in monitoring systems was examined to determine the most suitable approach.

The development phase of this study comprises system planning, development, and testing. The development process is divided into three main stages: system planning, system assembly, and system testing. System planning covers software and hardware development, as well as the mechanical design of the toolbox. During the software planning stage, block diagrams and flowcharts were created to map the system's workflow—ranging from data acquisition by sensors to data transmission to the server and information display on the web interface [7].

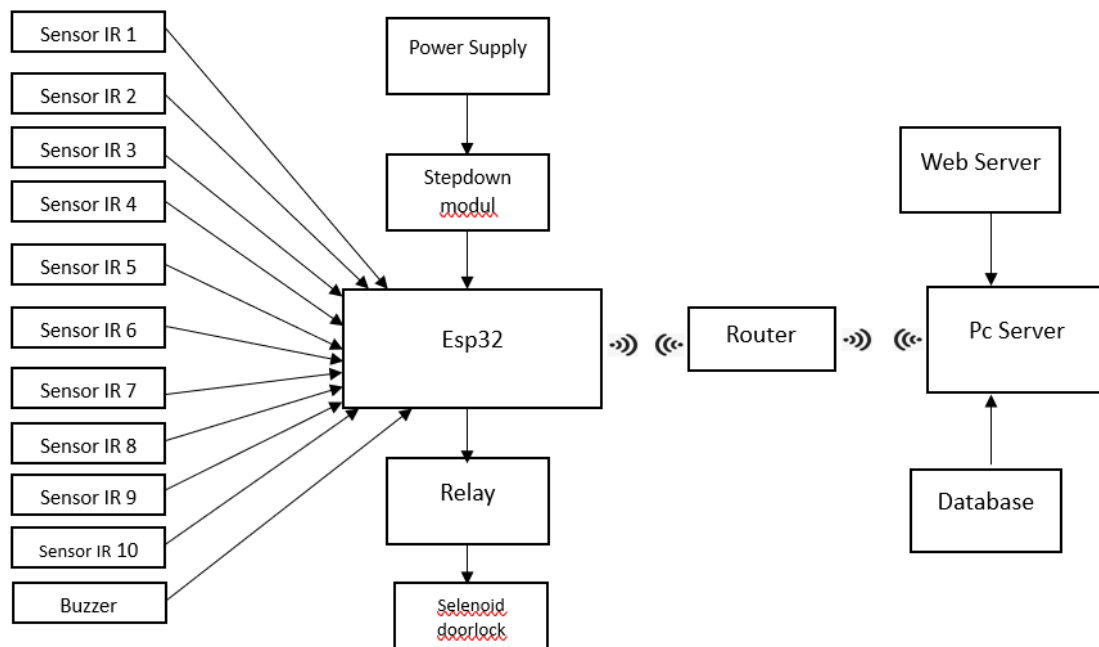


Figure 1. Block diagram of proposed system

Figure 1 illustrates the design of a wireless toolbox monitoring system that utilizes infrared sensors connected directly to an ESP32 microcontroller. The system is designed to detect the presence of tools within the toolbox and provide real-time information via a web interface, giving users full oversight of their tools' status. The sensors serve as the primary components for tool detection; they operate by emitting an infrared beam via an LED, which is reflected off an object (the tool) back to a phototransistor. Based on the intensity of the reflected light, the sensor determines whether an object is present in front of it [8]. Each infrared sensor is connected to a GPIO pin on the ESP32, which processes the signal to determine the tool's status—either "Detected" or "Not Detected."

The ESP32 microcontroller serves as the control and data processing hub of this system. Upon receiving input from the sensors, the ESP32 processes the data to determine the status of the tools within the toolbox. Equipped with built-in Wi-Fi, the ESP32 enables wireless data transmission to the local network. The processed data is transmitted via Wi-Fi to a server and stored in a database on a PC server. A web server on the PC then displays this data through a web interface, which users can access in real-time from any internet-connected device [9].

The system also utilizes a relay to control the solenoid door lock. The relay acts as an electronic switch that regulates the electric current to the solenoid door lock based on signals received from the ESP32 [10]. If all tools are detected, the ESP32 sends a signal to the relay to lock the toolbox. Conversely, if any tool remains undetected, the ESP32 cuts off the current to the solenoid door lock, keeping the toolbox unlocked. This relay is crucial for ensuring the toolbox locks only when all tools are in their designated places, thereby maintaining tool security. Both the ESP32 and the relay are powered by an external power supply. Since the ESP32 operates at 3.3V or 5V while the solenoid door lock requires 12V, a step-down module (DC-DC converter) is used to adjust the voltage from the power supply to meet the specific requirements of each component. This module ensures that every component receives the correct operating voltage, preventing damage caused by overvoltage [11]. Data processed by the ESP32 is transmitted wirelessly to a router connected to the local network. The router links the ESP32 to a PC server. This server, which also hosts a web server, stores the data in a database and displays information via a web interface accessible to users. The system enables users to monitor the status of tools within the toolbox in real-time from any location using an internet-connected device [12].

Overall, this toolbox monitoring system integrates various electronic components and software to provide an efficient and reliable solution for tracking the status of tools inside the toolbox. Infrared sensors and the ESP32 work in tandem to detect and process data, which is then transmitted to the server via a wireless connection. Supported by a power supply integrated with a step-down module, a relay controlling a solenoid door lock, and capabilities for real-time data storage and web-based access, this system offers a comprehensive solution for monitoring tools within the toolbox, thereby facilitating more efficient operations and improved tool management. The system's workflow is outlined and presented in the flowchart shown in Figure 2 below.

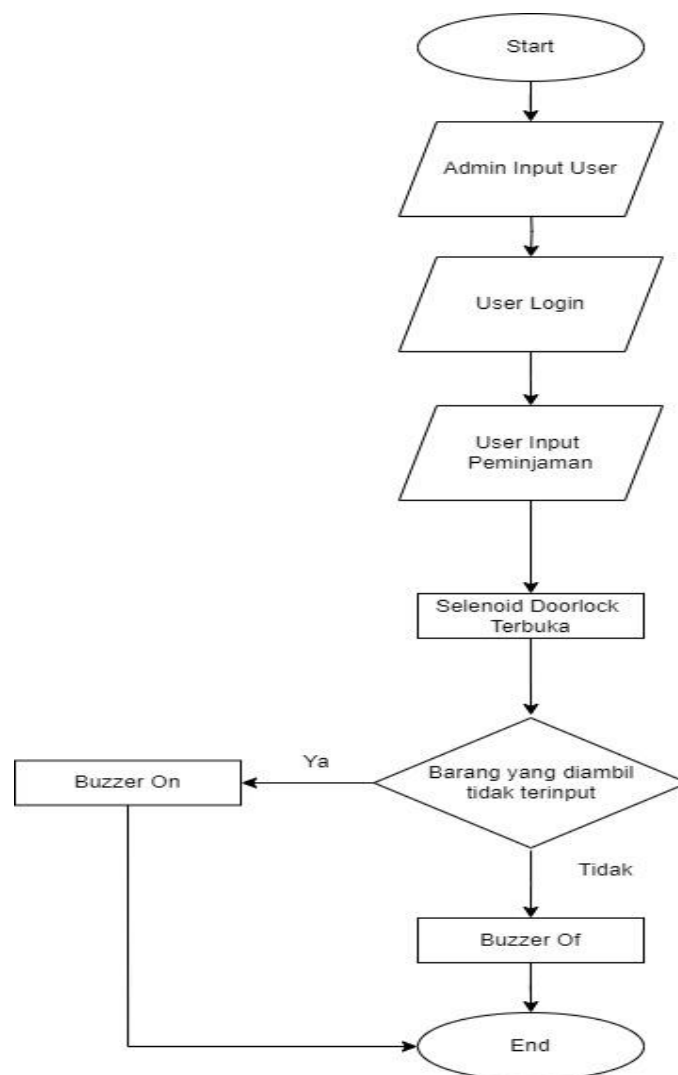


Figure 2. Flowchart of toolbox monitoring system

Figure 2 above presents a flowchart detailing the workflow of the item-lending management system. The process begins with an initiation step marked "Start." Next, the administrator enters the data for new users who will utilize the system. Once the user data is entered, users can log in using their registered credentials. After successfully logging in, users can input information regarding the items they wish to borrow. If the lending input is valid, the door—controlled by a solenoid lock—opens to grant the user access to the desired items. After an item is retrieved, the system verifies whether it matches the recorded input. If the system detects that a retrieved item was not properly logged, a buzzer sounds to signal an error. Conversely, if the item was correctly logged—or once the error is resolved—the buzzer stops. The process concludes with the "End" step, signifying the completion of the entire lending workflow. This diagram illustrates how the system manages each step of the lending process, from user registration to error handling. The following section outlines the system's overall configuration.

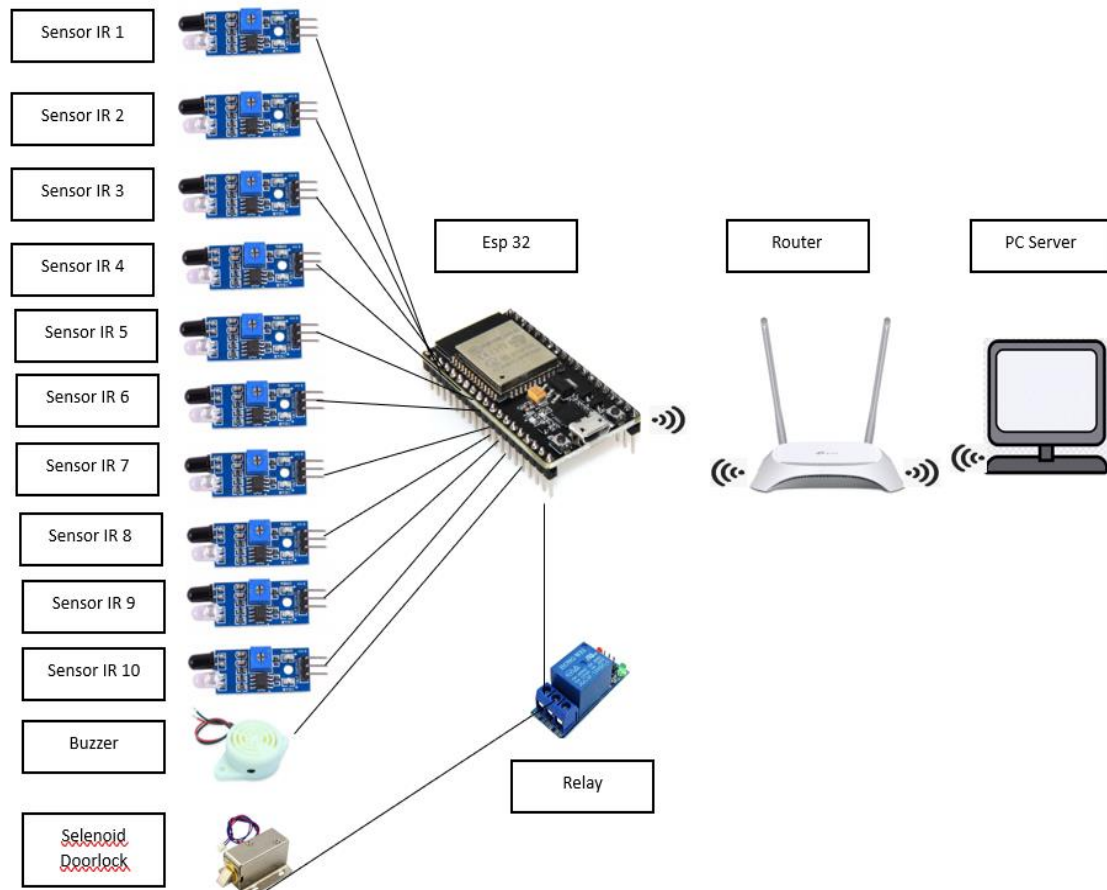


Figure 3. The circuit of proposed system

Figure 3 illustrates the circuit configuration of the entire system. This circuit encompasses all components involved in the system's operation. It shows ten IR sensors connected directly to the ESP32, which serves as the central controller; these sensors detect whether an item has been removed. Data from the sensors is processed by the ESP32 and transmitted to the server via a router. Power is supplied from an AC source, converted to 9V by an adapter, and distributed to the ESP32 and other components to operate the system. A solenoid door lock, controlled via a relay, manages the door mechanism; the relay opens or closes the door based on commands issued by the ESP32 through its programming. Additionally, a buzzer connected to the ESP32 provides alerts in the event of errors, such as an item being removed without being logged in the system. High and Low logic states in the programming control the relay and buzzer: a High state activates the solenoid door lock and the buzzer, while a Low state deactivates them. Wireless communication between the ESP32 and the server takes place via the router, enabling real-time data monitoring on the server PC. Overall, this circuit demonstrates the interconnection of all components in operating an automated and integrated item-lending system [13]-[15].

3. RESULTS AND DISCUSSION

System and software testing was conducted using an infrared sensor positioned at specific distances from the tool within the toolbox. The testing aimed to evaluate the reliability of the sensor in detecting the tool and the accuracy of transmitting the tool's status data to the system. To ensure accurate results, tests were performed with the tool placed at varying distances from the sensor—specifically 1 cm, 5 cm, and 10 cm—while ensuring the tool remained fully within the sensor's detection range. The testing also involved monitoring the performance of the software responsible for processing and displaying data received from the ESP32 microcontroller. Data transmitted by the sensor is processed by the software, which then displays the tool's detection status and measures data transmission time to ensure a rapid and accurate response. The results of the system and software measurements and tests are presented in Table 1.

Table 1. Infrared Sensor Testing

Tool	Sensor distance	Status
Hammer	1 cm	Detected
	5 cm	Detected
	10 cm	No Detected
Wrench	1 cm	Detected
	5 cm	Detected
	10 cm	No Detected
Pliers	1 cm	Detected
	5 cm	No Detected
	10 cm	No Detected
Meter	1 cm	Detected
	5 cm	Detected
	10 cm	No Detected
Phillips screwdriver	1 cm	Detected
	5 cm	No Detected
	10 cm	No Detected
Flat-head screwdriver	1 cm	Detected
	5 cm	No Detected
	10 cm	No Detected
L key	1 cm	Detected
	5 cm	No Detected
	10 cm	No Detected
Small Screwdriver	1 cm	Detected
	5 cm	No Detected
	10 cm	No Detected
Voltage tester	1 cm	Detected
	5 cm	No Detected
	10 cm	No Detected
Cutter	1 cm	Detected
	5 cm	Detected
	10 cm	No Detected

Infrared sensor range sensitivity testing indicates that the sensor can detect objects at distances of 1 cm and 5 cm, but not at 10 cm. When testing with a hammer, wrench, tape measure, and utility knife, detection occurred at 1 cm and 5 cm but not at 10 cm, demonstrating effective detection capabilities for short to medium ranges. Conversely, testing with pliers, a Phillips screwdriver, a flathead screwdriver, an Allen key, a small screwdriver, and a voltage tester resulted in detection only at 1 cm, suggesting the objects were likely too small or insufficiently reflective. The inability to detect objects beyond 5 cm may be attributed to small object size, low sensor sensitivity, or the presence of obstructions. Infrared sensors focus more on changes in light intensity than on specific distances; therefore, if detection issues arise, it is recommended to adjust the sensor sensitivity or check for obstructions in the detection path.

Table 2 presents the results of the monitoring system testing. Based on these results, it can be concluded that the wireless toolbox monitoring system demonstrates excellent performance regarding data detection and transmission. Every change in the tool's status—whether it was removed or returned—was successfully detected and transmitted to the server without any transmission failures. Data transmission times consistently fell within the 0.25 to 0.36-second range, indicating that the system operates rapidly and stably. There were no significant differences in transmission times across the various tools tested, demonstrating the system's ability to handle different types of tools with consistent performance. This indicates that communication between the ESP32 and the server proceeds smoothly and without interruption, ensuring the system's reliability under real-world operational conditions.

Table 2. Monitoring testing results

Tool	Condition	Amount	Time (Sec)	Status
Hammer	Taken	1	0.30	Success
Wrench	Placed	1	0.36	Success
Pliers	Taken	1	0.29	Success
Meter	Placed	1	0.31	Success
Phillips screwdriver	Taken	1	0.25	Success
Flat-head screwdriver	Placed	1	0.35	Success
L key	Taken	1	0.30	Success
Small Screwdriver	Placed	1	0.29	Success
Voltage tester	Taken	1	0.32	Success
Cutter	Placed	1	0.35	Success

This comprehensive system test was conducted to gather data on the presence of tools within the toolbox and to verify the effectiveness of sensor detection and data transmission by the ESP32 microcontroller. The test aimed to evaluate the system's overall operational performance, including tool detection accuracy and data transmission speed. Assessments were carried out by positioning tools at varying distances from the sensor—specifically 1 cm, 5 cm, and 10 cm—while ensuring they remained fully within the infrared sensor's detection range. The table below summarizes the results of the monitoring system's stability test, covering tool presence detection, tool status (taken or placed), and the recorded data transmission status.

Table 3. Overall System Testing

Tool	Sensor distance	Detection Status	Condition	Amount	Time (Sec)	Send status
Hammer	1 cm	Detected	Taken	1	0.30	Success
	5 cm	Detected	Taken	1	0.41	Success
	10 cm	No Detected				
Wrench	1 cm	Detected	Placed	1	0.36	Success
	5 cm	Detected	Placed	1	0.44	Success
	10 cm	No Detected				
Pliers	1 cm	Detected	Taken	1	0.29	Success
	5 cm	No Detected	Taken	1		Fail
	10 cm	No Detected				
Meter	1 cm	Detected	Placed	1	0.31	Success
	5 cm	Detected	Placed	1	0.45	Success
	10 cm	No Detected				
Phillips screwdriver	1 cm	Detected	Taken	1	0.25	Success
	5 cm	No Detected	Taken	1		Fail
	10 cm	No Detected				
Flat-head screwdriver	1 cm	Detected	Placed	1	0.35	Success
	5 cm	No Detected	Placed	1		Fail
	10 cm	No Detected				
L key	1 cm	Detected	Taken	1	0.30	Success
	5 cm	No Detected	Taken	1		Fail
	10 cm	No Detected				
Small Screwdriver	1 cm	Detected	Placed	1	0.29	Success
	5 cm	No Detected	Placed	1		Fail
	10 cm	No Detected				
Voltage tester	1 cm	Detected	Taken	1	0.32	Success
	5 cm	No Detected	Taken	1		Fail
	10 cm	No Detected				
Cutter	1 cm	Detected	Placed	1	0.35	Success
	5 cm	Detected	Placed	1	0.47	Success
	10 cm	No Detected				

Table 3 above presents the results of testing various sensors used to detect tools—such as hammers, adjustable wrenches, pliers, tape measures, Phillips and flathead screwdrivers, hex keys, precision screwdrivers, voltage testers, and utility knives—at distances of 1 cm, 5 cm, and 10 cm. The results indicate that sensor sensitivity varies according to the detection distance. All sensors successfully detected the tools at a distance of 1 cm, indicated by a "Detected" status. At a distance of 5 cm, most sensors also successfully detected the tools, with the exception of those assigned to pliers, Phillips and flathead screwdrivers, hex keys, precision screwdrivers, and voltage testers, which failed to detect the tools at this range. At a distance of 10 cm, no tools were detected, indicating that the maximum effective detection range for all sensors is approximately 5 cm. Whenever a tool was detected, the status data was successfully transmitted to the system

with reception times ranging from 0.25 to 0.47 seconds, demonstrating rapid and reliable data transmission performance. Overall, the detection and data transmission system functioned effectively, with all transmissions recorded as "Successful," except in instances where detection failed at the 5 cm and 10 cm ranges. This analysis demonstrates that the system is reliable for detecting tools at short to medium ranges, though improvements are needed to enable detection at greater distances.

4. CONCLUSION

This research demonstrates that the developed wireless toolbox monitoring system significantly improves operator work efficiency by reducing the time required to check for and locate tools. The system also proves effective in enhancing tool management security through automated, real-time monitoring, thereby minimizing the risk of tool loss and ensuring tool availability when needed. Furthermore, the system ensures accurate tool presence detection, wireless data transmission, and database storage. The database also serves as a source for technician reports on tool maintenance, facilitating the monitoring of tool conditions over time and supporting decisions regarding necessary maintenance and replacement.

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