Journal of Industrial Automation and Electrical Engineering
Vol. 02, No. 01, June 2025, pp. 104~111
ISSN: 3089-1159

Design of navigation light using Microcontroller

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Article Info

Article history:

Received February 16, 2025
Revised March 29, 2025
Accepted May 21, 2025

Keywords:

Microcontroller
Navigation Light
Monitoring
Arduino Mega 2560
Maritime Safety System

ABSTRACT

This final project discusses the design and development of a icrocontroller-based navigation light system. This system aims to improve maritime safety by providing a more accurate and comprehensive control and monitoring system for navigation light conditions. The system uses an Arduino Mega 2560 microcontroller as the main controller, equipped with current and voltage sensors to monitor lamp condition parameters periodically. Manual control of the navigation lights is done via pushbuttons, and information about the lamp conditions (voltage and current) is displayed on an LCD screen. In addition, the system is equipped with a buzzer as an early warning alarm if abnormal conditions are detected in the lamp, such as voltage or current exceeding normal limits. It is hoped that this system can provide a solution to maritime safety problems by providing more complete and accurate information regarding the condition of navigation lights, as well as enabling more effective preventative actions.

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1. INTRODUCTION

Indonesia, as the world's largest archipelagic country, has 17,504 islands with a coastline of 99,093 kilometers [1]-[3]. Its strategic geographic position between the Indian and Pacific Oceans makes Indonesia a vital international shipping lane. Data from the Ministry of Transportation (2023) recorded more than 200,000 ships sailing in Indonesian waters annually, with an average increase of 15% per year in the last five years. This condition requires a reliable shipping safety system. This shipping safety system is regulated by various regulations, including the International Regulations for Preventing Collisions at Sea (COLREGs) and national regulations related to maritime safety [4]. Therefore, to optimize ship operations, ships must be supported by various equipment for greater comfort and safety when carrying out activities at sea. One factor that can support this is the deployment of additional communication and positioning systems, particularly navigation lights. Navigation equipment is very important to help determine the ship's precise position and determine the route the ship must take to reach its destination quickly and safely [5].

Navigation lights or also known as Navigation Lights are navigation tools that are often used to determine the direction, position, and type of ship in foggy conditions and at night. Without Navigation Lights or navigation equipment on a ship, accidents will occur on the ship. Generally, there are three main causes of ship accidents, including: (1) human error, (2) damage to the ship's engine, and (3) internal and external elements such as navigation lights [5]. Ship accidents are unpredictable and can happen anywhere. When a ship is not equipped with adequate navigation tools, it will usually cause one of these things on board: (1) collision with another ship (Collision); (2) running aground; (3) sinking due to weather; (4) fire; and (5) engine failure [6].

In maritime safety, navigation lighting systems play a crucial role. Research [7] has shown that implementing an appropriate navigation lighting system can improve maritime safety and reduce the risk of collisions between vessels. This is further supported by a study [8], which shows that navigation lighting systems on ships can improve the effectiveness of nighttime navigation [9]. Technological developments in the field of ship navigation systems have made significant progress. Research [10] on microcontroller-based navigation light design shows that the use of an automatic control system can improve navigation lighting systems compared to manual systems. The implementation of a microcontroller in a navigation lighting system also allows for monitoring of light status and detection of navigation lighting failures [11]. However, various challenges remain in the development and implementation of an optimal navigation lighting system. Data from the National Transportation Safety Committee (KNKT) indicates that 35% of ship accidents in 2022 were caused by inadequate navigation systems, 40% of which were related to navigation lighting system failure [12].

Facing these challenges, the development of a navigation lighting system is an urgent need. Several previous studies, such as those conducted by [13], have demonstrated the potential use of automation technology in navigation light systems, but implementation in Indonesia remains limited [14]. Subsequent research [15] focused on an Android-based Navigation Light Monitoring and Control Application on the KRI Sampari 628. In this study, researchers used a mobile app-based approach to monitor and control the navigation lights. The limitation of this study was its focus on the basic on/off function of the lights, with the implementation of app-based control or light sensors. This limitation lies in the system's lack of ability to periodically monitor light condition parameters, such as current and voltage, which can provide an alarm of potential light failure. Without comprehensive monitoring, early detection of navigation light problems becomes difficult, which can increase the risk of accidents.

Based on this urgency, this study aims to develop a microcontroller-based Navigation Light system equipped with current and voltage sensors. This system allows manual control of the navigation lights using pushbuttons, then monitors and displays light parameters on an LCD screen. Furthermore, this system is equipped with a buzzer that will activate as an alarm when an abnormal condition is detected in the lamp, such as voltage or current that exceeds the normal limit. The condition of the lamp and the buzzer are used for warnings if damage occurs. [16]. Thus, sailors can obtain more complete and accurate information regarding the condition of the navigation lights, as well as get early warning if there is a problem, allowing for more effective preventive measures. This development is expected to provide solutions to shipping safety problems.

2. METHOD

The process of building the device begins with hardware construction, which involves placing all components in a safe place and according to the design. Once the hardware is complete, the next step is to program the sensors and other components using the Arduino IDE, which stands for Integrated Development Environment, to ensure that the device operates as designed. The block diagram in Figure 1 shows all the components used in this final project. This diagram shows how each component relates to each other and how they function within the designed system.

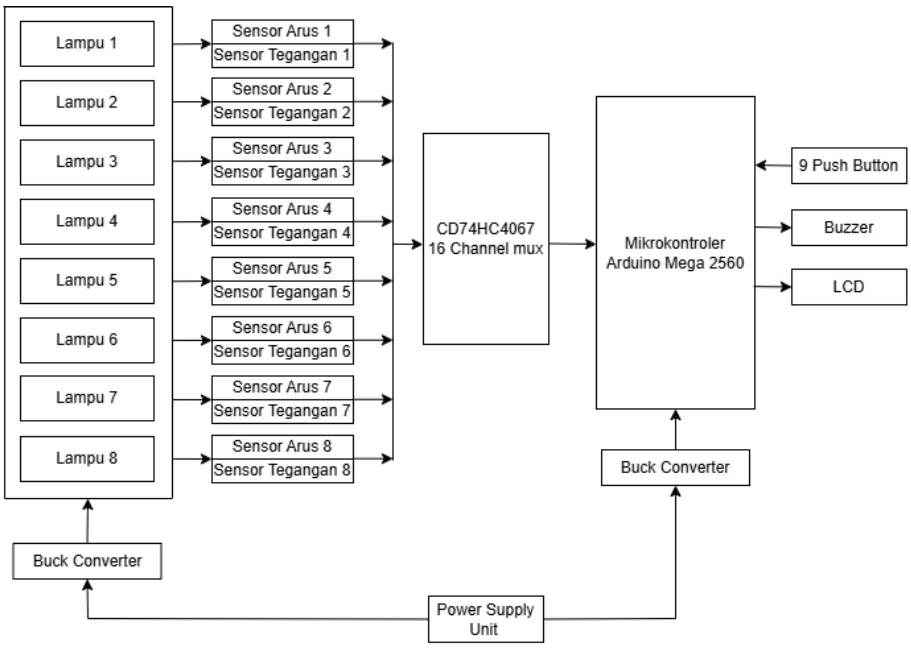

Figure 1. Block diagram of the proposed navigation light

Based on the block diagram above, the design of each block diagram has the following functions: 1) Power Supply functions as a Power Supply functions as a supplier or provides electric current from a voltage source that was previously in the form of alternating current (AC), which then converts it to direct current (DC). 2) Buck Converter or DC-DC step down converter, has a function to reduce the voltage from the Power Supply Unit to the Arduino Mega 2560 Microcontroller, and navigation lights. 3) The microcontroller used is the Arduino Mega 2560 which functions as the working processor of the tool to be made. Arduino Mega is the main component in the work of this tool, containing a program that will process the output based on the input given. 4) The voltage sensor functions to measure the electric voltage on the lamp. This sensor converts the electric voltage into a signal that can be read by the Arduino. 5) The current sensor functions to measure the electric current flowing in the lamp. The value of the electric current will be converted by the sensor into a signal that can be read by the Arduino. 6) LCD as an interface for the parameters that will be displayed, namely voltage and current. 7) The buzzer is used as an alarm or marker on this tool. 8) Push buttons function to activate each navigation light, 9) Multiplexer or MUX which functions to combine input from several sensors used into a single output. This tool is to save the use of digital communication pins on the Arduino Microcontroller.

This tool has the main components, namely 8 pushbuttons, 8 lights, 8 current sensors, 8 voltage sensors, a 16x2 LCD, and a buzzer. The working principle of the Navigation Light begins when the system receives power, where the Arduino Mega 2560 microcontroller will initialize all connected components. Users or operators can operate the eight navigation lights manually via 8 pushbuttons available on the control panel according to the ship's condition. Each pushbutton pressed will send a signal to the microcontroller to turn on the corresponding light. When the lights are on, the current and voltage sensors installed on each light will begin to take measurements. The measurement results from the eight current and voltage sensors will be sent to the microcontroller via the CD74HC4067 multiplexer which functions as a signal selector. The measurement data is then displayed on a 16x2 LCD screen so the operator can monitor the condition of each lamp. If a lamp fails, indicated by a drop in current or zero current, the microcontroller will activate a buzzer to alert the operator that a lamp requires inspection or repair.

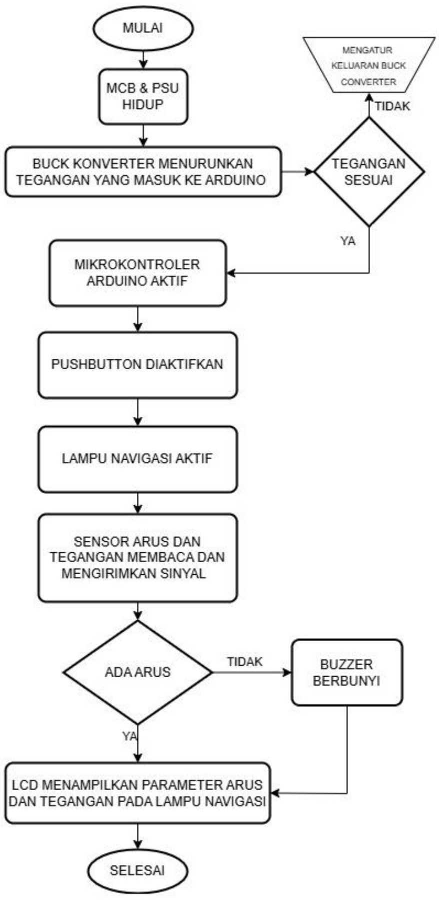

Figure 2. Flowchart of ship navigation light system equipment

In Figure 2, the system begins by turning on the MCB and PSU as the main power sources. After that, the buck converter works to lower the voltage that will be input to the Arduino. The system then checks the voltage compliance—if the voltage is correct, the Arduino microcontroller will activate and then activate the pushbutton. Once the pushbutton is activated, the navigation light will turn on. The system then reads the current and voltage and sends a signal. At this stage, the system checks for the presence of current. If current is detected, the LCD will immediately display the current and voltage parameters on the navigation light. However, if no current is detected, a buzzer will sound as a warning, and the LCD will continue to display the existing parameters. Once all these processes are complete, the system will terminate. This entire flowchart shows the workflow of a current and voltage monitoring system on a navigation light controlled by an Arduino microcontroller.

Hardware design is a crucial step before starting the actual tool manufacturing process. By doing this design, we can estimate the required components. In working on this final assignment, hardware design is very crucial, because hardware allows us to test whether the system is functioning well or not. The design results of this system can be seen in Figure 3.

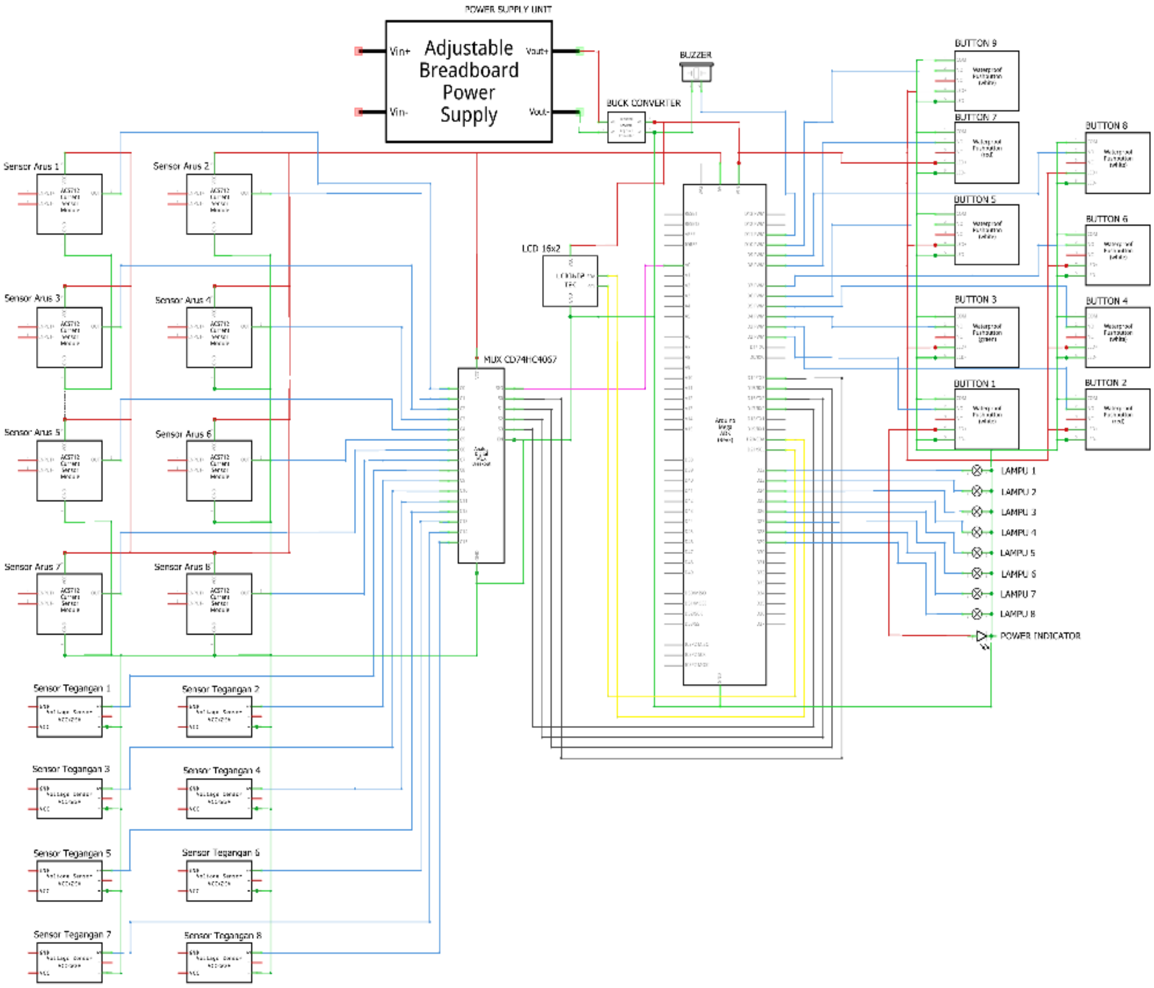

Figure 3. Navigation light system circuit schematic

Figure 3. The overall schematic design illustrates the integration of all components of the navigation light system. This circuit shows the relationship between the microcontroller and each previously designed input, output, and monitoring component. The Arduino Mega 2560 acts as the control center, connecting eight pushbuttons as inputs, eight lights as outputs, an LCD as an information display, and a buzzer as a warning signal. A CD74HC4067 multiplexer is used to manage the readings from 16 sensors, consisting of eight current sensors and eight voltage sensors. All components are powered from a voltage source appropriate to their respective needs.

3. RESULTS AND DISCUSSION

The mechanical design consists of two important parts, namely the panel box and the miniature ship. The panel box as a protector of the electronic circuit has a height of 43.6 cm and a width of 31 cm. On the panel door there are pushbuttons, buzzers, power indicator lights, and also LCD. Then the miniature ship used to place the navigation lights has a length of 27.5 cm, a width of 11 cm, and a height of 23 cm, as shown in Figure 4.

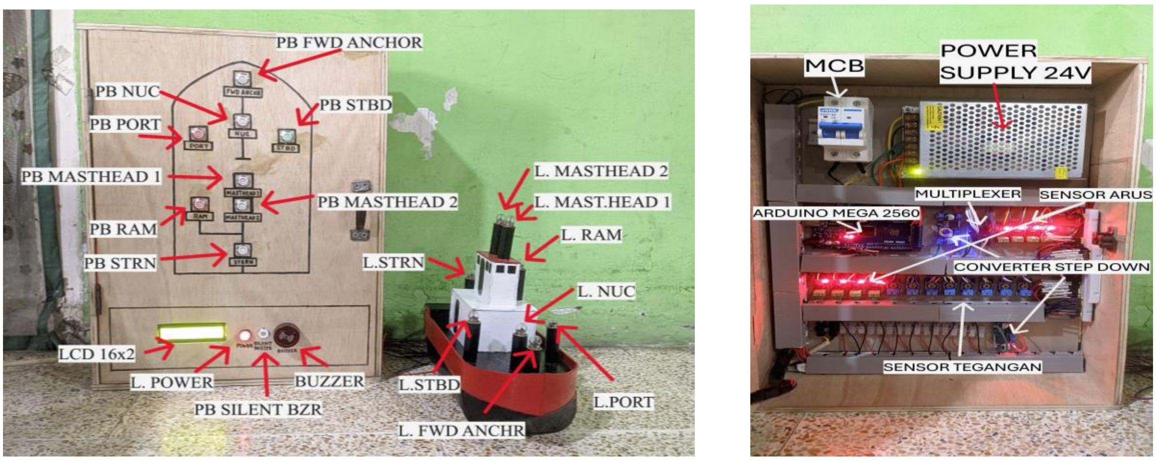

Figure 4. Results of making the mechanics and circuit of the ship's navigation light system

This tool uses AC voltage as a source then the power supply (24V 5A) converts the AC voltage to DC voltage. The first buck converter will reduce the voltage from the 24 V power supply to 7 V for the input voltage of the Arduino Mega 2560, buzzer, pushbutton lamp, and LCD. This choice is in accordance with the Arduino Mega specifications which require an input voltage between 7-12V. The second buck converter will be the voltage source for the lights on the miniature ship. The Arduino Mega 2560 will take power from the source to operate the pushbutton, lamp, current sensor, voltage sensor, multiplexer, LCD, and buzzzer to suit the predetermined design.

3.1 Pushbutton Testing

In this test, each pushbutton (buttons 1 through 8) was pressed to verify that each button activated the corresponding light. The test results showed that each pushbutton successfully activated the light, and the light was on. This test demonstrates that the microcontroller is able to accurately respond to each button input and pass commands to the appropriate light, as written in Table 1. .

Table 1 Pushbutton Testing

No.	Name	Pushbutton State	Light Status
1	Forward Anchor	OFF	Lamp 1 is off
		ON	Lamp 1 is on
2	Starboard	OFF	Lamp 2 is off
		ON	Lamp 2 is on
3	Port	OFF	Lamp 3 is off
		ON	Lamp 3 is on
4	NUC	OFF	Lamp 4 is off
		ON	Lamp 4 is on
5	Masthead 1	OFF	Light 5 is Off
		ON	Lamp 5 is on
6	Masthead 2	OFF	Lamp 6 is on
		ON	Lamp 6 is on
7	RAM	OFF	Lamp 7 is Off
		ON	Lamp 7 is on
8	Stern	OFF	Lamp 8 is Off
		ON	Lamp 8 On

Based on the table above, the results of the tests carried out on the lamp and pushbutton system, it can be concluded that all pushbuttons (buttons 1 to 8) function properly in activating the appropriate lamp. Each pushbutton is tested by pressing it in two conditions, namely OFF and ON. In the OFF condition, the lamp being tested does not light up, while in the ON condition, the lamp lights up correctly according to the button number pressed. The test results show that each lamp, from Lamp 1 to Lamp 8, can be turned on by pressing the appropriate pushbutton, without any indication of failure or system malfunction.

3.2 Voltage Sensor and Current Sensor Reading Testing

In this microcontroller-based navigation system, an ACS712 current sensor and a voltage divider-based voltage sensor are used to read the parameters on the lamp. Before using the multiplexer, the first step is to take a sensor reading directly to the Arduino analog pin to determine how accurately the sensor reads the actual value compared to the measuring instrument, as shown in Table 2.

Table 2. Testing Voltage Sensor and Current Sensor Readings

No	Light	Condition	Voltage Sensor	Voltmeter Reading	Current Sensor	Ammeter Reading
1.	Lamp 1	Light ON	2.2	2,347	0.167	0.285
		Lights OFF	2.5	3,182	0.106	0
2.	Lamp 2	Light ON	2.3	2,355	0.171	0.276
		Lights OFF	2.5	3.2	0.103	0
3.	Lamp 3	Light ON	2.3	2,594	0.177	0.242
		Lights OFF	2.5	3,183	0.111	0
4.	Lamp 4	Light ON	2.4	2,543	0.170	0.256
		Lights OFF	2.5	3,219	0.105	0
5	Lamp 5	Light ON	2.3	2,675	0.165	0.249
		Lights OFF	2.5	3,219	0.101	0
6.	Lamp 6	Light ON	2.3	2,446	0.172	0.297
		Lights OFF	2.5	3,183	0.106	0
7.	Lamp 7	Light ON	2.3	2,522	0.168	0.294
		Lights OFF	2.4	3,206	0.110	0
8.	Lamp 8	Light ON	2.3	2,652	0.174	0.257
		Lights OFF	2.5	3,194	0.116	0

Despite the inaccuracy in the absolute readings in the table above, the system still demonstrates good consistency in distinguishing lamp status. This is evident in the consistent reading patterns between ON (approximately 0.170A and 2.3V) and OFF (approximately 0.105A and 2.5V) conditions. This consistency allows the values to be used to determine lamp status, although they are not as accurate as standard measuring instruments. The limitations of this system are influenced by several technical factors such as noise or interference, ground loops, etc. For future development, several improvements can be made in both hardware and software. From the hardware side, improvements to the PCB design, better ground isolation, and replacement of the ACS712 5A sensor type can be made. Meanwhile, from the software side, reading and compensation algorithms can be implemented to improve sensor reading accuracy.

3.3 Current and Voltage Sensor Reading Testing via Multiplexer

Continued In this section discusses the testing of the CD74HC4076 Multiplexer device used in the system. The multiplexer has 16 input channels, 4 control pins, and 1 output channel, where 16 channels are connected to current sensors and voltage sensors. 8 voltage sensors are connected to channels 0-7, while the voltage sensor is connected to channels 8-15. 4 control pins are connected to the Arduino Digital I/O pins, and 1 multiplexer output channel is connected to the Analog pin on the Arduino. Testing is done to measure the accuracy of the sensor if the data is sent through a multiplexer before entering the Arduino.

Based on the test results, the CD74HC4067 multiplexer is able to transmit signals from current and voltage sensors with fairly good accuracy. In the current sensor test, there is a slight difference between the readings via the multiplexer and the readings directly from the sensors. The maximum difference occurs in Channel 2 at 0.026 A, while the smallest difference is in Channel 0 at 0.005 A. Overall, these differences are relatively small and insignificant, indicating that the multiplexer can maintain the accuracy of current data well even though there are slight variations between channels. Meanwhile, in the voltage sensor test, the results show that most channels have no reading difference (0 V difference), except for Channels 9 and 12 which have a difference of 0.1 V. This difference is still classified as low tolerance, indicating that the multiplexer is able to transmit voltage signals without significant changes. Thus, the multiplexer is proven to work well to transmit data from sensors to Arduino with a high level of accuracy, as shown in Table 3.

Table 3 Sensor Testing via Multiplexer

Channel	Sensor Type	Reading Results	Reading using Sensor	Difference
Channel 0	Current	0.162 A	0.167 A	0.005
Channel 1	Current	0.154 A	0.171 A	0.017
Channel 2	Current	0.151 A	0.177 A	0.026
Channel 3	Current	0.160 A	0.170 A	0.010
Channel 4	Current	0.159 A	0.165 A	0.006
Channel 5	Current	0.165 A	0.172 A	0.007
Channel 6	Current	0.156 A	0.168 A	0.012
Channel 7	Current	0.157 A	0.174 A	0.018
Channel 8	Voltage	2.2 V	2.2 V	0
Channel 9	Voltage	2.2 V	2.3 V	0.1
Channel 10	Voltage	2.3 V	2.3 V	0
Channel 11	Voltage	2.4 V	2.4 V	0
Channel 12	Voltage	2.2 V	2.3 V	0.1
Channel 13	Voltage	2.3 V	2.3 V	0
Channel 14	Voltage	2.3 V	2.3 V	0
Channel 15	Voltage	2.3 V	2.3 V	0

3.4 Overall Tool Testing

This tool testing was conducted to ensure that the microcontroller-based navigation system can work properly in reading, displaying, and analyzing electrical parameters from navigation lights. The testing involved an ACS712 current sensor and a voltage divider-based voltage sensor connected to a CD74HC4067 multiplexer and controlled by an Arduino Mega 2560 microcontroller. The test results were compared with reference measurements using a digital multimeter to validate the system's accuracy, as shown in Table 4.

Table 4. Sensor Testing via Multiplexer

No	Lamp Name	Pushbutton Status	Voltage (V)	Current (A)	Light Status	Buzzer (ON/OFF)
1.	Forward Anchor	Pushbutton ON	2.2	0.163	The lights are on	OFF
		Pushbutton OFF	2.2	0	Lights off	ON
2.	Starboard	Pushbutton ON	2.3	0.115	The lights are on	OFF
		Pushbutton OFF	2.3	0	Lights off	ON
3.	Port	Pushbutton ON	2.3	0.182	The lights are on	OFF
		Pushbutton OFF	2.3	0	Lights off	ON
4.	NUC	Pushbutton ON	2.3	0.109	The lights are on	OFF
		Pushbutton OFF	2.3	0	Lights off	ON
5	Masthead 1	Pushbutton ON	2.2	0.129	The lights are on	OFF
		Pushbutton OFF	2.2	0	Lights off	ON
6	Masthead 2	Pushbutton ON	2.3	0.106	The lights are on	OFF
		Pushbutton OFF	2.3	0	Lights off	ON
7	RAM	Pushbutton ON	2.3	0.132	The lights are on	OFF
		Pushbutton OFF	2.3	0	Lights off	ON
8	Stern	Pushbutton ON	2.4	0.112	The lights are on	OFF
		Pushbutton OFF	2.4	0	Lights off	ON

The test results show that the microcontroller-based navigation system works well in reading, displaying, and analyzing electrical parameters on the navigation lights . The detected voltage ranges from 2.2 V to 2.4 V when the lights are on, while the measured current reaches a maximum value of 0.182 A, depending on the active lights. This system shows a consistent response to pushbutton conditions, where the lights are on when the pushbutton is in the ON condition and off when the pushbutton is OFF, according to the desired control logic. In addition, the buzzer function works well, active (ON) only when the lights are off, as a marker or alarm for certain conditions.

4. CONCLUSION

Based on the results of testing and analysis conducted on the Arduino Mega 2560 microcontroller-based navigation light system, it can be concluded that this system has successfully met the main objectives that have been set. Tests show that the system is able to monitor the condition of the lights and provide an effective warning mechanism in detecting potential failures. With the use of current and voltage sensors, as well as the integration of multiplexer ICs, this system not only improves the reliability but also the operational efficiency of the navigation lights. The results obtained indicate that this system can improve shipping safety in Indonesian waters, considering the high number of accidents caused by navigation system failures.

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