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Design and Implementation of Wind Speed-Based Radar Antenna Safety System Prototype

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Abstract – **Air defense radar is a system that detects the presence of one or more air objects at a certain distance, altitude, and direction. One type of air defense radar used by the Indonesian National Armed Forces (TNI) is the Thomson TRS 2215D. An essential part of the radar is the rotating part of the radar antenna support called the antenna pivot. The rotation of the radar antenna must constantly be monitored and controlled for rotational stability at a speed of 6 Rotations per Minute (RPM) with a maximum wind speed of 120 km/h to prevent damage to the driving gear. Stormy weather with high wind speeds can cause the rotation speed of the radar antenna to be uncontrollable, which can cause damage. The solution offered in this study is to build a safety system that will lock the radar antenna automatically when the wind speed is detected to exceed tolerances and maintain the security of the radar antenna and its support system. The safety system was designed using an ESP32 Wi-Fi device equipped with an anemometer wind speed sensor, a Liquid Crystal Display (LCD) monitor, a Direct Current (DC) motor, and a Blynk Internet of Things (IoT) application. The test was conducted in a simulation using a multi-meter and oscilloscope measuring instrument. Testing the radar antenna's safety system prototype on a laboratory scale shows that the safety system can work as designed. The system can lock the radar antenna when the airflow is set at a speed of 54 km/h or 15 m/s, communication with the Blynk server works well, and the ESP32 device can transmit data at a maximum distance of 14 meters.**

Keywords: Antenna, pivot antenna, air defense radar, safety system, Thomson TRS 2215D

I. INTRODUCTION

The air defense radar, a cornerstone of the Indonesian National Armed Forces (*Tentara Nasional Indonesia*) under the National Air Operations Command (NAOC), is vital to our nation's defense system. Operated by Radar Units strategically positioned across Indonesia, these radars play a crucial role in detecting any air object that enters our sovereign airspace, guiding fighter aircraft to intercept unidentified aerial objects.

The detection capability relates to the Early Warning (EW) feature that a radar must have. In contrast, the ability to guide an ambush fighter aircraft to unidentified aerial objects is related to the Ground Controlled Interception (GCI) feature. GCI capabilities are implemented when a single intercept fighter flight requires visual identification and must be guided by GCI operators. Visual identification is needed for any unidentified aerial object, also called black flight, to ensure that the aerial object is friend or foe [1].

Among the many radar systems operated by NAOC Radar Units, one of them is the Thomson TRS 2215D radar, which is equipped with the ability to detect 3D targets, namely the direction of the object's flight to the radar antenna (bearing), the distance of the object to the radar antenna (range), and the height of the object's flight from the surface of the earth (altitude), as well as equipped with electronic technology EW System (EWS) and GCI.

Detection of the presence of airborne objects is done by comparing the travel time of the transmitted signal with the travel time of the reflected signal (echo) by the object. In terms of airspace sweep that will be displayed on the Plan Position Indicator (PPI) screen, Thomson TRS 2215D is designed to perform radar antenna rotations of up to six Rotations per Minute (RPM) with a tolerance of 10% at a maximum wind flow speed of 120 km/h [2]. Then, the information on the PPI screen will be updated every 10 seconds. Thomson TRS 2251D radar antenna is shown in Figure 1.

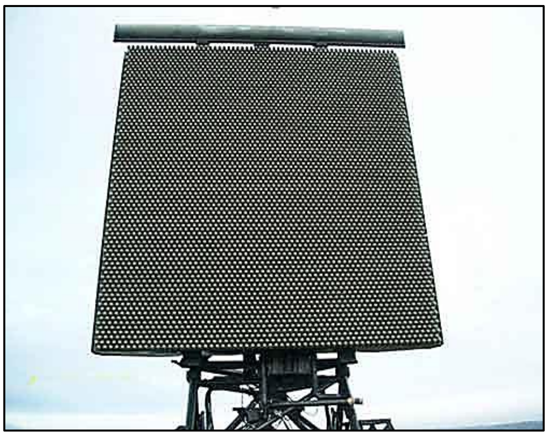

Figure 1. Thomson TRS 2215D radar antenna [2]

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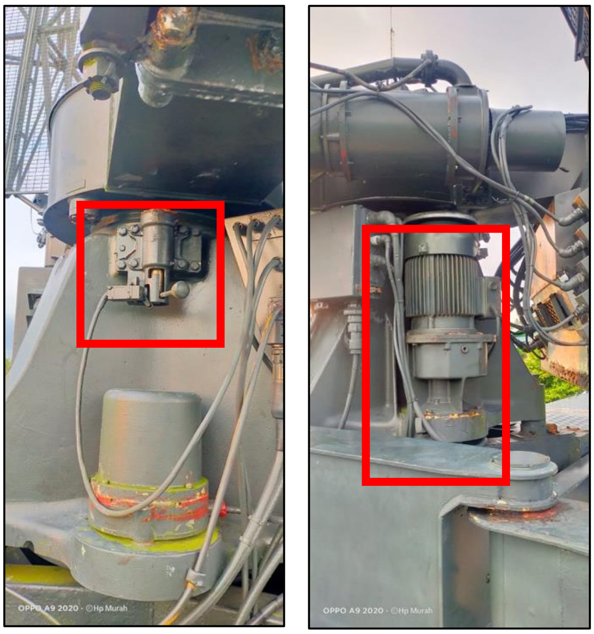
The 360° rotation of the radar antenna supported by the antenna pivot is controlled by a reduction motor using a three-phase Alternating Current (AC) motor. The rotational speed of the antenna must constantly be monitored and controlled for stability at a maximum speed of six RPM with the ability of the antenna to withstand maximum wind speeds of 120 km/h (33.3 m/s). If the wind speed exceeds the maximum limit, the radar antenna must be turned off so that there is no damage to the gears of the reduction motor. The antenna pivot is essential because it will always move around the radar antenna.

For this reason, to prevent damage to the gears of the reduction motor, a conventional lock has been prepared to stop the rotation of the pivot antenna in case of bad weather with very high wind speeds, as shown in Figure 2. However, bad weather situations can prevent radar personnel in the field from manually locking because the radar antenna is quite far from the operational cabin. On the other hand, research on the impact of wind load on antenna pivots is almost nonexistent, and the only research available is aimed at analyzing wind load on the ability of servos to move radar antennas [3].



(a) (b)

Figure 2. (a) Manual pivot antenna lock and (b) reduction motor [2] inside the red striped box

This study presents a practical solution to maintaining radar antenna stability in high wind conditions. This research addresses a crucial issue in the field by designing and implementing a prototype safety system that can automatically lock the radar antenna pivot when the wind speed exceeds the antenna's tolerance. The system, which integrates hardware and software, demonstrates the potential of sensor technology and the Internet of Things (IoT) in enhancing radar antenna safety.

II. METHODOLOGY

A. Research Object

The object of research is the manual locking mechanism of the pivot antenna, which is the primary support for the rotation of the radar antenna. Where the principle of the mechanism can be replaced with a safety system using an automatic locking mechanism that utilizes wind speed sensors or anemometers combined with IoT technology, this radar antenna safety system utilizes an ESP32 microcontroller featuring a 2.4 GHz Wireless-Fidelity (Wi-Fi) combo chip [4], and Bluetooth. It is compatible with mobile devices and requires low power for operation in various application scenarios [5], [6]. Direct Current (DC) motors rotate and lock the antenna, which is then synchronized with the reduction motor during a field-scale implementation.

Because of its features, the ESP32 microcontroller chip has been applied for various applications, whether in industrial processes [7] or other usages such as for smart home automation [6],[8], weather monitoring systems [9]-[12], and temperature monitoring system [13]. Other exciting features are low power requirements and the ability to utilize the Arduino Integrated Development Environment (IDE) for source code generation [9],[10],[13]. An example of an ESP32 microcontroller is shown in Figure 3.

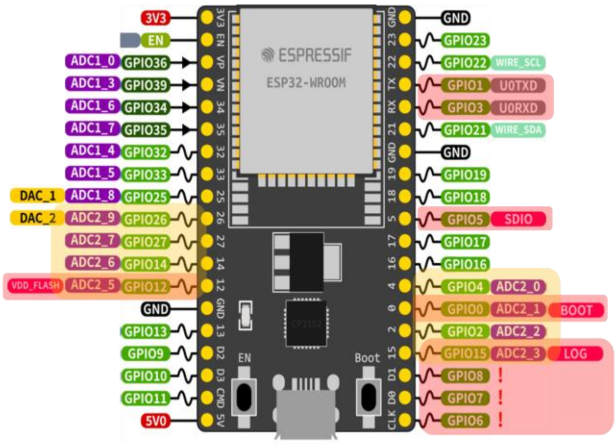


Figure 3. ESP32 microcontroller [14]

The Blynk application [15] will monitor wind speed conditions and lock and unlock radar antenna pivots. It utilizes IoT data from the ESP32 microcontroller connected to the wind speed measuring sensor by programming it to read the sensor sensing results [16]. In addition to displaying data, performing hardware commands, and displaying visual data, Blynk also serves data storage [15], [17], [18].

B. Tools and Materials

To design and implement the radar antenna's safety system prototype, hardware, software, measuring instruments, and their supporters are needed. All required materials are shown in Table I. A Pulse Width Modulator

(PWM) regulates the rotational speed of the DC1 and DC2 motors by changing the duty cycle and observing the response of the two drive motors. The duty cycle is a representation of the logical condition of high in a signal period expressed as a percentage (%) with a range of 0% to 100% [19],[20].

Table 1. Devices, Measuring Instruments, and Supporting Equipment

Hardware	Software	Measuring Instru-ments	Supporting Equipment
ESP32 Micro-controller	Arduino (IDE)	Multi-meter	Laptop
Anemo-meter	Blynk IoT Apps	Multi-meter, Oscillo-scope	Interrupt
DC Motor	-	Multi-meter	PWM, Fan for wind speed simulation

C. System Block Diagram

This windspeed-based radar antenna safety system consists of two subsystems: a control subsystem consisting of an anemometer as a speed sensor, an ESP32 microcontroller, and a pair of DC motors (DC1 and DC2). The second subsystem shown in the dotted line is a wireless monitoring subsystem through a smartphone, laptop, or computer device installed with the Blynk apps application and connected to the Blynk cloud server via the internet network. The block diagram of the system can be seen in Figure 4.

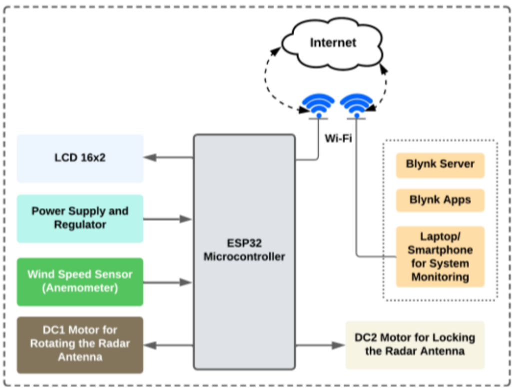


Figure 4. Block diagram of radar antenna safety system based on wind speed

The power supply provides a voltage source of 12 Volts, and the LM2596 regulator makes its output voltage of 5 Volts, and 3.3 Volts is the power source of the ESP32 microcontroller and other integrated circuits (ICs). An anemometer, as a wind speed sensor, senses the amount of wind speed as a reference for the control part to control both DC motors. The ESP32 microcontroller, as the system control center, controls the DC1 motor as the antenna player and the DC2 motor as the antenna lock.

Liquid Crystal Display (LCD) serves as a viewer of wind speed information and the pivot condition of the antenna, which is locked or rotating. The ESP32 microcontroller equipped with a Wi-Fi module will send data via the internet to the Blynk Apps application server so that monitoring results can be displayed on the web and accessed from anywhere and anytime. Blynk is an IoT simple-to-code application that enables users to control any system remotely. It has been applied to some applications such as smart energy meters combined with NodeMCU ESP8266 [21], smart home systems [22], and wireless sensor networks [23].

D. Hardware Design

The block diagram in Figure 4 shows how implementation is carried out to the hardware form by creating a schematic diagram of the circuit, as shown in Figure 5, pouring it into the Printed Circuit Board (PCB), and assembling all electronic components into a complete system.

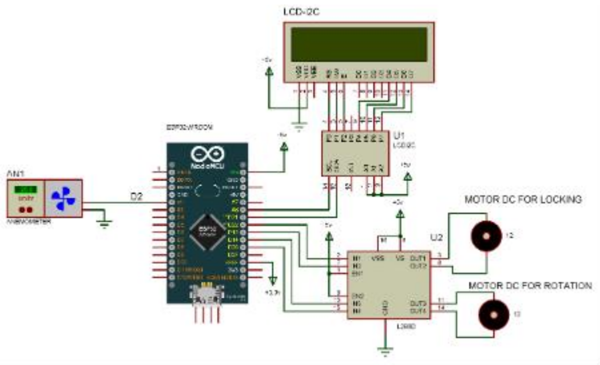


Figure 5a. Schematic diagram of radar antenna safety system based on wind speed

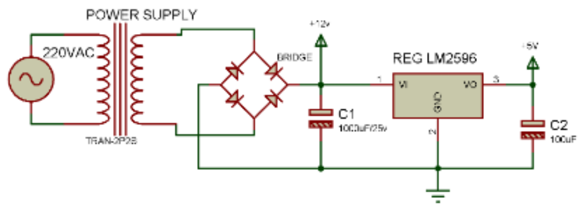


Figure 5b. Schematic diagram of power supply for radar antenna safety system based on wind speed

Figure 5a shows that the wind speed sensor is connected to the input pin D2, a General-Purpose Input Output (GPIO) pin of the ESP32 microcontroller. The output of the ESP32 microcontroller is connected to a 16x2 LCD via an inter-integrated Circuit (I2C) module consisting of a Serial Clock (SCL) and Serial Data (SDA); the L298D IC is used as a driver for a pair of DC motors that act as antenna rotators and radar antenna pivot lockers. Figure 5b is a power supply for the radar antenna safety system circuit with an output voltage of 5 Volts.

E. Software Design

Software design includes creating a flow chart, as shown in Figure 6, followed by its implementation in source code form through the ESP32 microcontroller development board with the help of Arduino IDE for source code compilation.

The software's process begins with initialization to recognize the wind speed sensor connected to the input port of the ESP32 microcontroller. It then reads the sensor sensing results and calibrates them. The sensor readings are displayed on the LCD screen. Based on these readings, the ESP32 microcontroller instructs the L298D drive to rotate the DC1 motor to move the radar antenna while monitoring the results of wind speed sensor sensing.

If the wind speed exceeds a tolerance of 10% of the maximum speed of 120 km/h, the ESP32 microcontroller instructs the L298D drive to turn off the DC1 motor and instructs the DC2 motor to lock the antenna. The read wind speed data is also sent via the internet to the Blynk server to be able to access it via a smartphone, laptop, or computer device with the Blynk Apps application to inform the in-charge radar personnel regarding the current situation of the radar operational.

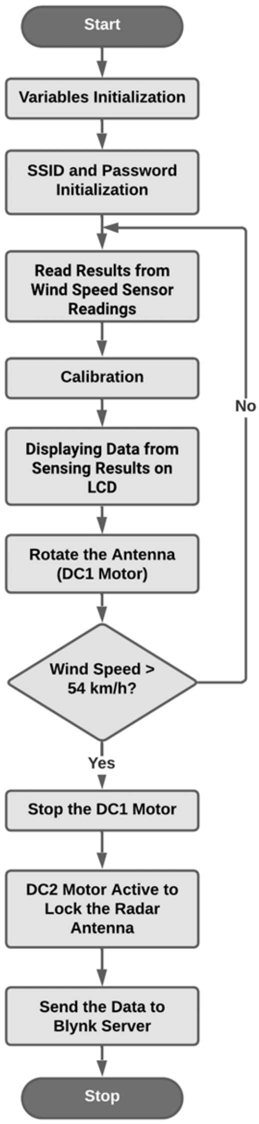


Figure 6. The computer program flowchart of the wind speed-based radar antenna's safety system

III. Results and Discussion

A. Wind Speed Sensor Testing

Wind speed sensor testing aims to determine the performance of the anemometer used. Anemometers use optocouplers with digital voltage output. The test is carried out through two stages: voltage testing using a multi-meter and observing the output as a digital signal through an oscilloscope. The test results of wind speed sensors are shown in Table 2. Unless otherwise stated, all voltages used in this research are Direct Current (DC) voltages in Volts.

Table 2. Sensor Test Results

Treatment	Output Voltage (Volts)	Result
Blocked	0	Good
Not Blocked	4.7	Good

The test results show that the sensor has worked well based on changes in the output voltage when blocked and unobstructed. The output voltage when blocked is 0 Volts, and when unobstructed, which is 4.7 Volts. Testing is also carried out to ensure the sensor works appropriately by looking at the output signal's response to changes through an oscilloscope. The test results are shown in Figure 7.

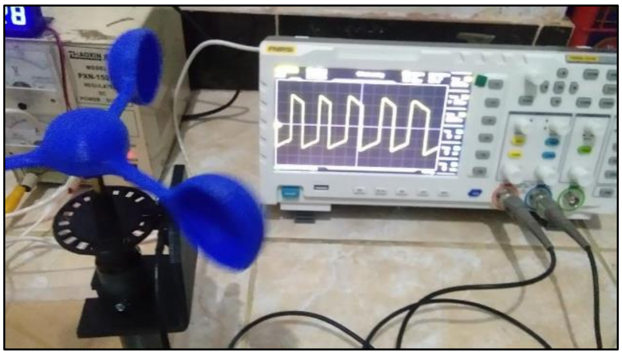


Figure 7. Output signal of the wind speed sensor at an unobstructed state through an oscilloscope

B. Power Supply Testing

The power supply, as the leading provider of voltage sources for all components in the system, must be ensured after being passed to the regulator. Tests are carried out using a multi-meter by taking measurements at voltage points. The voltage source of 12 Volts is regulated to 5 Volt and 3.3 Volt. The power supply testing method is shown in Figure 8, while the test results can be seen in Table 3.

Table 3. Power Supply Test Results

Input Voltage (Volts)	Test Points (Volts)	Output Voltage (Volts)
12	Regulator (5)	4.71
12	Regulator (3.3)	3.28

This study took an input voltage of 5 Volts with a tolerance of 4.5 to 5.5 Volts to operate the LCD and L298D and a voltage of 3.3 Volts to operate the ESP32 microcontroller and wind speed sensor. The test results in Table 3 show that the power supply produced is sufficient for the system's needs.

Figure 8. The amount of power supply voltage that has been passed to the regulator

C. DC Motor Testing

DC motor testing aims to determine the performance of the L298D IC and a pair of DC motors that rotate and lock the radar antenna. The test is carried out by changing the PWM value, observing the output voltage on the motor, and observing the motor rotation. The tests of the two DC motors are shown in Figure 9, which is carried out by assigning a specific PWM value to the PWM pin ESP32. The test results of the two DC motors can be seen in Table 4.

Figure 9. Testing of radar antenna rotator DC1 motor and radar antenna locking DC2 motor

Table 4. DC Motor Test Results

PWM Value	%	PWM Output Voltage (Volts)	DC1 Motor Speed	DC2 Motor Speed
0	0	0	Stop	Stop
50	20	2.3	Slow	Slow
100	39	3.2	Fast	Fast
255	100	4.3	Very Fast	Very Fast

From the results of the two DC motors shown in Table 4, the higher the PWM value, the higher the PWM output voltage will also increase and affect the motor rotational speed. So, both DC motors have worked well because they can correctly follow the PWM values changes.

D. Wi-Fi Connection Distance Testing

This test was carried out to determine the quality and accuracy of data transmission from wind speed sensor readings by the ESP32 microcontroller displayed on the LCD with the readings displayed on Blynk Apps. From Table 5, it is obtained an information that the maximum connection distance between the ESP32 microcontroller and smartphone devices is 14 meters (m).

On the other hand, the distance between the radar antenna and the operational cabin ranges from 10 meters, so that distance is qualified for use in natural conditions. However, air defense radars other than Thomson TRS 2215D can differ in the maximum distance between the radar antenna and the operational cabin.

Table 5. Wi-Fi Data Connection Testing

Distance (m)	Signal Reception Status	Meaning
0	Good	Information from the locking system is displayed on Blynk apps
2	Good	
4	Good	
6	Good	
8	Good	
10	Good	
12	Good	
14	Good	
16	Not Good	Information from the locking system is not displayed on Blynk apps
18	Not Good	
20	Not Good	
22	Not Good	
24	Not Good	

E. Overall System Testing

Figures 10 and 11 show prototype testing of the overall radar antenna safety system. It is done by simulating the activation of the antenna rotating motor, giving wind gusts to the wind speed sensor using a fan, and observing the response of the radar antenna locking motor if the wind speed exceeds 120 km/h, which in this case is simulated at the wind speed of the fan, which is 54 km/h. The results of system prototype testing are shown in Table 6.

Figure 10. Top view of the radar antenna's safety system prototype based on wind speed

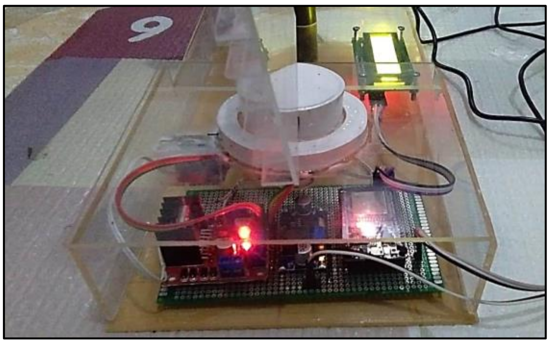


Figure 11. Side view of the radar antenna's safety system prototype based on wind speed

Based on the test results in Table 6, the wind speed sensor's sensing results show that the ESP32 microcontroller successfully drives the DC1 motor to rotate the radar antenna when the wind gust is below a maximum speed of 54 km/h or 15 m/s, turns off the DC1 motor when the wind gust reaches 54 km/h, and drives the DC2 motor to lock the radar antenna pivot.

Table 6. Overall Testing of Wind Speed-Based Radar Antenna Safety System Prototype

Wind Speed (km/h)	DC1 Motor Response	DC2 Motor Response	Wind Speed Display on Blynk (m/s)
0	Rotates	Off	0
3.6	Rotates	Off	1
10.8	Rotates	Off	3
18	Rotates	Off	5
25.2	Rotates	Off	7
32.4	Rotates	Off	9
39.6	Rotates	Off	11
46.8	Rotates	Off	13
54	Stop	On	15
61.2	Stop	On	17

The sensing results of the wind speed sensor, DC1 motor status, and DC2 motor status are shown both through the web application and on a smartphone as well as on the LCD connected to ESP32 and also show the same value as that displayed on Blynk Apps as shown in Figure 12, Figure 13, and Figure 14. Our application is written in Bahasa. The translation of the terminologies displayed on LCD and Blynk is shown in Table 7.

Figure 12. How Blynk Apps appear on the web

Table 7. Translation of Terminology in Applications and Displays

Location	Abbre-viation	Bahasa	English
LCD	"Kec"	Kecepatan	Speed
Blynk	"Disp"	-	Display
Blynk	-	Grafik Kecepatan Angin	Wind Speed Graph
Smartphone	"Kec. Angin"	Kecepatan Angin	Wind Speed
Blynk and Smartphone	-	"Safety Putaran Antena Rotor"	Antenna Rotor Rotation Safety

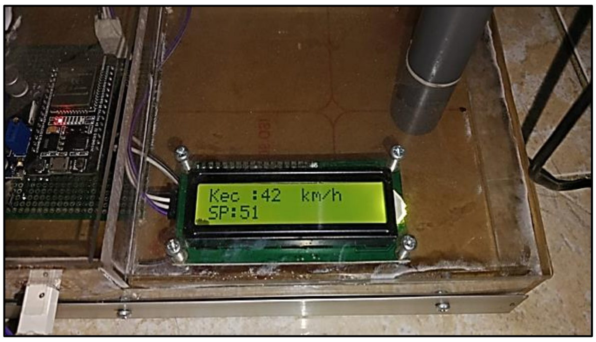


Figure 13. Display of information on the LCD screen

Figure 14. Display Blynk Apps on smartphones

IV. CONCLUSION

A prototype of a radar antenna safety system based on wind speed has been produced. In line with this, a combination of hardware and software as its implementation has been tested on a laboratory scale. The prototype was built with the Thomson TRS 2215D radar system use case. It performed well by stopping the antenna rotation when the wind speed reached 54 km/h. It could be monitored remotely using a smartphone using the Blynk application up to a maximum distance of 14 meters relevant to natural conditions in the field. Based on the test results, the prototype of this safety system is prospective to be further developed into a prototype form that can be tested under relevant conditions. The Thomson TRS 2215D radar antenna pivot system currently does not provide an antenna locking facility, so this research has contributed that the antenna locking system is highly likely to be applied in natural conditions. The next step is to increase the size of the prototype of the radar antenna's safety system to test its feasibility when used in natural conditions.

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