Standard Calibration Tool Lending System With Iot Integrated Fingerprint Identification At PT Sentral Tehnologi Managemen

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Abstract – *The Internet of Things (IoT) is a network of interconnected devices that enables these objects to collect and exchange data. IoT offers an efficient solution for various fields, including the database recording of borrowing and returning calibration standard measuring instruments. This research aims to design and implement an automated IoT-based borrowing and returning system to support database recording effectiveness. The focus of this research includes the design of the borrowing and returning system, the method of transmitting data to Google Sheets, and email notifications when borrowing or returning activities occur. The research methods include the design of hardware consisting of a fingerprint sensor, infrared sensor, ESP32 microcontroller, liquid crystal display (LCD), and 4x4 keypad, as well as database recording to Google Sheets utilizing Google Sheets scripts and email notifications via Simple Mail Transfer Protocol (SMTP) connection. The research results show that the system was successfully developed with a high success rate for personnel identification accuracy, reaching up to 92%, with an average identification time of 1.42 seconds. Additionally, the developed system proved to be an effective solution for replacing the manual borrowing system, based on a survey of laboratory personnel.*
Keywords*: IoT, fingerprint, database recording, email notification.*

1. Introduction

Technological advancements have continuously driven the development of precision measurement tools and data management systems. The evolution of technology has progressed from the early industrial revolution—marked by the introduction of steam engines and electrical power to the era of automated systems, and now to modern technologies such as the Internet of Things (IoT) and artificial intelligence (AI) [1], [2]. These advancements have facilitated significant improvements in efficiency, accuracy, and reliability across operational processes. In particular, data acquisition systems have transitioned from manual recording toward digital and computer-based platforms. In the context of Industry 4.0, interconnected devices allow real-time monitoring, remote system access, and seamless integration of data streams through internet-based infrastructures, leading to smarter and more responsive environments.

These technologies are widely applied in various fields of life, including data collection, moving from conventional manual recording methods to modern computer-based systems. In Industry 4.0, most systems are interconnected via the internet, enabling real-time monitoring and control. [3], [4]. This manual approach allows records to be accessed only at the physical location of the logbook, making data transparency and oversight limited. Additionally, manual identity verification during borrowing opens the possibility of data falsification or the misuse of another person’s identity. The accumulation of physical documents also increases administrative workload and paper waste, highlighting the inefficiency of the current system. Therefore, transitioning to a more systematic, digital, and accountable equipment lending process is necessary to ensure operational reliability and proper documentation.

To address these challenges, several studies have proposed IoT-based systems to improve inventory and loan management. For example, IoT-based inventory systems evaluated using the ISO/IEC 25010 quality framework have shown improvements in accuracy, efficiency, and real-time monitoring capabilities within academic environments [5]. Similarly, systems integrating radio frequency identification (RFID) and web-based databases have been implemented to support automated tracking and notifications of equipment movement. Implementations in library settings demonstrate that digital loan logging combined with automated alerts such as Telegram bot notifications can significantly enhance oversight, reduce unauthorized borrowing, and provide better access to historical records. These findings reinforce that IoT-connected platforms can transform conventional borrowing systems into transparent and efficiently controlled operations.

In parallel with IoT innovations, biometric authentication technologies have also advanced rapidly. Fingerprints, which are unique and permanent for each individual, have become one of the most widely used biometric identifiers. Applications range from attendance systems and secure door access to authentication for personal electronic devices [6], [7]. Recent research integrating fingerprint sensors with microcontrollers and web-based databases demonstrates improved system security and accuracy in identifying users across various settings, including laboratories and campuses [8]. Such systems ensure that only authorized personnel can borrow equipment and facilitate verifiable records for each loan event, thereby enhancing traceability and accountability.

Based on these technological trends and challenges, this resarch proposes the development of a fingerprint-based IoT tool loan management system equipped with infrared sensors to detect equipment availability in real time. The integration of fingerprint authentication ensures secure and accurate identification of borrowers, while the infrared detection mechanism provides automatic monitoring of tools entering or leaving the storage system. This innovation is expected to improve efficiency, accuracy, and traceability in calibration laboratory operations compared to conventional manual logbook systems. The system is designed to streamline loan and return procedures, reduce administrative workload, prevent unauthorized equipment usage, and support more transparent data management. This research also includes system testing and evaluation to assess performance, usability, and reliability relative to existing manual practices.

2. Method

Quantitative research is a systematic and structured method characterized by clear stages and procedures, with the primary objective of explaining or describing social phenomena. Compared to qualitative research, which focuses on narrower issues with limited variation, quantitative research generally addresses broader and more diverse problems [9].

The purpose of quantitative research is to produce findings that can be generalized. By employing statistical approaches, the results of data analysis can be interpreted computationally, thereby allowing conclusions to represent the characteristics of the population under study.

This research method requires empirical evidence in the form of numerical data, which is subsequently analyzed using mathematical or statistical techniques. The use of large datasets ensures that the results obtained are reliable and representative of the population.

In terms of research design, quantitative research is divided into two categories: experimental design and non-experimental design. Experimental design is conducted under controlled conditions to demonstrate a known truth or to test the validity of a hypothesis. Its defining feature is control, which distinguishes it from non-experimental design, where external influences are not managed.

2.1. Research Tools

In this study, the research tools are categorized into two main types, namely hardware and software. The hardware components include sensors, microcontrollers, fingerprint modules, infrared detectors, and network communication devices that operate as the primary elements for data acquisition and system control. Meanwhile, the software components consist of the embedded firmware for device operation, web-based applications for data management and monitoring, and database systems for storing and processing recorded information. Together, these hardware and software components form an integrated system that supports real-time data collection, authentication, and monitoring within the tool lending workflow.

2.1.1. Hardware

In the hardware design stage, all components that namely the keypad, LCD, ESP32 microcontroller, infrared sensor, and fingerprint sensor are integrated into a single system. The schematic of the design is presented in Figure 1, where the components are labeled as follows: (1) keypad, (2) LCD, (3) ESP32 microcontroller, (4) infrared sensor, and (5) fingerprint sensor. Furthermore, the hardware implementation is illustrated in Figure 2, which shows four fingerprint sensors installed on each level of the cabinet and a control panel positioned adjacent to the cabinet.

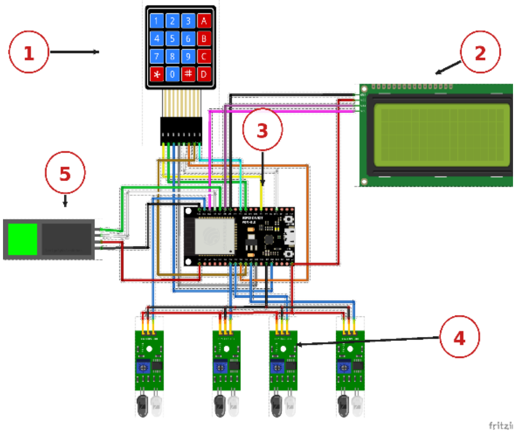


Figure 1. Schematic design.


Figure 2. Hardware desig

A. ESP32

ESP32 is a type of microcontroller that is included in the SoC (System on Chip) type equipped with integrated Wi-Fi 802.11, dual-mode Bluetooth version 4.2, and various peripherals. ESP32 consists of a series of low-power embedded systems developed by Espressif System [10]. This microcontroller is the next generation of the 8266 version which prioritizes the implementation of two cores (two cores) with a clock speed of up to 240 MHz. ESP32 also has more pins than the 8266 version [11]. ESP32 is equipped with a dual-core Tensilica microprocessor that has higher processing power and can facilitate multitasking and execution of complex and efficient tasks. Peripherals owned by ESP32 include SPI, I2C, UART, and PWM. The programming language commonly used on the ESP32 is C++, which is most commonly used using the Arduino IDE or platformIO software [12]. The physical form of the ESP32 is shown in Figure 3 [13].


Figure 3. ESP32.

ISSN (e): 2540-9123
ISSN (p): 2502-1982

B. Fingerprint Sensor AS608

Fingerprint sensor is a system that scans and analyzes the user's fingerprints and verifies a person's identity. Sensor that functions to detect fingerprints which are phenotypic genetic features that people have since birth and are formed at the fingertips [14]. The physical form of the fingerprint sensor looks like in Figure 4. There are 3 types of fingerprint sensors, namely optical fingerprint recognition, capacitive fingerprint recognition, and ultrasonic fingerprint recognition. Optical fingerprint recognition or optical fingerprint sensors use the principle of refraction and reflection of light to produce images, have replaced ink to obtain fingerprints since the invention of computers. Charge-coupled devices are the central elements of optical scanning systems (CCD and CMOS). Existing fingerprint sensors can be categorized as capacitive or optical. The optical type has a smaller size (4×0.9 mm^2) and greater resolution, consists of an optical binder with the same refractive index as the overlay glass, and has a single shear direction. Capacitive and inductive fingerprint sensors share a "flat" plate with hundreds of integrated semiconductor devices and a surface layer that is generally several microns thick. The unevenness of the fingertip fingerprint, the actual distance between the bumps and bumps that touch the plate varies when the finger is placed on the surface of the capacitive sensor, resulting in different capacitance values. Ultrasonic fingerprint sensor is the most precise and accurate instrument for obtaining fingerprint images. There are two main imaging techniques: pulse echo imaging and impedance imaging. Ultrasonic fingerprint imaging is based on the reflection effect of ultrasound as it propagates in different impedance media. When a finger is placed on the touchpad of a mobile phone, the pressure sensor detects the pressure and sends an electrical pulse to activate the ultrasonic fingerprint sensor, which emits an electrical pulse wave. Due to the difference in acoustic impedance between human tissue and air, the echo amplitude of human tissue is larger than that of air therefore, the weave pattern can be determined by determining the echo amplitude at each point [15], [16]. The sensor used in this study is the AS6088 which is a type of optical fingerprint sensor [17].

Figure 4. Fingerprint sensor.

C. Infrared Sensor FC-51

The FC-51 infrared sensor is a type of proximity sensor, namely a sensor that functions as a detector of changes in the distance of an object or thing. This sensor consists of two elements, namely an infrared light source and an infrared light detector. Both of these elements are included in the photodiode. The infrared light source used in the FC-51 infrared sensor module is an infrared LED. Infrared LED is a type of LED that emits infrared light so that it is invisible to the human eye [18], [19]. Figure 5 is a visualization of the infrared FC-51 [20].

ISSN (e): 2540-9123
ISSN (p): 2502-1982

Figure 5. Infrared sensor.

D. Liquid Crystal Display (LCD) 20x4

In this study, the measured values need to be presented to the user in a clear and readable format. To achieve this, a 20x4 Liquid Crystal Display (LCD) was employed, which is a low-power digital data presentation element capable of conveying measurement results to humans efficiently [21]. The layout and appearance of the 20x4 LCD used in this research are shown in Figure 6.

Figure 6. LCD 20x4 [22].

E. Keypad 4x4

In this study, the system requires input to function properly. A 4x4 keypad was employed to provide numerical or selection input, which is converted into ASCII code for processing by the microcontroller [23]. Figure 7 illustrated the 4x4 keypad used, showing the arrangement of keys and labeling relevant to system operation [24].

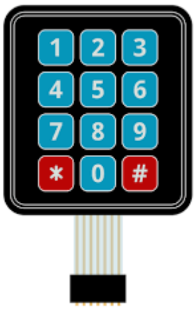


Figure 7. Keypad 4x4.

2.1.2. Software

A. Arduino IDE

Arduino IDE (Integrate Development Environment) is software used to create, edit program code, verify, and upload program code to Arduino. Arduino uses its own programming language. Arduino IDE consists of a text editor for creating and editing program code, a message area, a text console, and a tool bar and buttons with general functions. Programs created using the Arduino IDE software are called “sketch” written in a text editor and saved in the form of an extension “.ino” [25]. The Arduino IDE program flowchart is shown in Figure 8.

In Figure 8, the Arduino program was created with the required variables defined as global variables. The void setup function was executed to initialize and configure the necessary device functions. After initialization, the program entered a loop that started with detecting the device’s

ISSN (e): 2540-9123
ISSN (p): 2502-1982

presence using the infrared sensor. Next, the program handled registration or loaning via fingerprint identification. If the device had not been registered, personnel registered their fingerprint by entering an unregistered ID number. If the fingerprint was already registered, the registration step was skipped, and the device could be borrowed or returned directly. The process began with fingerprint verification, followed by device selection. When the device was available, the borrowing data was automatically recorded in a Google Sheet, and a notification email was sent.

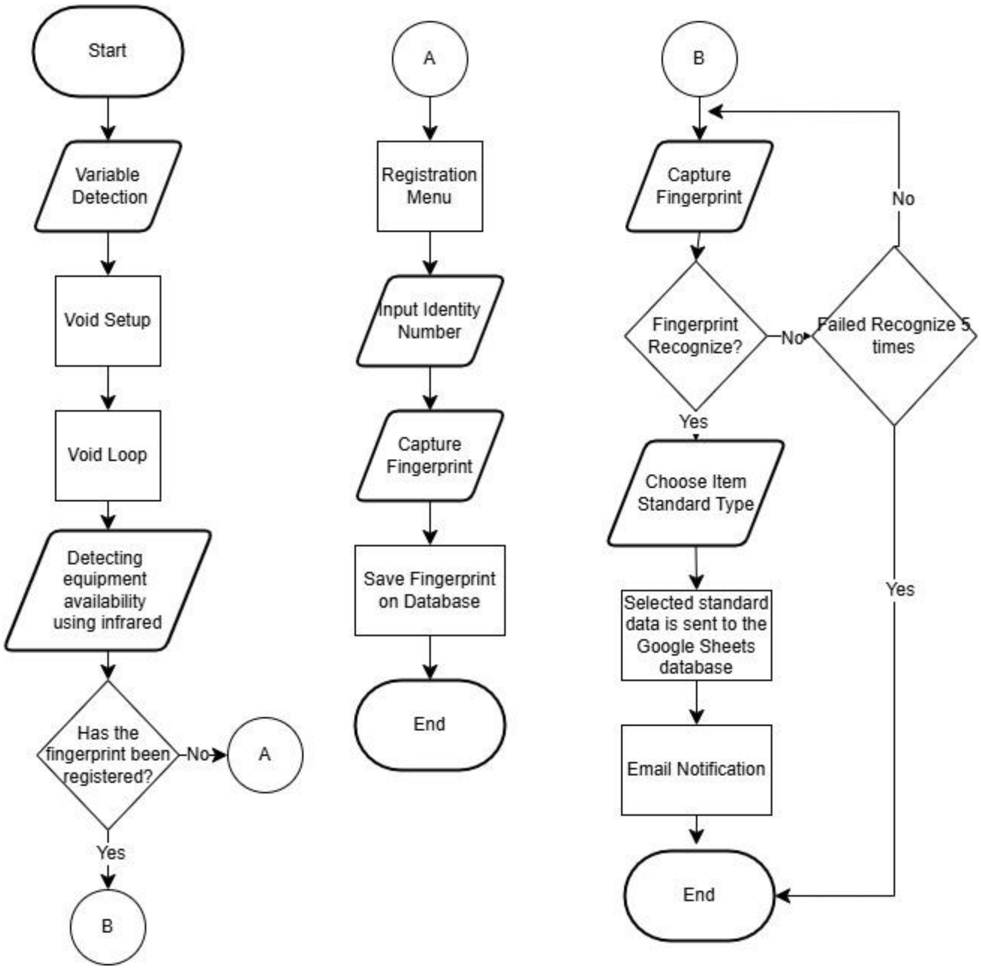


Figure 8. Flowchart Arduino IDE.

B. SMTP

SMTP stands for Simple Mail Transfer Protocol, an email protocol that is primarily focused on sending emails. In addition, this protocol is connected to POP3 and IMAP to receive emails online. In essence, SMTP is a set of instructions used to authenticate and control the flow of emails. SMTP is based on TCP (Transmission Control Protocol), which ensures email delivery. SMTP uses several commands, such as the sender's email address, the recipient's email address, and the email content, to tell the server what to do. SMTP manages the sending and receiving of messages between the sending and receiving servers, processing the sending of headers containing information about the email being sent, and the email body containing the email content to the receiving server [26].

ISSN (e): 2540-9123
ISSN (p): 2502-1982

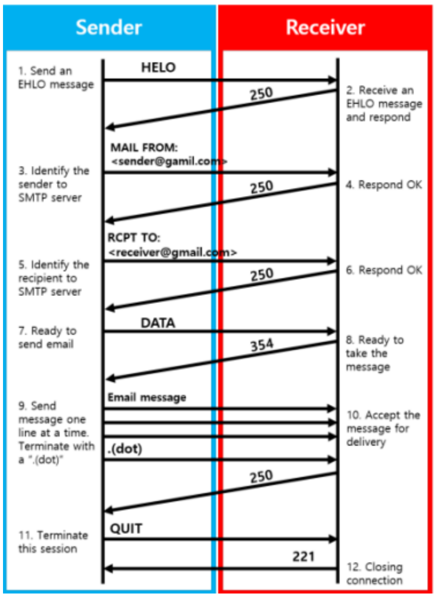


Figure 9. SMTP sequence diagram.

Figure 9 explains the SMTP sequence diagram. The picture explains how SMTP works. In the picture, the "MAIL" and "RCPT" commands determine the sender and recipient of the email. While the "DATA" command functions to send the contents of the email to the recipient. The recipient responds by sending the full command request code 250. The '.' (dot) command serves as a marker that the sending data has ended.

C. Google Sheet

Spreadsheets were created to organize the arrangement of information that the human brain cannot remember. Spreadsheets help human work in sorting and labeling in a way that makes sense, so that we can reference them and do calculations. Google Sheets is a spreadsheet application created by Google. Google sheets work like other spreadsheet tools, but because it is an online application, it offers more than most spreadsheet tools.

3. Results and Discussion

This lending and returning system begins with the personnel fingerprint registration process (enrollment) which is then given a unique identity. In the enrollment process, the optical fingerprint sensor detects the personnel's fingerprint to be entered into the database. The enrollment process is carried out 2 times fingerprint detection to improve the accuracy of fingerprint detection. This fingerprint identity database is stored in the memory provided by the fingerprint sensor module. After going through the enrollment process, personnel can borrow and return standard calibration tools.

The process of borrowing standard calibration measuring tools begins by selecting the menu provided, namely the enrollment, borrowing, and returning processes displayed on the LCD. When the tool borrowing and returning process is selected, personnel identify themselves using registered fingerprints. When the personnel's identity has been recognized, personnel can see the availability of the tool on the LCD as shown in Figure 10. There is a description of the availability represented by the letter 'Y' which states that the tool is available, and the letter 'N' which states that the tool is not available. Personnel can select the standard calibration measuring tool to be borrowed by inputting the identity number via the keypad provided and pressing the '#' button which functions as enter. The borrowing process is complete and the personnel identity data and the identity of the borrowed tool are recorded on the Google Sheet. In addition, there is an email notification stating that there is a tool borrowing and returning activity. Then the personnel can take the borrowed tool and will change the infrared sensor output condition on the borrowed tool so that the display on the LCD changes from the 'Y' condition to the 'N' condition.

Figure 10. LCD menu display.

3.1. Sensor Testing

The research conducted fingerprint and infrared sensor testing. Each sensor was tested for accuracy or the level of accuracy of the sensor function. The fingerprint sensor was tested for accuracy in detecting fingerprint identity and response time to detect the identity of each fingerprint. Meanwhile, for the infrared sensor, only accuracy testing was carried out in detecting objects.

3.1.1. Fingerprint sensor testing

Fingerprint sensor accuracy testing is done by testing registered fingerprints (enrolled). In this test, 10 different fingerprint identities were tested and repeated 5 times. The test results for each personnel are shown in Table 1.

Table 1. Fingerprint sensor testing.

Personnel	No. Identification	Test 1	Test 2	Test 3	Test 4	Test 5
AG	5	Ok	Ok	Ok	Ok	Ok
AH	6	Ok	Ok	Ok	Ok	Ok
AM	7	Ok	Ok	*Fail*	Ok	Ok
AR	8	Ok	Ok	Ok	Ok	*Fail*
DN	9	Ok	*Fail*	Ok	Ok	Ok
FH	10	Ok	Ok	Ok	Ok	Ok
IH	11	Ok	Ok	Ok	Ok	Ok
SH	4	Ok	Ok	Ok	Ok	Ok
SN	3	Ok	Ok	Ok	Ok	Ok
SY	2	Ok	Ok	*Fail*	Ok	Ok

Based on the test results in table 1 of the fingerprint test, there were several failures, therefore it is necessary to calculate the accuracy value of the fingerprint used.

$$Accuracy = \frac{True\ Positif + True\ Negatif}{True\ Positif + True\ Negatif + False\ Positif + False\ Negatif} * 100\%$$

$$Accuracy = \frac{46}{50} * 100\%$$

$$Akuracy = 92.0\%$$

In addition, a fingerprint identification time test was also carried out. This test aims to determine how long it takes for the fingerprint sensor to recognize the fingerprint. This test was carried out by sampling 1 personnel with a total of 30 repetitions. The purpose of the large number of repetitions is to ensure that the data taken is reliable.

Table 2. Time respon fingerprint identification.

testing	time (second)
1	1.59
2	1.37
3	1.48
4	1.47
5	1.40
6	1.56
testing	time (second)
7	1:38
8	1.32
9	1.45
10	1.38
11	1.25
12	1.27
testing	time (second)
13	1.34
14	1.30
15	1.39
16	1.29
17	1.28
18	1.51
19	1.49
20	1.57
21	1.48
testing	time (second)
22	1.43
23	1.39
24	1.40
25	1.48
26	1.51
27	1.46
28	1.52
29	1.53
30	1.42

Based on the test results in Table 2 of fingerprint identification time testing with identity no. 2, there is a variation in time when fingerprint identification is carried out. Therefore, it is necessary to calculate the average time required to carry out fingerprint identity identification time. The average identification time is calculated using equation 2.

$$x_{mean} = \frac{x_{1+}x_{2+}x_{3+} \ldots \ldots . x_n}{n}$$

$$x_{mean} = \frac{1.59 + 1.37 + 1.48 + \cdots 1.42}{30}$$

$$x_{mean} = 1.42 \text{ second}$$

The fingerprint sensor test was conducted and achieved an accuracy of 92%. This value was obtained by testing the fingerprint identity of 10 previously registered fingerprints using the enroll function implemented in the system. The accuracy test was repeated 5 times, resulting in a total of 50 fingerprint identification trials. Out of these, 4 attempts failed to detect the correct fingerprint. The failures included errors in identifying the fingerprint and one instance where no identity was detected. These failures were caused by factors such as dust on the sensor optics, incorrect hand positioning compared to the enrollment process, and sweaty fingers.

The response time for fingerprint identification was measured, yielding an average value of 1.42 seconds. This value was obtained from tests performed on a single fingerprint identity (identity number 2 in Table 1). The response time test was repeated 30 times to ensure consistency.

3.1.2. Infrared Sensor Testing

In this study, infrared sensors are used as a tool to detect the availability of calibration tools. The output of the infrared sensor used is in digital form, namely high or low conditions. Both of these conditions are used to detect the condition of the tool. The high infrared sensor condition indicates that the tool is available, while the low condition indicates that the tool is not available. Infrared sensor testing is carried out by recording the condition of the sensor output when no objects are given and when objects are given as in Figure 11, namely the condition of the infrared sensor when no objects or obstacles are given, and Figure 12 when objects are given.

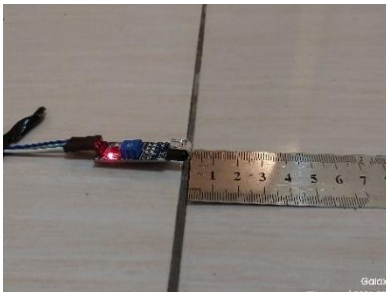


Figure 11. Infrared conditions without objects.

Figure 12. Infrared conditions with objects.

Infrared sensor testing was carried out on all sensors used. Each sensor was tested 30 times, with the number of repetitions chosen to ensure the reliability of the test data. Each infrared sensor was tested at distances of 3 cm, 3.5 cm, 4 cm, 4.5 cm, 5 cm, 5.5 cm, 6 cm, 6.5 cm, 7 cm, 7.5 cm, 8 cm, and 8.5 cm. In addition, the analog output values were recorded during the tests. These analog output values indicated that a value between 0–511 corresponded to a "high" output condition, whereas a value between 511–1023 corresponded to a "low" output condition. The "high" condition meant that the sensor had successfully detected the presence of an object, while the "low" condition meant that the sensor had failed to detect an object. The test results were taken as the average values presented in the infrared sensor test table. Figure 13 shows the test data for infrared sensor 1 as a sample of the changes in distance to the sensor.

Based on the results of the distance tests for infrared sensor 1, the sensor was determined to have a maximum detection distance of 7.5 cm. Variations in the analog output values were observed at distances from 3 cm to 7 cm. From 3 cm to 6.5 cm, no significant differences in the analog output values were detected, whereas at 7 cm and 7.5 cm, significant differences were noted compared to other measurements; however, the condition remained “high.” At 7 cm, the infrared sensor also displayed the “low” condition occasionally, similar to the results at 7.5 cm. At 8 cm and 8.5 cm, the analog output values reached approximately 1000, indicating a “low” condition. Figure 13 illustrates the changes in the analog output relative to the sensor distance.

ISSN (e): 2540-9123
ISSN (p): 2502-1982

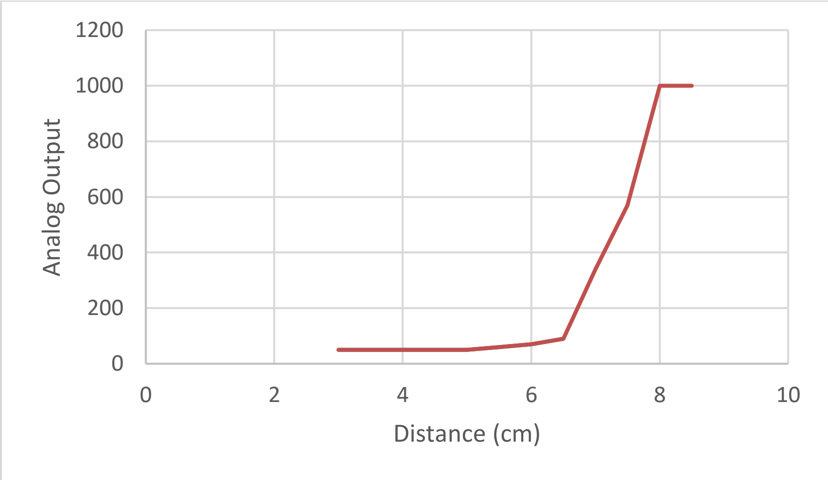


Figure 13. Effect of distance to infrared output.

In general, the test results of the effect of distance on the infrared sensor output have a 100% detection response at 3 cm to 5.5 cm. In addition, testing of the effect of the tilt angle on the infrared sensor was also carried out. This test was carried out on all infrared sensors used. The detection angle test method is that the sensor is given a tilt at a certain angle and given an object at a distance of 5 cm. The angle values selected in this test are -35º, -30º, -20º, -10º, 10º, 20º, 30º, and 35º.

Based on the results of testing the effect of the angle on infrared sensor 1, data was obtained that the infrared sensor has an optimal detection angle in the range of -20º to 30º has a stable analog output value and the infrared condition always displays the same condition when given an object at that distance. While at angle of inclination of -35º, -30º, and 35º the infrared sensor output condition is "low" and has an analog output value close to 1000. Figure 14 shows a visualization of the change angle to the infrared analog output.

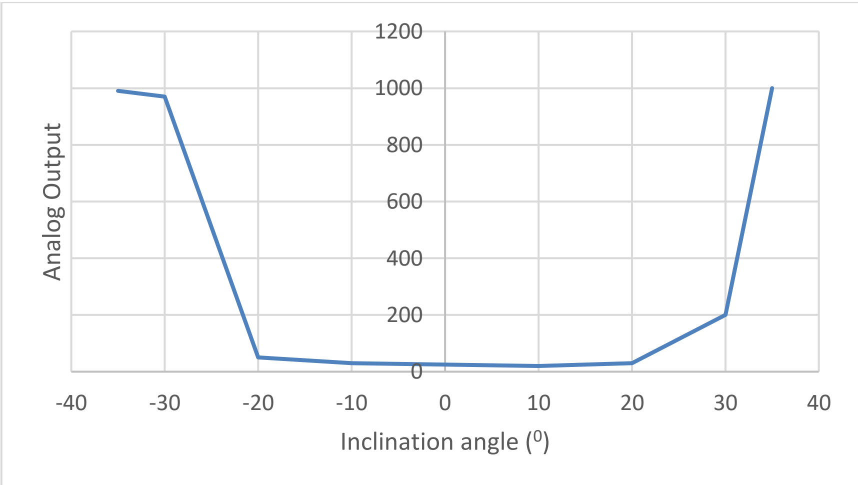
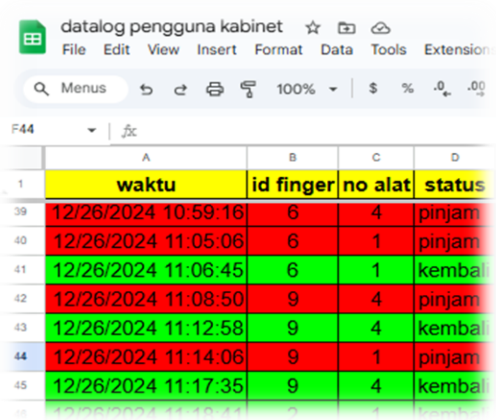


Figure 14. Effect of angle to infrared output.

In general, the results of testing the effect of angle on the infrared sensor do not have a significant effect on the range of up to -20 º to 30 º.

3.2. System Testing

System testing is conducted to determine overall performance. This system testing focuses more on data acquisition and email notification. Testing requires an internet network for data acquisition and sending email notifications. The test results obtained that the system successful recording in Google Sheet and email notification. The accuracy level of Google Sheet recording has an accuracy of 100% of the 40 testing which means there was no failure at all during testing. Data recording on Google Sheet is shown in Figure 15 as follows.



	waktu	id finger	no alat	status
39	12/26/2024 10:59:16	6	4	pinjam
40	12/26/2024 11:05:06	6	1	pinjam
41	12/26/2024 11:06:45	6	1	kembali
42	12/26/2024 11:08:50	9	4	pinjam
43	12/26/2024 11:12:58	9	4	kembali
44	12/26/2024 11:14:06	9	1	pinjam
45	12/26/2024 11:17:35	9	4	kembali

Figure 15. Data recording on google sheet.

Meanwhile, the accuracy level of email notification is 92.5%. In this email delivery process, there were 3 failed email delivery times out of a total of 40 attempts. The cause of the email delivery failure was the weak internet network strength. The results of sending notification emails are shown in Figure 16.

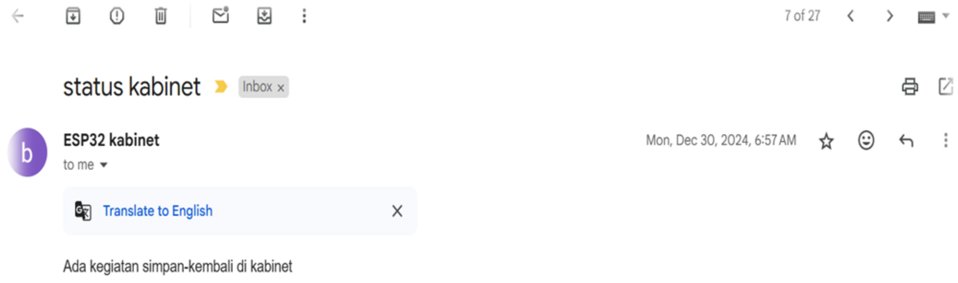


Figure 16. Email notification.

3.3. System Effectiveness

The research conducted is an implementation of a tool lending and returning system in a small scope and a limited tool database, namely 4 standard calibration tools and 10 laboratory personnel. Therefore, a survey was also conducted to determine the effectiveness of the system that has been created. The survey was made in the form of an online questionnaire in the form of questions regarding the ease and effectiveness of the system created. The survey was given to all laboratory personnel whose fingerprints were registered and had tried the tool lending and returning system. The survey was conducted by giving 5 questions to personnel. The questions given have linear scale answers ranging from 1 to 5. Scale 1 states very ineffective and scale 5 states very effective.

In general, the survey conducted gave positive feedback, as evidenced by the majority of respondents giving a scale value of 4 and 5 for each question. Therefore, the system created is effective enough to replace the manual tool lending and returning system.

4. Conclusion

Based on the results of the research and testing, a loan and return system for standard calibration measuring instruments was successfully developed using fingerprint identification. The system integrated fingerprint sensors for personnel verification, infrared sensors for tool

ISSN (e): 2540-9123
ISSN (p): 2502-1982

availability detection, Google Sheets as the database, and email notifications for updates. The personnel detection accuracy was 92%, while the infrared sensor detected objects with 100% accuracy within an effective distance of 3.5 cm to 5.5 cm and an angle of -20° to 30°. Compared to the manual lending process, the system improved time efficiency, database accuracy, and ease of access to lending records. Questionnaire results showed full support from respondents, indicating 100% approval for the system's implementation.

Acknowledgements

Praise and gratitude I pray to Allah SWT, because with His blessings and grace, I can complete this paper. Acknowledgements to my workplace PT. Sentral Tehnologi Managemen and Universitas Global Jakarta who have allowed this research to be carried out so that in the future it can be applied in real terms in the laboratory area. Thank you to the lecturers for their criticism, suggestions, and guidance so that this paper can be completed. The writing of this Journal was carried out in order to fulfill one of the requirements to obtain a Bachelor's degree and hopefully this journal can be useful for both the author and the reader.

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