

Arduino Mega-Based Transporter Robot for Box Handling in a Maze Arena

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ABSTRACT

The objective of this study was to develop a transporter robot designed to move boxes from one location to another within an Arduino Mega-based maze arena. The problems addressed by this transporter robot include autonomous navigation in the maze area, detection of boxes based on their colors, transferring boxes from one location to another, and climbing inclined surfaces. The method used to control the transporter robot was based on input from the TCS3200 color sensor and ultrasonic sensors, which were employed to detect box objects and navigate the robot. The Arduino Mega was used to process sensor data and control the robot according to the sensor inputs. A servo motor was utilized to actuate the robot arm and gripper, while DC motors were used to drive the wheels of the transporter robot. The results of this study indicate that the transporter robot was able to complete the mission of navigating the maze and transferring box objects to their designated locations, achieving a success rate of up to 70%, with an average mission completion time of 6.8 minutes, while unsuccessful mission attempts required up to 9.6 minutes.



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I. INTRODUCTION

A robot is a device developed to assist human tasks, consisting of an input unit employing sensors and transducers, a processing unit using a microcontroller or microcomputer, and an output unit utilizing actuators [1]. Several types of robots are commonly used to support human activities in industrial applications, one of which is the transporter robot. A transporter robot is a type of robot capable of moving objects from one location to another by integrating a mobile robot platform and a robotic arm into a single robotic system [2]. The objective of this study is to develop a transporter robot system capable of transferring box objects from one location to another within a maze arena, using an Arduino Mega as the main controller of the transporter robot.

In practice, several previous studies have implemented transporter robot-based systems for advancing knowledge and assisting human tasks. Yudha et al. implemented an

object detection system on a transporter robot using the Darknet YOLOv3 method [3]. In that study, the researchers developed an object detection-based transporter robot using an ESP32-Cam and YOLOv8 with an ESP32-based processing platform. Jabbar et al. implemented an adaptive gripper control system on a transporter robot for industrial object handling [4]. In their study, an Arduino Uno was used as the main controller to operate the robot. Furthermore, Sirmayanti et al. developed a gripper control system through a transporter robot for lifting loads in a designated area [5]. The results demonstrated that the robot operated successfully using a control system based on the ESP8266 microcontroller. Additionally, Rusimamto et al. developed a transporter robot training kit for robotics education based on an Android application [6]. In that study, the researchers utilized an Arduino Uno as the microcontroller to develop the transporter robot.

Furthermore, Yandhika et al. designed a transporter robot that could be remotely controlled using an Android

smartphone [7]. In that study, the researchers used an Arduino Uno connected to a Bluetooth communication device to control the movement of the transporter robot. In addition, Sirmayanti et al. engineered a gripper control system for a transporter robot using a wireless system [8]. The researchers employed an ESP8266 to control the transporter robot by utilizing the built-in wireless communication capability of the microcontroller. Moreover, Buditjahjanto et al. developed a transporter robot as a learning medium for microcontroller education [9]. In that development, the researchers used the ATmega8 microcontroller as the main controller of the transporter robot. Furthermore, Gumilang et al. designed a transporter robot that could be remotely operated through Bluetooth communication via an Android smartphone [10]. In that study, the researchers used an Arduino Uno integrated with a Bluetooth module to remotely control the robot through a mobile smartphone platform.

Unlike previous studies, which generally focused only on robot navigation or gripper systems separately, this study integrates autonomous maze navigation, color-based object identification, and object handling capabilities into a single embedded-system-based transporter robot platform. In addition, the robot was designed to autonomously navigate within a constrained maze environment while simultaneously performing object manipulation using a robotic arm and gripper. The integration of navigation and object manipulation capabilities simultaneously within a maze arena constitutes the main contribution of this study. This paper comprehensively discusses the results of the research. The Introduction presents the research background and problem statement. The Methodology explains the techniques used to solve the research problems. The Results and Discussion section presents the research findings followed by a detailed discussion. Finally, the Conclusion provides a summary of the main findings, along with recommendations for future research development.

II. METHOD

In this study, the researchers developed a transporter robot designed to automatically move boxes to their designated locations based on color identification within a maze environment using an Arduino Mega microcontroller. The researchers designed a system architecture that enables the transporter robot to accomplish its task of transferring boxes. There are three main components in the proposed robot system architecture: the input unit, which includes the sensor reading system; the processing unit based on the Arduino Mega microcontroller; and the output unit, which functions to control the robot mobility system and actuate the robotic arm of the transporter robot. Figure 1 illustrates the architecture of the proposed system.

Based on the information presented in Figure 3, it can be observed that the developed transporter robot consists of three main components: input, processing, and output units.

The input unit includes five ultrasonic sensors that function to detect the walls of the maze, enabling the robot to perform navigation within the maze. An ultrasonic sensor is a device capable of detecting objects based on distance measurement by utilizing the reflection of ultrasonic waves transmitted from the sensor transmitter to the receiver [11]. In addition, the input unit is equipped with a TCS3200 sensor, which functions to detect the color of the boxes. The transporter robot then places each box in its designated location according to its detected color. The TCS3200 is a color sensor capable of identifying object colors based on their Red, Green, and Blue (RGB) values [12].

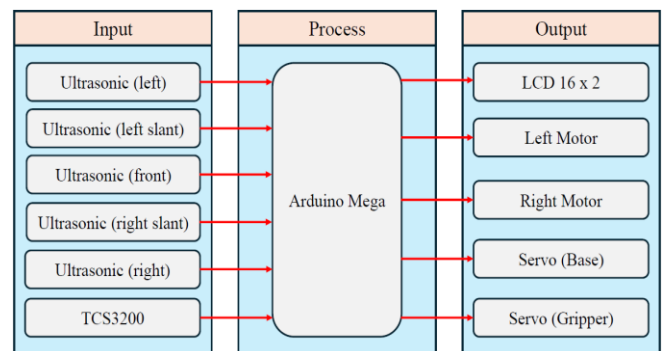


Figure 1. Robot transporter system architecture

Furthermore, in the processing unit, an Arduino Mega is employed as the main platform for data acquisition and processing of the robot system. The Arduino Mega is a member of the Arduino microcontroller family that provides 54 digital input/output pins and 16 analog input pins [13]. Table 1 presents the list of input and output pins used to acquire sensor data and control the outputs of the transporter robot.

TABLE I
ARDUINO MEGA PIN CONNECTED TO DEVICES

| Devices | Input / Output Pin |
|---------------------------------|--------------------|
| Ultrasonic Sensor (Left) | 2 and 3 |
| Ultrasonic Sensor (Left slant) | 4 and 5 |
| Ultrasonic Sensor (Front) | 6 and 7 |
| Ultrasonic Sensor (Right slant) | 8 and 9 |
| Ultrasonic Sensor (Right) | 10 and 11 |
| TCS3200 Sensor | 12, 13, 14, and 15 |
| Motor Driver L2938N | 16, 17, 18, and 19 |
| LCD 16 x 2 | 20 and 21 |
| Servo Motor (Base) | 22 |
| Servo Motor (Gripper) | 23 |

Furthermore, the output unit includes an L298N motor driver, which functions to control the movement of the left and right wheels of the robot. The L298N is an integrated circuit device that can be used to control up to two DC motors using PWM control signals [14]. A DC motor is one of the most commonly used motor types in mobile robots for driving robot movement based on commands from the microcontroller [15]. In addition, the output unit is equipped

with an LCD 16x2 display, which functions to present text messages of the transporter robot according to the control output from the Arduino Mega microcontroller [16]. Moreover, the output unit contains two servo motors that function to actuate the robotic arm of the transporter robot, including the base and gripper mechanisms. A servo motor is a type of motor capable of rotating to a specific angular position based on pulse control signals [17].

In this study, the researchers implemented a path-planning algorithm to navigate the robot within the maze and subsequently transfer the boxes from one location to their respective designated positions based on color classification. A path-planning algorithm is a computational method used to determine the best or most efficient route from an initial point to a target destination while avoiding obstacles [18]. Furthermore, in this study, the transporter robot employed a wall-following method based on multi-ultrasonic sensor readings to navigate within the maze arena. The robot maintained a specific distance from the maze walls using the left and right ultrasonic sensors. The robot movement direction was determined based on the distance readings obtained from five ultrasonic sensors installed at the front, left, right, left-slant, and right-slant sides of the robot. Table 2 presents the truth table used to determine the robot movement direction based on the input from the ultrasonic sensors for wall detection in centimeters (cm).

TABLE 2
ROBOT NAVIGATION MOVEMENT BASED ON THE DISTANCE OF THE ULTRASONIC SENSOR TO THE WALL (IN CM)

| Ultrasonic Sensors - Wall (in cm) | | | | | Robot Moves |
|-----------------------------------|------------|-------|-------------|-------|-------------|
| Left | Left Slant | Front | Right Slant | Right | |
| < 10 | > 10 | > 10 | > 10 | < 10 | Forward |
| > 10 | > 10 | > 10 | > 10 | > 10 | Forward |
| < 7 | < 10 | > 10 | > 10 | > 13 | Turn Right |
| < 7 | < 10 | < 10 | > 10 | > 10 | Turn Right |
| < 10 | < 7 | < 10 | > 10 | > 10 | Turn Right |
| > 13 | > 10 | > 10 | < 10 | < 7 | Turn Left |
| > 10 | > 10 | < 10 | < 10 | < 7 | Turn Left |
| > 10 | > 10 | < 10 | < 7 | < 10 | Turn Left |
| > 7 | > 7 | < 7 | > 7 | > 7 | Backward |
| > 7 | < 7 | < 7 | > 7 | > 7 | Backward |
| > 7 | > 7 | < 7 | < 7 | > 7 | Backward |
| > 7 | < 7 | < 7 | < 7 | > 7 | Backward |

Based on the information presented in Table 2, it can be observed that the wall-following method was implemented to navigate the robot within the maze arena. In this study, the wall-following method was selected because it has lower computational complexity compared to SLAM or graph-based path-planning methods, making it more suitable for implementation on the Arduino Mega microcontroller, which has limited memory capacity and computational power. In addition, compared to the line-following method, the wall-following approach is more flexible because the

robot does not require a predefined line track within the maze arena.

III. RESULTS AND DISCUSSION

The implementation of a transporter robot capable of moving boxes from one location to their designated positions using an automatic control system based on the Arduino Mega has been carried out in this study. Figure 2 illustrates the hardware components of the developed transporter robot.

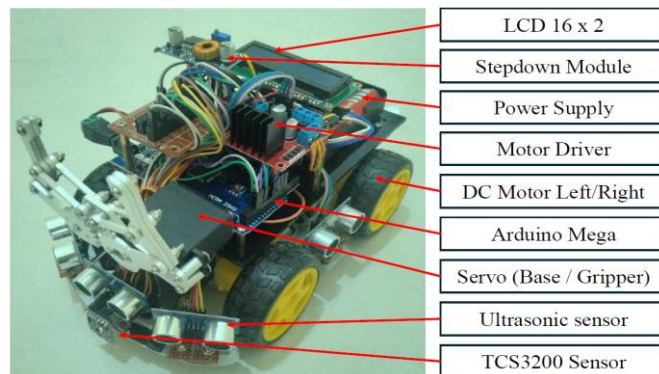


Figure 2. Robot transporter results

Based on the information presented in Figure 2, it can be observed that several hardware components are interconnected in the transporter robot, enabling the robot to operate automatically. These components include an LCD 16x2, a step-down module, a power supply unit, an L298N motor driver, DC motors, an Arduino Mega, servo motors (for actuating the base and gripper), ultrasonic sensors, and a TCS3200 sensor.

The function of the LCD 16x2 in the developed transporter robot is to display text messages, with a capacity of 16 characters in each row. Furthermore, the function of the step-down module is to reduce the voltage from 12 VDC to 6 VDC as the power source for driving the DC motors. The power supply unit functions as the main voltage source of the robot. In the developed transporter robot, the researchers used a battery with a supply voltage of 12 VDC. In addition, the robot is equipped with an L298N motor driver, which functions as the driver circuit for controlling the rotation of the DC motors mounted on the robot wheels based on commands from the Arduino Mega. The developed transporter robot utilizes four DC motors connected to the robot chassis. The rotation of these DC motors can be controlled according to commands from the Arduino Mega microcontroller interfaced with the L298N motor driver.

The developed transporter robot is also equipped with an Arduino Mega, which functions as the central data-processing unit of the robot system. The Arduino Mega provides numerous input/output pins that can be interfaced with sensors and actuators. In addition, it offers relatively large program memory capacity, making it suitable for

developing complex robotic projects. Furthermore, the transporter robot employs two servo motors to actuate the robotic arm so that it can pick up boxes, grip them, and place them in their designated locations. These two servo motors are assigned to different functions: one servo motor controls the base mechanism for lifting and lowering the robotic arm, while the other servo motor operates the gripper mechanism. In addition, the robot is equipped with ultrasonic sensors that function to detect the maze walls, enabling the robot to navigate within the maze environment. The ultrasonic sensors measure the distance between the robot and the maze walls based on ultrasonic waves reflected between the transmitter and receiver integrated in the sensor. The ultrasonic sensors used in this study are capable of detecting objects at distances of up to 300 cm. Finally, the transporter robot is equipped with a TCS3200 sensor, which functions to detect box objects based on their colors. Table 3 presents the color-reading data used by the TCS3200 sensor to identify boxes in the maze arena.

TABLE 3
RED (R), GREEN (G), AND BLUE (B) DATA VALUE OF THE BOX

| Box Colour | R, G, B Values |
|------------|---------------------|
| Yellow | RGB (250, 248, 152) |
| Green | RGB (85, 107, 47) |
| Blue | RGB (173, 216, 230) |
| White | RGB (237, 234, 222) |

Referring to the RGB value data of the boxes presented in Table 3, it can be observed that each box color has different RGB values, depending on the respective box color. The accuracy of the TCS3200 sensor in detecting the boxes is highly influenced by the RGB value configuration implemented in the program. In this study, the TCS3200 sensor was utilized because it is capable of detecting the RGB composition of objects in real time with relatively low implementation cost. To minimize the influence of environmental lighting conditions, the experiments were conducted under relatively stable light intensity conditions, and the sensor was positioned at a fixed distance from the box objects. Nevertheless, variations in light intensity may still affect the color-reading accuracy and remain one of the limitations of this study. In this study, the researchers conducted several experimental trials of robot navigation from the start point to the finish point in the maze arena to transfer boxes from one location to another. The maze arena used in this study had dimensions of 300 cm × 300 cm with a path width of 30 cm. The arena consisted of eight intersections and several dead-end paths designed to evaluate the navigation capability of the transporter robot. The arena surface was constructed from flat wooden material, with several sections of the track having inclination angles of approximately 10°–15°. The box objects were placed at several designated points within the arena to evaluate the robot's capability in color detection and object handling. The dimensions of the robot used in this study were 20 cm in length, 15 cm in width, and 20 cm in height.

Figure 3 illustrates the navigation experiment of the transporter robot in the maze arena.

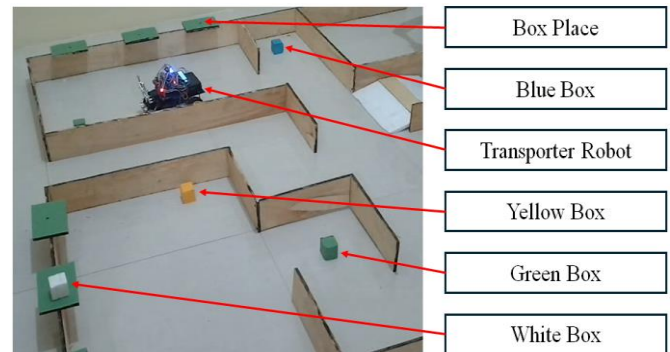


Figure 3. Transporter robot navigation in a maze

Based on the information presented in Figure 3, it can be observed that the transporter robot performs navigation within the maze to search for boxes and subsequently identifies the box colors—blue, yellow, green, and white—using the TCS3200 sensor. In the conducted experiments, the initial step of the transporter robot was to navigate the maze based on input data obtained from the ultrasonic sensors, followed by searching for box information according to the color data acquired from the TCS3200 sensor. When the sensor detected an object, the transporter robot commanded the base servo to lower the robotic arm, after which the gripper was opened and closed to grasp the object, and then the box was lifted. After the robotic arm successfully lifted the box, the transporter robot moved toward the storage area and placed the box in its designated position. This process continued until all boxes in the maze had been collected and stored in their respective locations. Once the transporter robot successfully completed its mission of placing all boxes in their designated positions, it then moved to the finish area to complete the overall mission and task. Table 4 presents the experimental results of the robot in completing the mission in terms of completion time and mission success rate, based on ten experimental trials.

Based on the information presented in Table 4, it can be observed that out of ten experimental trials, seven trials were successful and three trials failed, with different task completion times in each trial. In this experiment, the transporter robot was considered successful in completing the mission if it successfully detected the boxes, placed them in their designated locations, and subsequently navigated to the finish point. Conversely, the robot was considered unsuccessful if it failed to store all boxes in their proper locations or was unable to navigate to the finish point. In addition to the success rate and mission completion time, the system evaluation was also conducted based on the stability of the robot movement during navigation and the consistency of the experimental results across multiple repeated trials. The experimental results indicate that load variations when the robot carried the boxes affected the stability of the robot movement, particularly on turning paths

and inclined tracks. Therefore, based on the experimental results, the transporter robot system was able to perform autonomous navigation and object-handling functions with a success rate of 70%. Nevertheless, this success rate still indicates several system limitations that need to be improved for implementation in more complex environments. The success of the transporter robot in completing the mission depended on the accuracy of the sensors in navigating the maze, detecting the box objects, and accurately placing the boxes in their designated positions. In this study, the failure of the robot to complete the mission was generally caused by several factors, including navigation errors due to unstable ultrasonic sensor readings at certain angles, the inability of the TCS3200 sensor to accurately detect box colors due to lighting variations, and inaccuracies in the servo gripper position during object grasping. In addition, in several experiments, the robot experienced delays in decision-making when navigating intersections within the arena.

TABLE 4
TEST OF TRANSPORTER ROBOT NAVIGATION AND RESULTS

| Test | Times (Minutes) | Results |
|------|-----------------|---------|
| 1 | 6.4 | Success |
| 2 | 7.2 | Success |
| 3 | 9.4 | Fail |
| 4 | 6.2 | Success |
| 5 | 6.8 | Success |
| 6 | 8.9 | Fail |
| 7 | 7.5 | Success |
| 8 | 6.9 | Success |
| 9 | 9.8 | Fail |
| 10 | 6.7 | Success |

Furthermore, Figure 4 illustrates a comparative graph of the average time required by the transporter robot to complete its tasks. Based on the information presented in Figure 4, the transporter robot required an average of 6.8 minutes to successfully complete its mission of navigating the maze, transferring box objects, and reaching the finish point, whereas failed attempts had an average completion time of 9.4 minutes. The variation in the time required for successful and failed task completion was highly dependent on several factors, including the speed of the robot motors during movement, the accuracy of the ultrasonic sensors in detecting maze walls, the accuracy of the TCS3200 sensor in identifying box colors, the precision of the servo motors and robot movements during box handling, and the speed of the robot in reaching the finish point. In addition, the experimental results also indicate that variations in arena conditions, such as track inclination angles and changes in box positions, affected the performance of the transporter robot. On tracks with higher inclination angles, the stability of the robot decreased due to changes in load distribution when the robot carried the boxes. Furthermore, changes in object positions that differed from the initial experimental setup caused the robot to require a longer navigation time to detect and grip the objects. In this study, the researchers

employed a path-planning algorithm to move the robot from one section to another. This algorithm was selected because it facilitates the determination of the movement direction of the transporter robot according to its assigned mission.

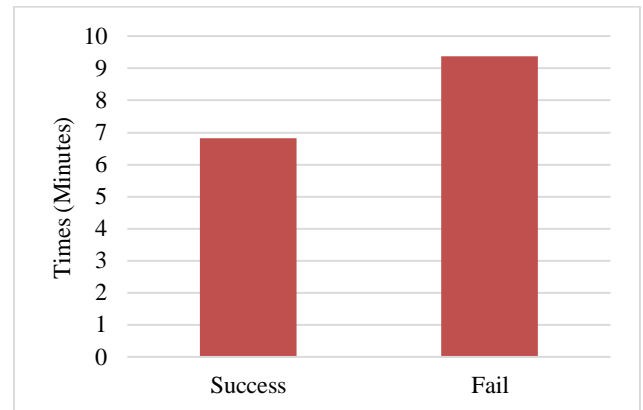


Figure 4. Average time for transporter robot to complete a mission

This study successfully implemented an automatic control system for a transporter robot to navigate the arena and transfer boxes from one location to their respective designated positions using an Arduino Mega-based control system. The sensors used for robot navigation were ultrasonic sensors, while a TCS3200 sensor was employed to detect box colors. In the output unit, servo motors were used to actuate the robotic arm of the transporter robot, while DC motors were utilized to drive the wheels of the robot. Based on the experimental results obtained from the robot testing, the performance of the transporter robot was influenced by several hardware limitations. The Arduino Mega has limitations in memory capacity and processing speed, resulting in the navigation algorithm remaining relatively simple. In addition, the ultrasonic sensors have limited accuracy at certain angles, and the TCS3200 sensor is sensitive to variations in environmental lighting conditions. The servo motors also have limited torque capability when lifting boxes with certain weights, which affects the stability of the robot gripping mechanism.

According to the research results, a recommendation for future development is that the transporter robot can be enhanced to communicate and collaborate with other robots through wireless communication using multi-robot communication system technology. This capability can be further developed by implementing a communication system based on the Internet of Things. In addition, although this study was conducted in a structured maze arena, the developed transporter robot concept has the potential to be applied in real-world environments such as warehouse logistics systems, smart warehouses, and autonomous indoor transportation systems. Nevertheless, implementation in real-world environments requires further development, such as the adoption of more accurate sensors, adaptive navigation algorithms, and Internet of Things-based communication systems.

IV. CONCLUSION

The implementation of a transporter robot designed to navigate a maze and place boxes in their designated locations using an Arduino Mega-based control system has been successfully carried out in this study. In the system input unit, ultrasonic sensors were employed to navigate the robot within the maze, while a TCS3200 sensor was used to detect boxes based on their colors. In the processing unit, an Arduino Mega served as the central data-processing controller of the robot. Furthermore, the output unit consisted of servo motors for actuating the robotic arm and gripper, DC motors for driving the robot wheels, and an LCD 16x2 for displaying messages. The algorithm applied in this study to navigate the robot and accomplish its mission in the maze arena was a path-planning algorithm. Based on the experimental results, the transporter robot was able to complete the mission of navigating the maze and placing the boxes in their designated locations with a success rate of up to 70%, an average successful mission completion time of 6.8 minutes, and an average failed mission time of 9.6 minutes. Therefore, it can be concluded that the transporter robot developed in this study was successfully constructed and was able to operate automatically to navigate the maze and transfer boxes to their designated locations. For future research development, it is recommended to implement a multi-robot communication system among transporter robots using network technology and the Internet of Things.

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