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# Design and Development of Object Detection Radar with IoT-Based Matlab Software Visualization

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***Abstract*** – *Radar is an abbreviation for Radio Detection and Ranging, which means an electromagnetic wave system that functions to detect, measure and map objects in the surroundings. So far, the development of radar technology has tended to focus on object detection without considering effective integration and connectivity. Therefore, this research aims to develop a radar that can detect, measure and differentiate between moving and stationary objects. This research does not only pay attention to the detection aspect, but also integrates Matlab R2022a for visualization, Internet of Things (IoT) for centralized connectivity and the Blynk mobile application to increase the efficiency of object monitoring. This research uses ultrasonic sensors and Passive Infra-Red (PIR) sensors, ultrasonic sensors to read distance parameters and PIR sensors to detect moving or stationary objects. The ultrasonic and PIR sensors will be controlled by the ESP32 and serve as a centralized connectivity system that will connect to a Web server and mobile devices, while the Matlab R2022a software will visualize the environment around the radar at a 180o angle and connect with Thingspeak and the PushBullet mobile application. The results of the test are compared with a standard measuring instrument, namely a meter. In this research analysis, error calculations are used to see the uncertainty value of the sensor readings used. Based on research, the ultrasonic sensor reading accuracy results were 98.99% and for the PIR sensor the sensor could read every test angle starting from 30, 60, 90 120 and 150 degree, however at angles 30 and 150 degree it had quite a long delay.*

**Keywords** – *Object Detection; Radar; IoT; Matlab Visualization; Ultrasonic Sensor.*

## I. Introduction

RADAR is an abbreviation for Radio Detection and Ranging, referring to an electromagnetic wave system used to detect, measure, and map surrounding objects [1]. The principle of radar operation is unique, sending and receiving waves through ultrasonic sensors, which allows the waves to pass through low attenuation levels [2]. Waves, as a medium of vibration energy, have similar magnitudes, including frequency and period [3]. The length of radar waves emitted varies from millimeters to meters, capable of penetrating smoke, fog, and not dependent on sunlight [4]. With many wave characteristics, we can analyze the emitted waves. From the wave reflections, we can determine the location and direction of the wave reflections [5].

The development of radar technology has focused solely on detection systems and providing visualization without information such as distance and movement of objects [6]. One of the most important capabilities of radar is to perform monitoring both day and night, which provides a significant contribution to defense and security [7]. Monitoring sensor parameters plays an important role in the process of data and information collection; monitoring is a continuous activity, involving continuous commands in the recording and collection of measured information [8].

Although radar technology has become a key player in object detection and monitoring, challenges arise when integrating radar with wider systems, especially through IoT [9]. The Internet of Things (IoT) is a promising scientific development to optimize everyday life, enabling communication or interaction between humans, electronic devices, and the internet [10]. A range of studies have explored the integration of radar with IoT for various applications. Hong [11] and Jadhav [12] both focus on the use of radar in IoT for target detection, with Hong specifically addressing the detection of UAVs. Akan [13] and Cui [14] discuss the potential of integrating radar with IoT for improved sensing and communication, with Akan proposing the

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concept of an "Internet of Radars" and Cui highlighting the benefits of integrated sensing and communication. Chen [15] reviews the use of radar in low-power IoT applications, particularly in healthcare and indoor positioning. Finally, Zhang [16] presents a case study of a marine radar monitoring IoT system for target detection, using image segmentation and deep learning methods. These studies collectively demonstrate the potential of radar-IoT integration for a range of applications, from security and monitoring to healthcare and marine navigation. However, there is still a need to develop simpler and more integrated solutions, particularly in the field of visualization [17]. As one of the software capable of visualization and performing mathematical calculations, Matlab provides interesting features to solve visualization problems [18]. All information from the ultrasonic sensor reading parameters will be displayed on Matlab software, which will show the scanning results or also called a radar map [19]. Matlab will display the distance reading results with different and gradient colors according to the object distance, becoming red for the closest object distance [20].

Previous research has explored the potential integration between radar technology and IoT (Internet of Things). The ESP32 microcontroller answers these challenges, where the ESP32 has Wi-Fi connectivity, making it a centralized connection and integration system in the IoT field [21]. Not only that, but the ESP32 can also be integrated with Matlab, allowing us to visualize the ultrasonic sensor reading results [22].

Based on the previous description, the researchers took the initiative to develop a radar that can be used as a security aid, whether implemented at home or in areas prone to crime [23]. Therefore, this research aims to create a solution that can provide accurate and integrated information, allowing users to easily monitor and respond to detected objects through the IoT interface.

## II. Research Methods

The method used in this research is the Waterfall Method. The Waterfall Method is a method that outlines a systematic and sequential approach to obtain clear results and make it easy to identify errors [24]. This method consists of five interconnected stages.

### *i. Searching for Tool-Making References*

A range of studies have explored the connection of microcontrollers like Arduino and ESP32 with MATLAB. Safari [25] and Biswas [26] both present methods for connecting microcontrollers to MATLAB, with Safari focusing on Pyboard and Biswas on Arduino. Bhookya [27] and Anuradha [28] demonstrate the use of MATLAB for control and analysis of microcontroller-based systems, with Bhookya using an IoT-based liquid level monitoring system and Anuradha using an induction motor drive. Karaduman [29] and Trunov [30] propose model-driven development and wireless control of mobile devices, respectively, for ESP-based IoT systems. Zim [31] analyzes the speed of the Xtensa LX6 microprocessor for neural network applications by ESP32, and Ahmed [32] designs and implements a robotic arm controlled via IoT with Arduino ESP32. These studies collectively provide a comprehensive understanding of the connection between microcontrollers and MATLAB, offering various methods and applications. The researcher also requires references on the design and basic programming of Arduino and Matlab to enable communication between them. The found references indicate that connecting the micro controller with Matlab software requires a special Add-Ons called the Matlab Support Package for Arduino Hardware. With this Add-Ons, the researcher can connect the micro controller with Matlab software and perform programming for the micro controller through Matlab without using the Arduino IDE.

Another reference involves creating a radar display GUI using Matlab. GUI (Graphical User Interface) is a program interface that acts as a communication medium between the user and the software [33]. The GUI is used to display readings from the surrounding environment with gradient color indicators.

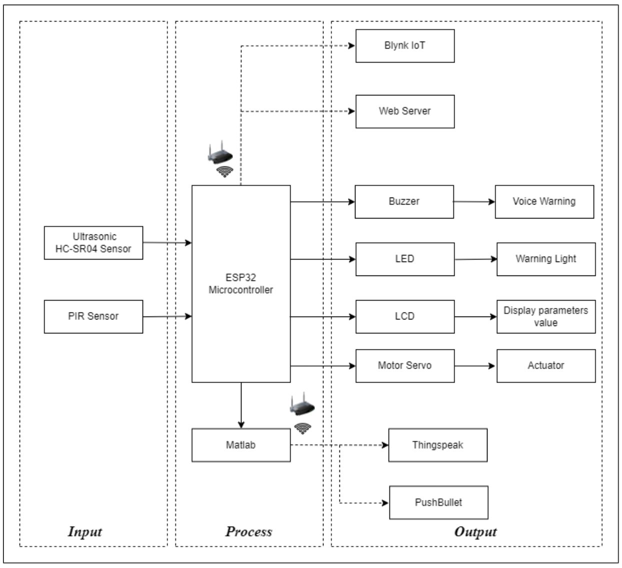


**Figure 1:** Process Diagram

### *ii. Tool Design*

The tool design aims to provide an overview and examine the suitability of the tool to be made. The tool

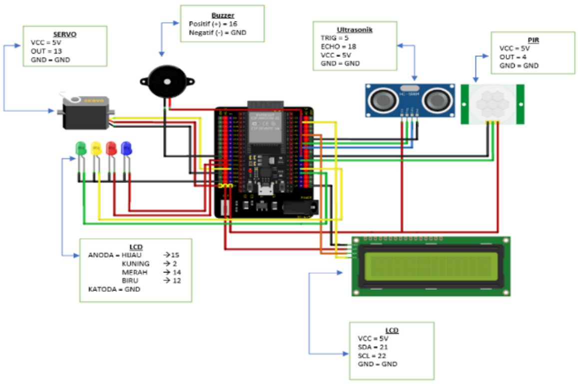


**Figure 2:** Electrical Circuit

design will show a process diagram (like Figure 1) to illustrate the flow of activities or processes of the tool being created. This stage also explains the input block used to collect data from sensors, then the process block will process the data obtained through the micro controller and Matlab. Finally, the output block will display the data processed by the micro controller and Matlab through hardware and software components.

### *iii. Tool Making*

The next stage is tool making, which involves two stages: mechanical and electrical construction. In the electrical stage, the adjustment between each component is essential to avoid short circuits and sensor reading noise. The electrical construction can be seen in Figure 2.

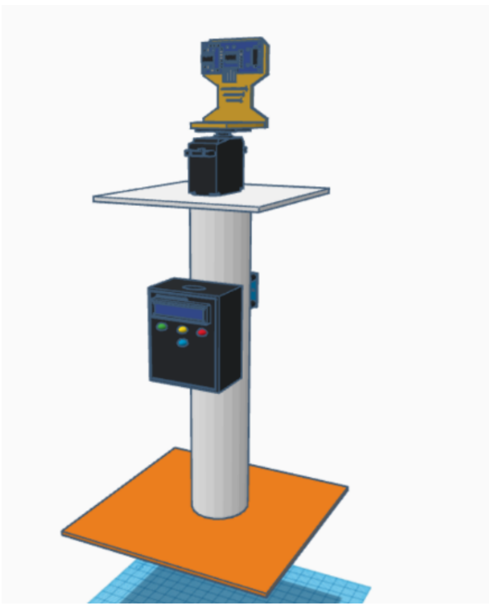

**Figure 3:** Mechanical Construction of the Tool

In the second stage, which involves tool making and placing each hardware component used to protect the electronic components from the surrounding environment that might damage them. The mechanical construction uses a black box measuring $14 \times 6cm$ and a pipe with a length of 60 cm. The mechanical construction of the tool can be seen in Figure 3.

### *iv. Tool Testing and Improvement*

Tool testing is used to determine whether the tool works well and follows the research process. The radar reading will be limited to two meters and there will be five reading angle points from the radar. The layout for tool testing is shown in Figure 4.

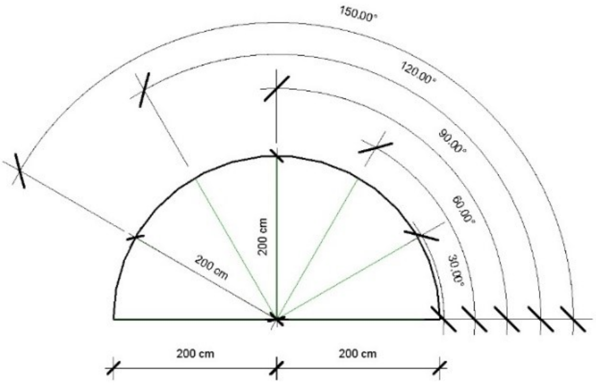


**Figure 4:** Tool Testing Layout

The improvement stage is the result of the evaluation from the testing phase, where the researcher examines the testing results and concludes whether the tool works well and follows the research path. During testing, if there are inconsistencies, corrections will be made to achieve optimal results.

### *v. Data Collection and Report Writing*

In data collection, the researcher will compare the sensor reading values with standard measuring tools. The mathematical equation used is the measurement difference, error, and accuracy value. The measurement difference is used to obtain the error value from the comparison between sensor readings and standard measuring tools. The measurement difference equation is shown in Equation (1).

$$\Delta = \text{reference value} - \text{measured value} \tag{1}$$

After obtaining the measurement difference value, we can find the error value. Error in numerical methods is the difference between the actual value (reference value) and the numerical method value (measured value) [34]. The error equation can be seen in Equation (2).

$$\text{Error\%} = \frac{\text{Measurement Difference}}{\text{Reference Value}} \tag{2}$$

The data obtained from the error testing is used to determine the accuracy value as in Equation (3).

$$\text{Accuracy} = 100\% - \text{error value} \quad (3)$$

Report writing is the result of presenting data in the research process, such as tool creation and design and the research results, which are then presented in the form of a report or research journal.

**Table 1:** Ultrasonic sensor test results with standard measuring tools

| No | $\xi$ | $\eta$ | $\delta$ | $\varepsilon$ |
|---|---|---|---|---|
| 1 | 20 | 20 | 0 | 0 |
| 2 | 40 | 40 | 0 | 0 |
| 3 | 60 | 61 | 1 | 1.6 |
| 4 | 80 | 82 | 2 | 2.5 |
| 5 | 100 | 102 | 2 | 2 |
| 6 | 120 | 119 | 1 | 0.83 |
| 7 | 140 | 142 | 2 | 1.42 |
| 8 | 160 | 161 | 1 | 0.625 |
| 9 | 180 | 182 | 2 | 1.11 |
| 10 | 200 | 200 | 0 | 0 |
| **Average** | 110 | 110.9 | 1.1 | 1.008 |
| **Accuracy** | 100% - 1.008% = 98.99% | | | |

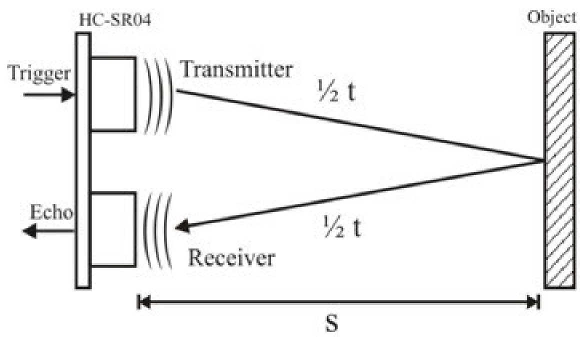


**Figure 5:** Working principle of the ultrasonic sensor

## III. Results and Discussion

The security system uses a radar system that has the ability to detect its surroundings, both in bright and dark conditions. This system can detect the presence of objects around the radar and determine the distance by providing indications in the form of color gradients. The system uses a scanning system so that the radar will continuously detect its surroundings and send data in real time to ensure the presence of objects around it. The radar in this study can also detect motion, thus distinguishing between moving and stationary objects.

### *i. Sensor Testing with Standard Measuring Tools*

Testing using standard measuring tools involves comparing sensor reading values with standard measuring tools such as a meter. This test aims to determine whether the sensor readings have accuracy and error by comparing them with standard measuring tools as shown in Table 1 with $\xi$ Reference Value (cm), $\eta$ Sensor Reading (cm), $\delta$ Measurement Difference (cm), and $\varepsilon$ Error (%).

**Table 2:** PIR sensor test results with standard measuring tools

| No | Reference Value (cm) | PIR Sensor Condition | | | | |
|---|---|---|---|---|---|---|
| | | $30^o$ | $60^o$ | $90^o$ | $120^o$ | $150^o$ |
| 1 | 20 | 1 | 1 | 1 | 1 | 1 |
| 2 | 40 | 1 | 1 | 1 | 1 | 1 |
| 3 | 60 | 1 | 1 | 1 | 1 | 1 |
| 4 | 80 | 1 | 1 | 1 | 1 | 1 |
| 5 | 100 | 1 | 1 | 1 | 1 | 1 |
| 6 | 120 | 1 | 1 | 1 | 1 | 1 |
| 7 | 140 | 1 | 1 | 1 | 1 | 1 |
| 8 | 160 | 1 | 1 | 1 | 1 | 1 |
| 9 | 180 | 1 | 1 | 1 | 1 | 1 |
| 10 | 200 | 1 | 1 | 1 | 1 | 1 |

The ultrasonic sensor test with standard measuring tools was conducted 10 times with intervals of 10 cm for each test to compare the suitability between the ultrasonic sensor readings and the standard measuring tools. At distances of 20 cm to 40 cm, the sensor can still read the same values as the standard measuring tools because the ultrasonic sensor waves are still easily returned to the sensor, resulting in high accuracy in distance readings. At readings from 60 cm to 180 cm, there is a discrepancy between the ultrasonic sensor readings and the meter, as the ultrasonic sensor waves have different times when returning to the sensor, causing time differences and resulting in different distance readings. This discrepancy can be reduced by using an average filter, which works by collecting the first 10 sensor readings and averaging them, then evaluating to determine the most appropriate reading value. The working principle of the ultrasonic sensor is shown in Figure 5.

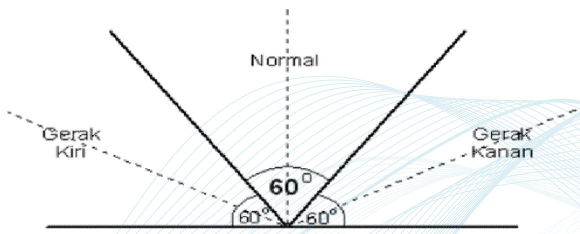


**Figure 6:** PIR sensor reading

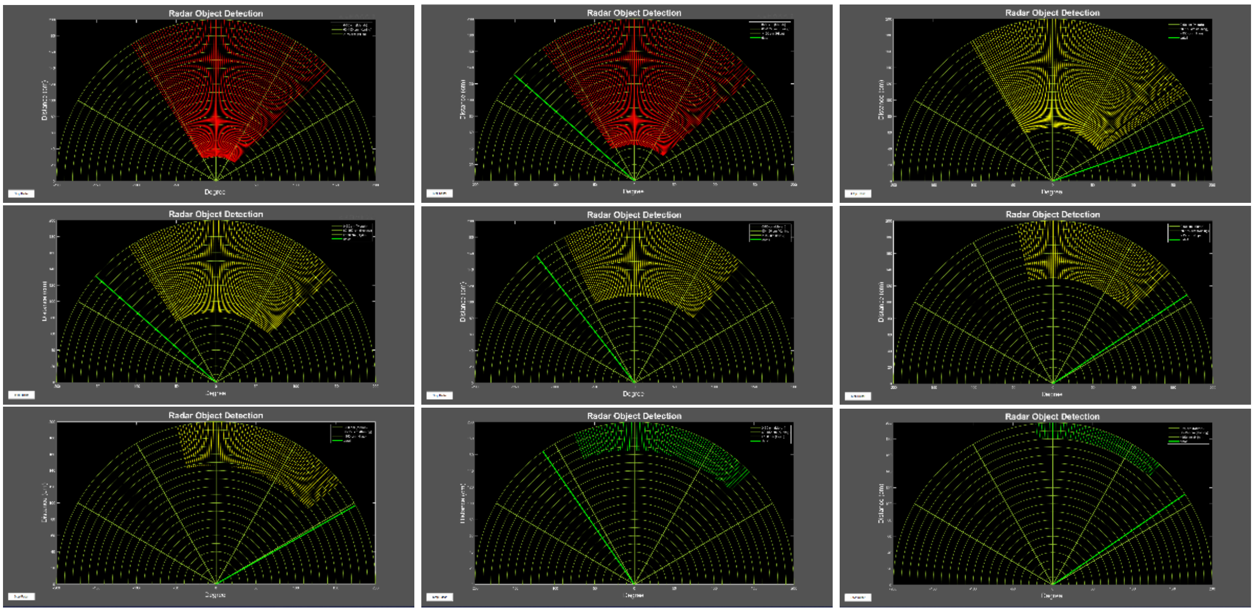


**Figure 7:** Radar scanning test results:20, 40, 60, 80, 100, 120, 140, 160, and 180

Subsequently, the PIR sensor was tested with standard measuring tools such as a meter, with 10 tests and five corner coordinate points. This test was conducted to see the accuracy of the PIR sensor readings against the surrounding movements. The test results can be seen in Table 2 with 1 for Detected and 0 for Not Detected.

In the PIR sensor testing, the researcher conducted tests to observe the accuracy and sensitivity of the PIR sensor readings. The PIR sensor has a reading angle value with a width of $60^o$ at its normal point, as shown in Figure 6.

In this PIR sensor test, it can be seen that the PIR sensor readings in each test condition produce a value of 1 (Detected). The PIR sensor readings have low sensitivity at angles $30^o$ and $150^o$ because these points are far from the normal point of the PIR sensor, resulting in low sensitivity. The PIR sensor can still read movements to the right and left, but with a delay of one to five seconds depending on the movement detected by the PIR sensor. The more active the movement detected, the more accurate the PIR sensor readings.

### ii. Radar Matlab Scanning Test

In this test, radar scanning was performed on predetermined objects. The scanning process was carried out five times, with the radar moving from $0^o$ to $180^o$, counting as one scanning cycle. This test also aims to see if there are blind spots in the radar readings during the five scanning cycles. The test results can be seen in figure 7.

It can be seen from figure 7 that the radar can detect and produce the same readings during the scanning process. The test results show no blind spots during the scanning process. The results also support the sensor accuracy test with standard measuring tools, where the ultrasonic sensor reading accuracy is 98.99%, making the radar scanning process more accurate and reducing blind spots in radar readings. The accuracy of radar readings is also influenced by the objects being read; the denser and more even the surface, the clearer and more accurate the radar readings. However, if the objects have softer and wavy surfaces, the radar readings will show blind spots. The object's surface condition also affects the radar scanning and distance reading values.

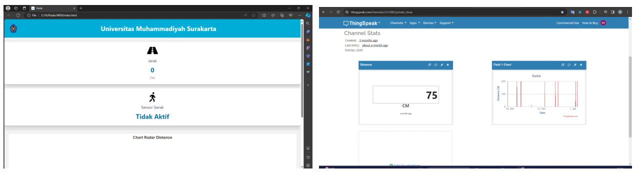


**Figure 8:** IoT display on computer or laptop

### iii. IoT Implementation and Results

The next stage is the IoT implementation for the interface between the user and the radar. This research uses four IoT platforms: ThingSpeak and Web Server for computer or laptop devices, and Blynk and PushBullet for monitoring via mobile devices. PushBullet is used for notifications to users and provides information about objects at certain distances. The IoT display is shown in Figures 8 and 9.

Using IoT is expected to facilitate users in monitoring radar readings. The IoT display will show two

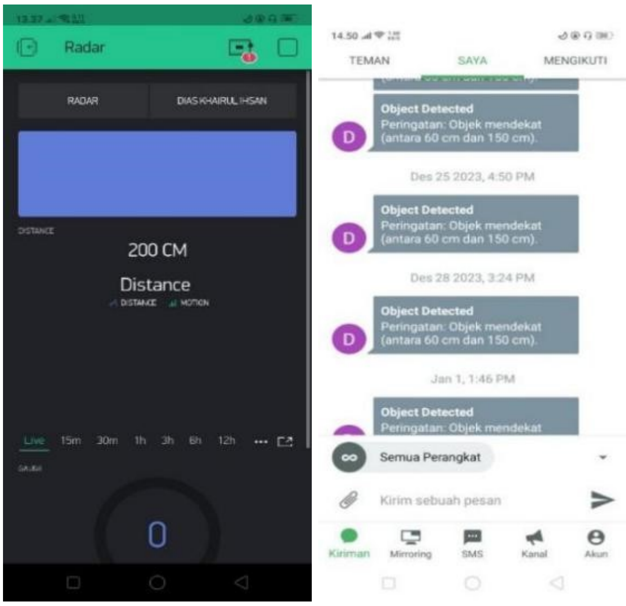


**Figure 9:** IoT display on mobile device

readings: ultrasonic sensor readings and PIR sensor readings. The ultrasonic readings will display the surrounding distance in real time, and the PIR sensor readings will display the movement readings of moving objects in real time. The development of radar systems using IoT is beneficial for future radar development, making it easier for users to monitor and ensure security around us.

## IV. Conclusion

Radar has become an essential technology in scanning and security monitoring processes. From the results of the Object Detection Radar with IoT-Based Matlab Software Visualization, this research successfully implemented an effective radar system for scanning by integrating Matlab software with IoT. The use of the IoT system is expected to assist users in wirelessly collecting data and accessing it flexibly from a distance via the internet. During the research process, the radar could detect with high measurement accuracy and a quick response time. Data analysis showed that the ultrasonic sensor's accuracy level was 98.99%, and the PIR sensor readings also had high accuracy, but with a relatively long delay at angles of $30^o$ and $150^o$. This radar system also used an average filter that helped reduce noise during ultrasonic sensor readings.

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