# Design and Development of an Item Retrieval Detection System for Lockers in the BRAIL Room

**Olivia Febrianti[1*], Rifqi Amalya Fatekha[2], Rifqy Afriza[3], Senanjung Prayoga[4]**

[1]Jurusan Teknik Elektro, Prodi Teknologi Rekayasa Robotika, Politeknik Negeri Batam, Batam, Indonesia

[*]Email: oliviafebriant2004@gmail.com

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***Abstract*—A locker item retrieval detection system based on the HC-SR04 ultrasonic sensor was developed to automatically monitor locker conditions by distinguishing between occupied and empty states based on distance measurements. The system is integrated with an ESP8266 microcontroller and a DS3231 real-time clock (RTC) module to record event timestamps in real time. Experimental testing was conducted using four different sensor placement positions, namely Center Top (CT), Center Back (CB), Left Middle (LM), and Right Middle (RM), with a predefined threshold value used as the classification boundary for locker conditions. The results indicate that the Center Back (CB) position achieved the highest detection accuracy of 92.90%, as its average distance measurement was closest to the threshold value, thereby minimizing relative classification error despite fluctuations caused by ultrasonic reflections within the enclosed locker space. These findings demonstrate that the proximity of sensor readings to the threshold value has a more significant impact on detection accuracy than measurement stability alone.**

**Keywords: Accuracy, Sensor Placement Analysis, Storage Locker, Ultrasonic, Item Detection System**

## I. INTRODUCTION

The development of automation systems and smart sensors has significantly contributed to improving security and facility management in educational environments, particularly for storage systems such as lockers [1]. These technologies aim to enhance the management and security of laboratory facilities, including storage lockers used by students and staff.

Traditional locker systems that rely on physical keys or RFID cards still suffer from several limitations, such as key loss, uncontrolled multiple access, and difficulties in monitoring user activity in real time [1], [2]. Therefore, a locker system capable of automatically and accurately monitoring the presence of items while maintaining security is required.

This research focuses on the design of an item retrieval detection system for lockers based on the HC-SR04 ultrasonic sensor. The main objective of the system is to automatically detect whether an item remains inside the locker or has been retrieved by the user. The HC-SR04 sensor operates based on the time-of-flight principle, which measures the travel time of ultrasonic waves emitted from the transmitter, reflected by an object, and received by the receiver [3], [4], [5]. This sensor was selected due to its stable measurement range of 2–400 cm, which is suitable for locker dimensions, and its high accuracy in confined environments [6].

Ultrasonic wave–based distance measurement is not limited to automatic locker systems but has also been widely applied in object detection radar systems and real-time distance and dimension measurement applications. These applications demonstrate that ultrasonic sensors, including the HC-SR04, offer high flexibility in detecting object presence based on sound wave reflections across various measurement environments [7], [8].

In this system, the ultrasonic sensor measures the distance between the object surface and the inner surface of the locker. If the measured distance is below a predefined threshold, the system identifies the status as item present. Conversely, if the measured distance exceeds the threshold, the system indicates that the item has been retrieved. Additionally, the system integrates a DS3231 real-time clock (RTC) module to record the timestamps when items are placed into or retrieved from the locker.

Several previous studies have utilized ultrasonic sensors for object presence detection. Deprimadoni et al. [1] implemented the HC-SR04 sensor in an IoT-based locker system and achieved an accuracy of 80% at distances <17 cm, while Kumar et al. [2] demonstrated the effectiveness of ultrasonic sensors in enclosed box environments for package detection. Other technical studies report that the accuracy of the HC-SR04 sensor is strongly influenced by sensor orientation, reflection angle, and object surface characteristics [4], [6], [9], [10]. However, limited research has investigated the optimal sensor placement for detecting items inside lockers.

Based on these considerations, this study designs an item retrieval detection system that evaluates several ultrasonic sensor positions, namely center top (CT), center back (CB), left middle (LM), and right middle (RM), to determine the most accurate placement. The ESP8266-based system integrates the HC-SR04 ultrasonic sensor and the DS3231 RTC module to automatically detect and log changes in item status.

## II. METHOD

The research method was designed to develop an automatic locker item retrieval detection system implemented in the BRAIL Room, Politeknik Negeri Batam. This system is designed to automatically detect the presence of items inside the locker and record the time of item placement and retrieval. Several stages in this research include system design by integrating the DS3231 RTC module and the HC-SR04 ultrasonic sensor with the ESP8266 microcontroller [11]; system programming using the Arduino IDE to manage distance measurement, time recording, and determination of the conditions “item present” or “item retrieved” [1], [2], [12]; data acquisition by testing the sensor at various positions inside the locker (Center Top (CT), Center Back (CB), Left Middle (LM), and Right Middle (RM)) to determine the most accurate position, where multi-position testing is required because ultrasonic sensor accuracy is strongly influenced by orientation and reflection angle, as reported in studies by Adhamatika et al. [6], Rihmi et al. [10], and Sze et al. [4]; and data analysis based on the calculation of mean distance values, reading deviations, and sensor accuracy at each position [13], [14].

### A. *Materials and System Design*

The three main components used in this study are the ESP8266 microcontroller, the HC-SR04 ultrasonic sensor, and the DS3231 real-time clock (RTC) module. According to previous studies [1], [2], and [6], accuracy, ease of integration, and low power consumption are the reasons for selecting this hardware.

Figure 1 shows the overall block diagram of the system used in this study

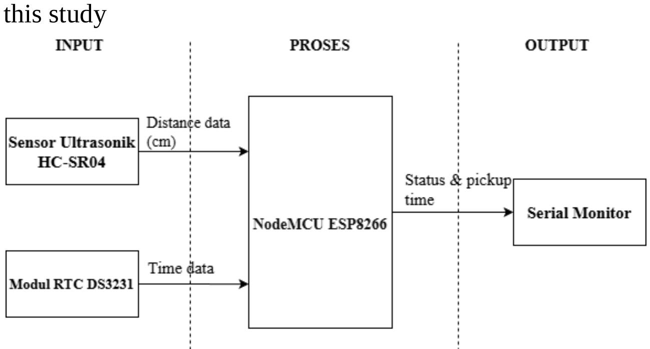



Figure 1 Block diagram of the locker item retrieval detection system

The ESP8266 microcontroller (NodeMCU) functions as the control center of the system and manages all operational processes. It performs several tasks, such as reading distance data from the ultrasonic sensor, acquiring time data from the DS3231 RTC, determining item status, and displaying data through the serial monitor. Studies by Kumar et al. [2] and Putra et al. [11] show that ESP32/ESP8266-based microcontrollers perform well in simple automation systems due to their good data processing capabilities, support for wireless connectivity (Wi-Fi), and consistent stability during long-term operation. The ESP8266 controls the main logical flow of this system. One of its tasks is to determine the condition of "item present" or "item retrieved," which is based on changes in distance readings from the HC-SR04 sensor.

The HC-SR04 ultrasonic sensor measures the distance between the sensor and the surface of the object inside the locker. This sensor operates based on the reflection principle of high-frequency sound waves (time-of-flight). The Trig pin emits a 40 kHz ultrasonic wave, and the Echo pin receives the reflected signal [5]. The distance between the sensor and the object is calculated based on the wave travel time using Equation (1), where the constant 0.034 represents the speed of sound in air in cm/μs [5]. The distance calculation uses the standard formula:

$$Distance\ (cm) = \frac{(Duration\ in\ \mu s) \times 0.034}{2} \tag{1}$$

Figure 2 shows an illustration of the working principle of the HC-SR04 ultrasonic sensor in measuring distance using sound wave reflection from an object in front of the sensor.

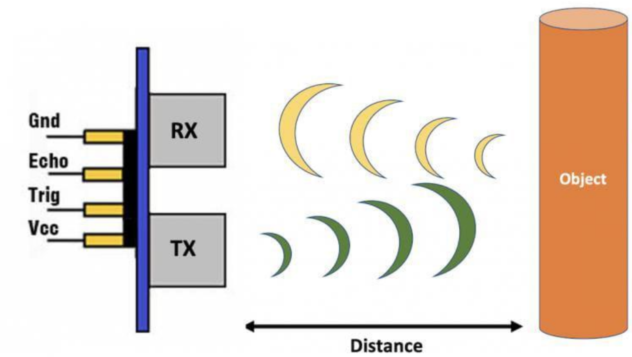
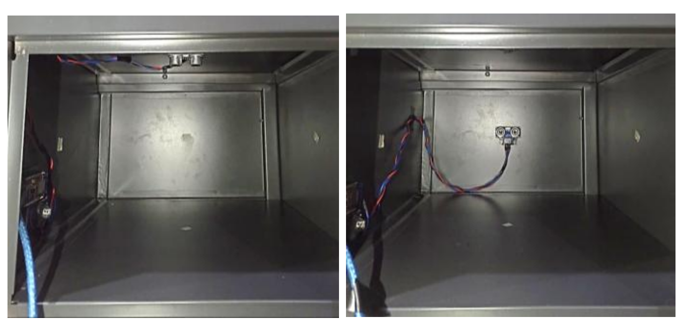


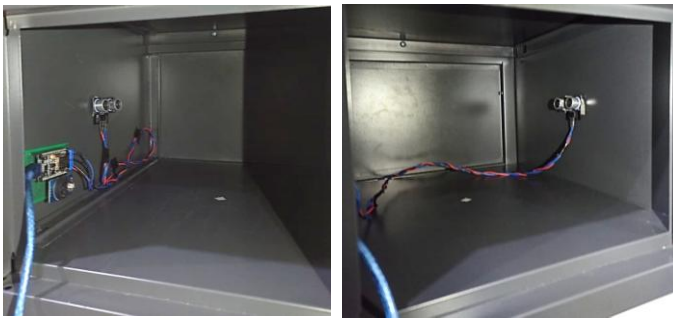

Figure 2 Working principle of the HC-SR04 ultrasonic sensor

The HC-SR04 sensor has a measurement range of 2–400 cm with high accuracy at short distances, making it very suitable for use in confined spaces such as lockers. Deprimadoni et al. [1] reported that this sensor achieved an accuracy of up to 80% at distances below 17 cm, while Adhamatika et al. [6] found that sensor orientation and reflection angle greatly affect distance measurement results. Based on this, in this study the sensor was tested at four different positions inside the locker, namely center top (CT), center back (CB), left middle (LM), and right middle (RM), to determine the most accurate position for detecting item presence.

The placement of these four positions is shown in Figure 3, which illustrates the sensor layout inside the locker during the testing process.



Center Top (CT) Center Back (CB)



Left Middle (LM) Right Middle (RM)

Figure 3 Placement positions of the HC-SR04 ultrasonic sensor inside the locker

For time recording, the system is equipped with a DS3231 RTC module. This module functions to store accurate time data for item placement and retrieval. The DS3231 RTC has a temperature-compensated crystal oscillator, allowing it to remain stable despite changes in environmental temperature. This module is also equipped with a backup battery, enabling the system to continue recording time even when the microcontroller is not supplied with power. Time data are recorded in date, hour, minute, and second formats for each event, and are displayed together with the sensor reading results.

To enable the system to automatically detect item conditions, the three main components are interconnected. The ESP8266 functions as the control center that manages decision logic and overall data acquisition processes. Meanwhile, the DS3231 RTC module is connected to the I2C line on pins D2 (SDA) and D1 (SCL), and the HC-SR04 sensor is connected to pins D5 (Trig) and D6 (Echo). All components receive power supply from the 3.3 V and GND pins of the NodeMCU. Figure 4 shows the hardware connection configuration and illustrates the overall pin relationships.

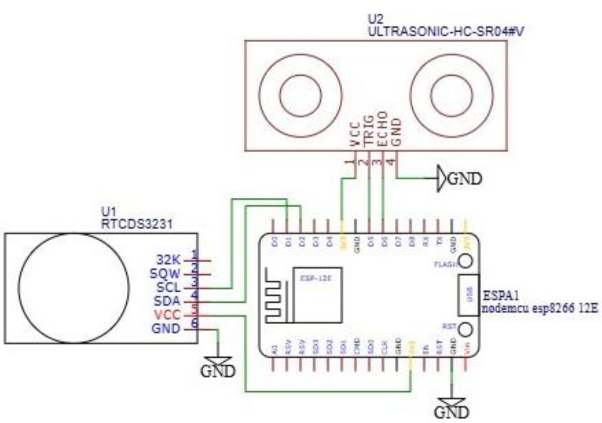



Figure 4 Hardware connection diagram

## B. Threshold Value Determination

The threshold value is used as a parameter to distinguish the condition of item presence inside the locker based on the distance readings obtained from the HC-SR04 ultrasonic sensor [1], [12]. Through this value, the system can determine whether the item is still inside the locker or has been retrieved.

The threshold is determined through preliminary testing by performing distance measurements under two conditions, namely when the locker contains an item and when the locker is empty, for each sensor placement position: center top (CT), center back (CB), left middle (LM), and right middle (RM). Data from both conditions are analyzed to identify a distance boundary that can consistently separate the conditions of “item present” and “item retrieved,” thereby reducing errors caused by fluctuations in sensor readings.

TABLE I
ULTRASONIC SENSOR THRESHOLD VALUES AT EACH POSITION

| Position | Threshold (cm) |
|---|---|
| CT | 15 cm |
| CB | 23 cm |
| LM | 21 cm |
| RM | 21 cm |

The differences in threshold values at each position are influenced by the orientation and installation characteristics of the sensor inside the locker, including the distance between the sensor and the object and the angle of ultrasonic wave reflection [4], [6], [10]. The threshold values used for each sensor position, as presented in Table I, are applied as fixed parameters during the testing process and system performance analysis.

The threshold values determined in the previous stage are subsequently used as the basis for decision-making in the system software. These values are directly implemented in the ESP8266 program logic to classify the locker condition based on the measured distance data obtained from the ultrasonic sensor. By using fixed threshold values, the system is able to perform consistent and repeatable condition classification across multiple measurement cycles. This approach also helps reduce misclassification caused by short-term sensor noise and distance fluctuations that may occur during system operation.

## C. Software Design

The software design is an important part of this study because all detection processes, data recording, and system logic are controlled by the program running on the ESP8266 microcontroller. This software system is developed using the Arduino IDE with the C++ programming language, which is designed to operate automatically, stably, and responsively when detecting changes in item conditions inside the locker. It is also able to manage distance readings from the HC-SR04 ultrasonic sensor, record time using the DS3231 RTC, and display testing log results through the Serial Monitor.

### 1) System Initialization

The first stage of the software is the system initialization process, during which the ESP8266 performs the initial configuration of all connected hardware. Serial communication is enabled at a baud rate of 115200 bps for debugging purposes, while the Wire.h and RTClib.h libraries are initialized to support I2C communication and time reading from the DS3231 RTC. In addition, internal variables such as status change flags, previous item status, current item status, and threshold values are initialized. Before the distance monitoring process begins, this stage ensures that the system is in a ready state.

*2) Distance Measurement Using the Ultrasonic Sensor*

Distance measurement is performed continuously using the time-of-flight method, in which the HC-SR04 sensor measures the travel time of ultrasonic waves from the sensor to the object and back to the sensor. The program sends a trigger pulse for 10 microseconds to the Trig pin, then receives the reflected signal through the Echo pin. The echo duration is calculated using the pulseIn() function and converted into distance using Equation (1). Data updates are performed periodically every 500 ms to reduce noise and obtain stable results. The measured distance becomes the basis for determining the item condition inside the locker.

*3) Determination of Item Condition Based on Threshold*

After the distance is measured, the software determines whether the item is inside the locker or has been retrieved by comparing the distance value with the threshold obtained from testing. The logic used is as follows:

- If distance < threshold, then status = Item Present
- If distance ≥ threshold, then status = Item Retrieved

The program detects status changes by comparing the current status with the previous status. The system records events only when a transition occurs from "Present to Retrieved" or vice versa. This method prevents repeated logging caused by minor instability in sensor readings.

*4) Time Recording Using the DS3231 RTC*

All changes in item status are recorded using the actual time from the DS3231 RTC. The system records the time when the item is placed and stores it as the placement time. Conversely, when the item is retrieved, the system records the retrieval time and calculates the storage duration based on the difference between the retrieval time and the placement time. The DS3231 RTC is selected due to its high accuracy, temperature compensation capability, and ability to continue operating even when the ESP8266 loses power, thanks to its backup battery.

*5) System Output Log Management*

The software generates real-time logs containing information on distance readings, item status, placement time, retrieval time, storage duration, and timeout status. These logs are essential for verifying whether the system operates as designed and serve as the basis for analyzing sensor stability at the four positions (CT, CB, LM, RM).

*6) Overall Program Flow*

The software workflow runs repeatedly within the loop() function. The system starts by reading distance data from the ultrasonic sensor. The measured value is then compared with the threshold value to determine the item status as "present" or "retrieved." If a status change is detected, the event time is recorded by the DS3231 RTC and logged through the Serial Monitor. After the logging process is completed, the program returns to the distance monitoring process consistently. This process is illustrated in a structured manner in the overall program flowchart, as shown in Figure 5.

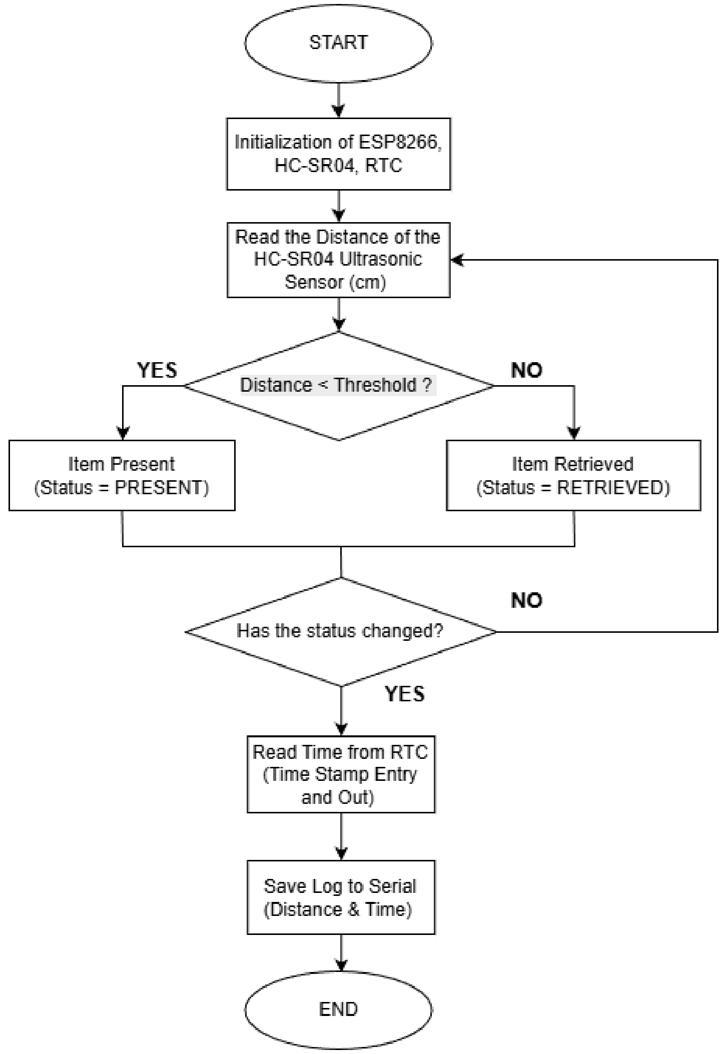



Figure 5 Flowchart of the Item Retrieval Detection System

## III. RESULT AND DISCUSSION

Data were collected using an ultrasonic sensor HC-SR04 installed at four different positions inside the locker. For each sensor installation position, a total of ten experimental trials were conducted, consisting of five tests under empty locker conditions and five tests under occupied locker conditions. During each trial, the sensor continuously measured the distance between the sensor and the detected object, and the readings were recorded by the ESP8266 microcontroller.

Overall, a total of 125 distance reading samples were obtained from all test scenarios. Repeated measurements were intentionally performed to ensure the consistency of the distance reading patterns and to reduce the influence of momentary noise, signal fluctuations, and reflection variations inside the locker. The collected distance data were then used to evaluate the sensor performance at each position by analyzing the average reading values, deviation of measurements, and classification accuracy relative to the predefined threshold.

### A. *Ultrasonic Sensor Testing*

Ultrasonic sensor testing using the HC-SR04 was conducted at four installation positions inside the locker, namely center top (CT), center back (CB), left middle (LM), and right middle

(RM). This testing aimed to evaluate the sensor's ability to distinguish between two primary system conditions: when an item is present inside the locker and when the item has been retrieved. Distance data were collected through periodic sensor readings and analyzed using boxplot visualization to examine data distribution, median values, data dispersion, and their relationship to the predefined threshold.

The results indicate that each sensor position produces distinct data distribution characteristics due to differences in sensor orientation, ultrasonic reflection angles, and locker geometry. Under empty locker conditions, the boxplot appears as a thin line at several positions because the lower quartile, median, and upper quartile values coincide, indicating very low data variability. The Center Back (CB) position demonstrates the most optimal performance, with the median value located closest to the threshold, resulting in the highest detection accuracy. The LM and RM positions exhibit moderate data dispersion with median values farther from the threshold, while the CT position shows more stable readings but is more susceptible to misclassification due to its median being near the classification boundary. These findings confirm that the proximity of the central tendency to the threshold has a greater impact on system accuracy than measurement stability alone [5], [6].

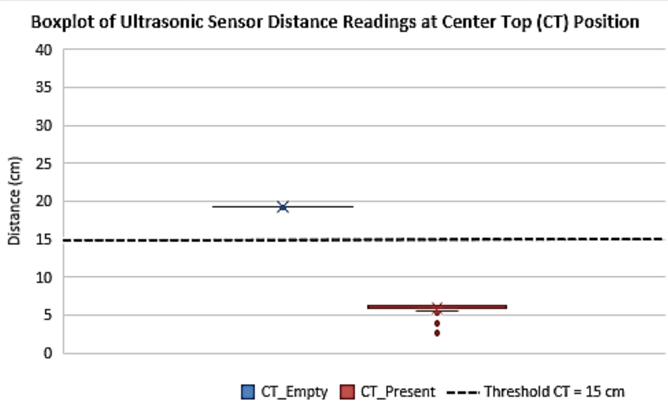



Figure 6.1 Boxplot of Ultrasonic Sensor Distance Readings at the Center Top (CT) Position

The boxplot at the Center Top (CT) position shows a relatively narrow interquartile range, indicating a high level of distance reading stability. This observation is consistent with the standard deviation value of 6.70 cm, which is the lowest among all sensor positions. Based on Table II, the mean distance reading at the CT position is 13.10 cm, while the applied threshold is 15 cm, resulting in a difference of −1.67 cm. This close proximity to the classification boundary increases the susceptibility to misclassification caused by minor measurement fluctuations. Consequently, despite its stable readings, the CT position achieves an accuracy of 88.67%, which is lower than that of the CB position.

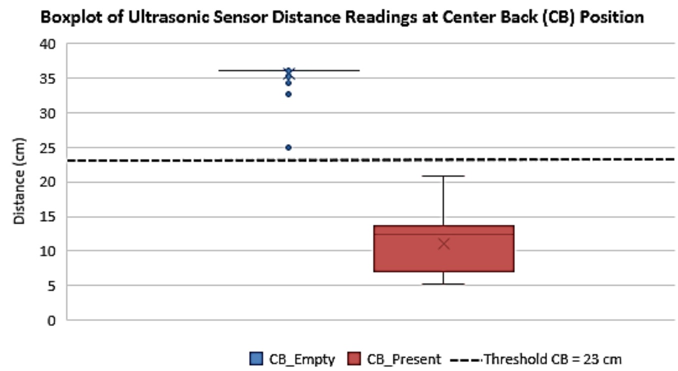



Figure 6.2 Boxplot of Ultrasonic Sensor Distance Readings at the Center Back (CB) Position

The Center Back (CB) position exhibits a wider data distribution, as indicated by a larger interquartile range and the highest standard deviation of 12.67 cm. However, the boxplot shows that the central tendency of the data is located closest to the threshold value. According to Table II, the mean distance reading at the CB position is 24.63 cm, which is very close to the threshold of 23 cm, with a difference of +1.63 cm, representing the smallest margin among all positions. Despite higher data variability, this position achieves the highest detection accuracy of 92.90%, demonstrating that proximity to the threshold has a greater impact on accuracy than measurement stability alone.

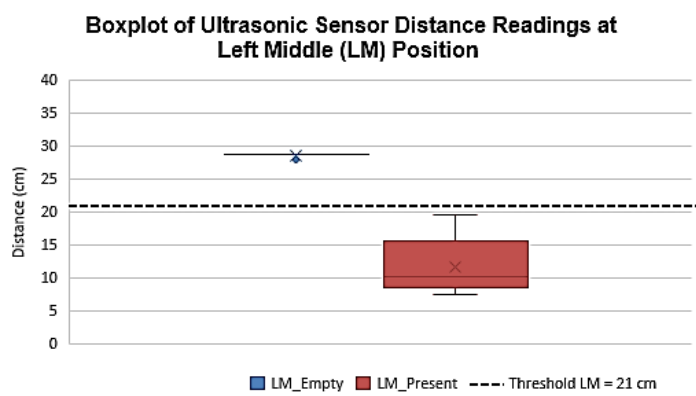



Figure 6.3 Boxplot of Ultrasonic Sensor Distance Readings at the Left Middle (LM) Position

The boxplot at the Left Middle (LM) position indicates a moderate level of data dispersion, supported by a standard deviation of 8.93 cm. The mean distance reading at this position is 18.89 cm, with a threshold value of 21 cm, resulting in a difference of −2.11 cm. This larger margin compared to the CB position reduces the system's sensitivity to changes in locker conditions. As a result, the LM position achieves an accuracy of 89.96%, indicating satisfactory performance but not optimal detection capability.

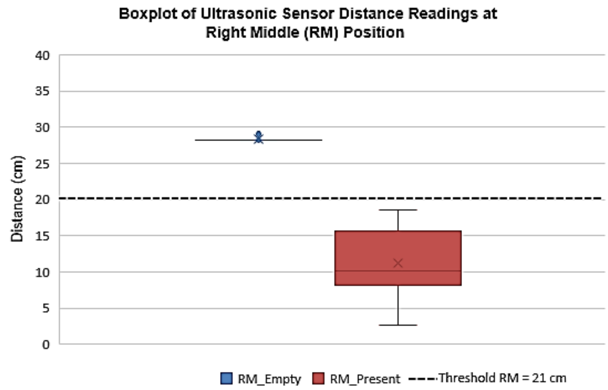


Figure 6.4 Boxplot of Ultrasonic Sensor Distance Readings at the Right Middle (RM) Position

The Right Middle (RM) position shows characteristics similar to those of the LM position, with moderate data dispersion reflected by a standard deviation of 9.35 cm. The mean distance reading at the RM position is 18.48 cm, while the threshold remains 21 cm, resulting in the largest difference of −2.52 cm among all positions. This large margin leads to the lowest system sensitivity, producing the lowest detection accuracy of 88.00%.

Figure 6 presents a comparative boxplot analysis of ultrasonic sensor distance readings across the four sensor placement positions. The Center Back (CB) position demonstrates the most distinct separation between locker conditions, with the central tendency of its data located closest to the threshold and the highest detection accuracy of 92.90%. In contrast, although the Center Top (CT) position exhibits the most stable readings, it is more prone to classification errors due to its mean value being close to the threshold. These results confirm that the proximity of distance readings to the threshold has a greater influence on system accuracy than measurement stability alone.

## *B. Analysis of Average Distance*

The average distance value, or mean, was obtained from all test data at each sensor position to evaluate the tendency of sensor readings at each position [11]. This mean value represents the dominant distance of the object measured by the sensor while the object is inside the locker.

TABLE II
AVERAGE SENSOR READING VALUES AT EACH POSITION

| Position | Average (cm) / Mean |
|---|---|
| CT | 13,10 cm |
| CB | 24,63 cm |
| LM | 18,89 cm |
| RM | 18,48 cm |

The calculation results show average values of 13.10 cm (CT), 24.63 cm (CB), 18.89 cm (LM), and 18.48 cm (RM). The CB position has the average value closest to the threshold, making it the most sensitive in distinguishing between the “Present” and “Retrieved” conditions. Conversely, the RM position has the average value farthest from the threshold, indicating that under one condition the readings tend to be more stable. The CT and LM positions fall into the intermediate category, with sufficiently clear distance differences, although both still have the potential to fluctuate relative to the threshold value. These results indicate that the sensitivity and accuracy of the detection system are strongly influenced by the proximity of the mean value to the threshold.

## *C. Analysis of Standard Deviation*

Standard deviation is used to measure the stability level of sensor readings at each installation position. This parameter is important because a good detection system does not only require an average value close to the threshold, but also stable data that does not fluctuate significantly [10]. The standard deviation calculation was performed using the sample standard deviation formula shown in equation (2):

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{n-1}} \qquad (2)$$

where represents the standard deviation, $xi$ s the i-th reading value, $\mu$ is the average reading, and $n$ is the number of data samples. This formula is used because the test data represent a sample of all possible sensor readings.

TABLE III
STANDARD DEVIATION OF SENSOR READINGS

| Position | Standard Deviation |
|---|---|
| CT | 6,70 cm |
| CB | 12,67 cm |
| LM | 8,93 cm |
| RM | 9,35 cm |

Based on the results in Table III, the CT position has the smallest standard deviation of 6.70 cm, indicating the most stable readings among all positions. In contrast, the CB position has the largest standard deviation of 12.67 cm, indicating the most fluctuating readings due to the influence of additional reflections from the back wall. Meanwhile, the LM and RM positions fall into the medium stability category, with standard deviation values of 8.93 cm and 9.35 cm, respectively, which are still adequate to support the detection process.

A low standard deviation indicates a high level of precision. Therefore, although the CT position is not the most accurate in classification, it remains the position with the best stability. Conversely, the CB position, which achieves the highest accuracy, exhibits the greatest fluctuation. This indicates that accuracy and stability may move in different directions, and therefore both parameters must be evaluated together to determine the most optimal sensor position.

## *D. Distance Margin Analysis (Difference between Mean and Threshold)*

Distance margin represents the difference between the average sensor reading value (μ) and the threshold value (T), which is used to evaluate the system’s ability to distinguish between the “Present” and “Retrieved” conditions. The smaller this difference, the more sensitive the system is to changes in the locker condition.

The analysis results show that the CT position has a margin of −1.67 cm, CB +1.63 cm, LM −2.11 cm, and RM −2.52 cm. The CB position has the smallest distance margin, indicating that its average reading value is the closest to the classification boundary. This condition allows the CB position to detect changes in locker status more responsively, since even small distance changes are sufficient to distinguish between the two conditions.

In contrast, the RM position has the largest distance margin, causing its readings to be more stable under a single condition but less sensitive to changes. The LM and CT positions fall within an intermediate range, where LM remains relatively stable despite having a larger margin, while CT, although having a smaller margin, is more prone to misclassification due to higher variation in readings.

The combination of a small distance margin and stable readings is the main reason why the CB position achieves the highest accuracy compared to the other positions.

### E. System Accuracy Analysis

Accuracy is used to evaluate how well the system can distinguish locker conditions when it contains an item and when it is empty. The determination of these conditions is based on comparing the ultrasonic sensor distance readings with the threshold value, which is defined as the boundary separating the two conditions. Therefore, the accuracy of threshold determination and sensor positioning has a significant impact on the overall system performance. Accuracy is calculated using a relative error approach with respect to the threshold, as shown in the following equation:

$$Accuracy = \left(1 - \frac{|\mu - T|}{T}\right) \times 100\% \qquad (3)$$

Equation (3) indicates that accuracy increases as the average sensor reading value (μ) approaches the threshold (T), since a smaller difference results in a lower relative error.

The test results show that the CB position achieves the highest accuracy of 92.90%, followed by LM at 89.96%, CT at 88.67%, and RM at 88.00%. The high accuracy at the CB position occurs because its average reading value is very close to the threshold, so even with some reading instability, the system can still classify the locker condition correctly. In contrast, the RM position has the lowest accuracy because its average reading value is the farthest from the threshold, resulting in a larger relative error. These results indicate that system accuracy is not solely determined by the stability of sensor readings, but is also strongly influenced by proper threshold selection and the proximity of the average reading value to the threshold, which is closely related to the sensor position inside the locker.

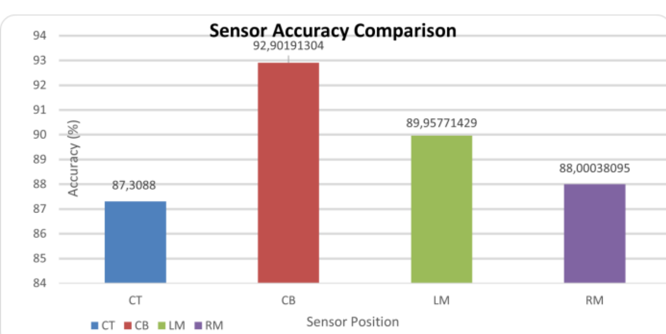



Figure 7 Sensor Accuracy Comparison Graph

The graph in Figure 7 illustrates the accuracy comparison of each sensor position more clearly. It can be seen that the CB position performs best, while the RM position shows the lowest performance. This visualization not only reinforces the numerical results but also makes it easier to identify the most effective sensor position for the system.

### F. Factors Causing Differences in Sensor Accuracy

Differences in accuracy among ultrasonic sensor positions were analyzed based on quantitative test data, including the average distance reading values (mean), standard deviation, and classification accuracy relative to the threshold value used in the system. The primary factor influencing accuracy differences is the position of the mean distance reading relative to the threshold. Based on the data in Table II, the sensor at the CB position has the mean value closest to the threshold, resulting in the highest accuracy, whereas the sensor at the CT position has a larger mean deviation from the threshold, leading to increased misclassification and reduced accuracy. These results indicate a direct relationship between the proximity of the mean value to the threshold and system accuracy, as also reported in previous studies [1], [12].

The next factor is the variation in distance readings, represented by the standard deviation value. Test data show that the CB position has a larger standard deviation compared to the LM position, indicating higher variation in distance readings. This condition is related to the placement of the CB sensor near the front wall of the locker, which allows additional reflections (multipath reflections) to occur. Nevertheless, the mean value at the CB position remains close to the threshold, so the increased data variation does not significantly affect system accuracy.

At the CT position, although the standard deviation value is relatively smaller, the resulting accuracy remains lower because the mean reading value is farther from the threshold. This finding confirms that reading stability alone is insufficient to guarantee high accuracy if the average reading position is not optimally located relative to the classification boundary.

In addition, the geometric configuration of sensor placement also affects measurement results. Sensors at the CB and LM positions, which are installed with orientations closer to being perpendicular to the object surface, produce more consistent distance readings, as reflected by the standard deviation values and data distribution in the test graphs. In contrast, the sensor orientation at the CT position, which is less perpendicular, alters the characteristics of ultrasonic wave reflections, resulting in a shift in the mean value and a decrease in accuracy. These findings are consistent with the operating principles of time-of-flight-based ultrasonic sensors reported in previous literature [3], [5], [14], [15].

## IV. CONCLUSION

The item retrieval detection system for lockers based on the HC-SR04 ultrasonic sensor developed in this study was successfully implemented and thoroughly tested. The system is capable of automatically detecting whether the locker is occupied or empty and consistently recording event timestamps using the DS3231 RTC module. The test results indicate that the sensor placement position has a significant effect on system accuracy, where the Center Back (CB) position provides the best performance with the highest accuracy of 92.90%. This result is achieved because the average sensor reading at the CB position is closest to the threshold value, allowing relative errors to be minimized despite fluctuations caused by reflections inside the locker. These findings demonstrate that the proximity of sensor readings to the threshold has a greater influence on accuracy than reading stability alone. Although the system has demonstrated good performance, this study still has limitations, as only one sensor was used in each locker and the tests were conducted under relatively controlled environmental conditions. Therefore, future research is recommended to explore the use of more than one ultrasonic sensor in a single locker to improve system reliability and accuracy, as well as to reduce the effects of multipath reflections.

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