Bitlis Eren Üniversitesi Fen Bilimleri Dergisi
BİTLİS EREN UNIVERSITY JOURNAL OF SCIENCE
ISSN: 2147-3129/e-ISSN: 2147-3188
VOLUME: 12 NO: 4 PAGE: 1139-1149 YEAR: 2023
DOI:10.17798/bitlisfen.1347396

Autonomous Cargo Carrier Robot in GPS Denied Indoor Environment

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Keywords: Mobile Robot, Indoor Navigation, Cargo Robot, Compass Sensor, Arduino.

Abstract
The mobile robot industry, which has become a rapidly growing sector, can easily perform many activities or tasks that can be dangerous, laborious or tiring for humans. A mobile robot helps people by performing the desired tasks in areas such as medical, military, household and cargo. Robots, which perform their duties indoor or outdoor environments, use navigation systems to reach the desired destination. While the global positioning system is generally used in the external environment, different navigation methods are used in the indoor environment. The accuracy of navigation is of great importance when passing through complex, narrow and obstructed roads while going to the relevant target location in the indoor environment. In this study, a cargo carrier robot that can autonomously travel to a location determined by the user in indoor conditions has been developed. After the target point is determined, the cargo vehicle takes action automatically from the starting point, and continuously detects location in order to reach the target with the compass sensor on it. Ultrasonic sensors have been used so that the cargo vehicle can continue to move without hitting any object that may come in front of it while it is going to the target location. A mobile application has been developed to give the destination location of the cargo vehicle and to follow the vehicle. The movements of the autonomous vehicle are controlled by the commands sent via Bluetooth.

1. Introduction

Today's technology is renewing itself day by day and making people's lives easier. Robot technology, which has accelerated the development process with the support of Industry 4.0 in recent years, serves people in many areas such as industry, household, cargo transportation, transportation, shopping [1]. Mobile robots that can move autonomously with the support of smart systems and sensor technologies are among the robot technologies used in indoor and outdoor environments and controlled by various navigation methods. Mobile robots, which have the ability to move autonomously by processing the data received from the sensors on them [2], can perform complex tasks such as transporting products within the factory, performing operations that are dangerous for human health, patrolling indoors, and performing repetitive processing processes [3].

Due to the increase in smart production and e-commerce activities carried out around the world and their inability to meet industrial requirements, traditional sorting and transportation processes have been replaced by contemporary logistics and smart storage methods. Intelligent robots used in operations carried out indoors can replace humans by making delivery and working processes smart. With autonomous transport systems, operations can be performed more efficiently and reliably [4]. In this progress, intelligent robots can make inferences similar to humans by observing the working environment. In the navigation studies carried out in a dynamic environment, it can direct the movement by improving the training process by making inferences from the objects or obstacles seen [5].

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Received: 21.08.2023, Accepted: 16.10.2023

Sensor technologies and smart algorithms are used to overcome such questions affecting navigation processes.

In this study, a cargo carrier robot that operates in the indoor environment and can autonomously travel from the starting location to the target location determined by the user has been realized. In the implemented system, the cargo carrier robot is guided towards the target location by using the compass sensor in indoor navigation processes. Servo motor and ultrasonic sensor were used to prevent the vehicle from being hit by any obstacle during the process of going towards the target location. In order to give the target location, a mobile application was developed and data transmission was ensured by communicating via Bluetooth. The cargo carrier robot that goes to the target location then returns to the starting location and ends its movement.

2. Related Work

With the advancement of artificial intelligence technologies in every field today, significant progress has been experienced in the robot industry. Technologies such as domestic service robots, food delivery robots, and cleaning robots that are offered to people can perform many tasks with their artificial intelligence-based interactions. Robots with artificial intelligence-based speech recognition systems handle some semantic symbols and extract information about their environment by basing these symbols on real reference points. As a result, robots try to recognize their internal environment and fulfill their duties [6]. While the robots used for service or service can easily move to target points with the support of GPS technology in outdoor environments, this process is more difficult in indoor environments. For this reason, the service robots can successfully move to the service robots during the trips to be made in indoor environments where GPS is not available [7]. In this section, some studies developed to fulfil various tasks in indoor environments and which have a place in the literature are given. A comparison table of the studies conducted in the literature is given in Table 1.

Nafais et al. [8], developed an IoT-based cargo carrier robot that can be used to transport products in cargo companies. For the control and sustainability of the system, Arduino Uno board, infrared sensor for tracking the lines on the route, pressure sensor for determining the weight of the object to be transported, position sensor for determining the position of the line, temperature sensor for detecting temperature, vibration sensor for controlling vibrations on the robot are used. The control of the robot was sent through the computer connected via the serial port. The performance of the robot in different conditions was discussed in the test operations carried out with straight, curved and intersection lines on the road. In the test results, it was seen that the robot follows the specified lines with an error margin of less than 1 cm. Chandra et al. [9], developed a vehicle prototype that can be used to transport products in a factory environment, reduce cargo handling accidents, and alleviate high-risk tasks for people to transport. The cargo robot, created with Arduino Uno controller card and Motor Shield card, is controlled via Bluetooth over mobile program. With the various commands sent over Bluetooth, the movements of the vehicle such as stop, forward, right, left and back were carried out. Kang et al. [10], developed a manipulation robot to autonomously perform product service operations indoors. The robot, which offers general-purpose use, has the ability to move in multiple directions and pass through narrow spaces. The robot, which can place and carry more than one object at the same time with the help of its arm during the product transport process, senses the objects around it thanks to its modular software and has the ability to navigate without hitting these objects. In test processes, it has demonstrated capabilities such as taking more than one product autonomously and transmitting it to the relevant areas during product service. Zeng et al. [11], developed a low-cost robot that can autonomously deliver food according to given commands. For the service robot, which will operate in indoor conditions, target detection has been made by means of infrared navigation method. The vehicle includes hardware MSP430 microprocessor, infrared sensor, ultrasonic sensor, Wi-Fi module, navigation module. Based on the information obtained from the sensors, PWM signals were given to the vehicle's motors and the movement of the vehicle was controlled. By combining the components inside the vehicle in a modular manner, the task of food delivery has been successfully accomplished. Tan et al. [12], developed a robot consisting of 3 different parts and working in the indoor environment. At the top of the robot are the IMU, camera, Ultra wide-band and laser radar used for navigation and location detection. In the middle section, there is the mechanism necessary for the robot to work. At the bottom, there are the STM32F103 microcontroller and DC motors used for the movement of the frame. The data received from the sensors at the top are processed with the Raspberry Pi 4 card and location information is obtained. The obtained location information is sent to the STM32F103 card in the lower section via serial communication protocol. The data coming to the lower section is processed and the vehicle is ensured to move towards the destination. In the test studies, it has been seen that the location detection and navigation process in the interior is done correctly with the system based on multiple sensors. Wu et al. [13], performed a precise positioning process in order to remotely monitor and control the robot, which will serve for food delivery indoors. Ultra wide band wireless transmitter module DWM1000 and ESP8266 microcontroller were used for indoor positioning. During the food delivery task of the robot, real-time location information is sent to the remote server in order to receive real-time location information and to remotely control the movements. This information is processed with various algorithms to control the indoor food delivery robot. Sun et al. [14], developed a food delivery robot that performs positioning and navigation by using sources such as ultra wide-band and sensor technologies (gyroscope, compass, and odometer). The kinematic equations for the accuracy and stability of the position are generated using an extended Kalman filter. In this way, it has been tried to provide more secure coordinate data. Thanks to this method, the food delivery robot has a wide usage area, low cost installation opportunity and high position accuracy. Cao et al. [15], developed a robot powered by Cloud and IoT technology that will serve for drug delivery in the indoor environment. When the robot starts to move, the relevant node information is received via the STM32F103RC microcontroller and sent to the data processing center with the Wi-Fi module. Depending on the processing of the received data, the direction of movement is determined. In the test processes in the laboratory environment, the performance analysis of the vehicle were made and the drug delivery times between the nodes were discussed. Mobile and PC terminals are designed for remote control of the robot.

3. System Overview

The working principle of the autonomous cargo carrier vehicle developed within the scope of the study is given in Figure 1. Arduino Uno microcontroller, compass sensor, ultrasonic sensor, Bluetooth module and motor driver circuit are used as hardware in the cargo carrier robot. Looking at the working process of the system, firstly it is expected that the data of the target location will arrive via the Bluetooth module. The cargo carrier robot, which takes action after the target location information is received, performs direction determination processes by detecting location and obstacles based on instant data from compass and ultrasonic sensors. With the developed direction detection algorithm, direction determination is made over the sensor data and the movement process is carried out by adjusting the motor directions towards the determined direction. In this section describes system overview inclusive of controller card, sensor configuration, software architecture, and mobile application platform.

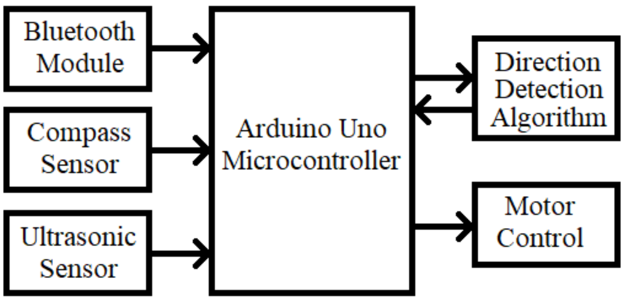

Figure 1. Working Principle of the Cargo Carrier Robot

Table 1. Literature Comparison

Ref.	Controller	Work Area	Environment	Movement Mode	Low Cost	Position Detection
8	Arduino Uno	Cargo	Indoor	Computer Control	Yes	Sensor System
9	Arduino Uno	Cargo	Indoor	Mobile Application	Yes	Manuel
10	Nvidia Jetson Xavier NX	Service	Indoor	Autonomous	No	SLAM
11	MSP430	Food Service	Indoor	Wi-Fi Communication	Yes	Infrared Tracking Navigation
12	Raspberry Pi 4 / STM32F103	Service	Indoor	Remotely Control	No	Laser Radar, UWB, Camera
13	ESP8266	Food Service	Indoor	Remotely Control	Yes	Ultra-wideband Navigation
14	STM32	Food Delivery	Indoor	Remotely Control	Yes	Ultra-wideband, Sensor System
15	STM32F103RC	Medicine Delivery	Indoor	Remotely Control	No	GPS
This Study	**Arduino Uno**	**Cargo**	**Indoor**	**Autonomous**	**Yes**	**Sensor System**

3.1. Arduino Uno Microcontroller

The Arduino platform is a technology that provides common use in the electronic and hardware information processing process and is becoming widespread with its open source applications. The microcontrollers used in this platform have a structure that can perform operations similar to a traditional computer structure and give outputs according to various data types. While there are many Arduino models available today, one of the most frequently used models is the Arduino Uno R3 model. This model, which contains the Atmega328 processor, has various input and output pins, both digital and analog. With the Arduino Uno card used in embedded systems, communication and data transfer operations are carried out between different systems via PWM, ADC, Timer, Interrupt and Serial communication modules [16]. Arduino Uno microcontroller is shown in Figure 2.

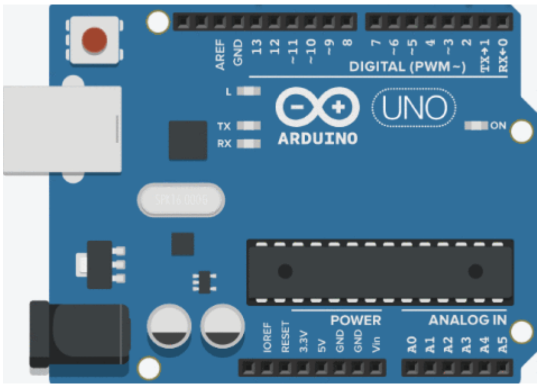

Figure 2. Arduino Uno R3 Microcontroller [16]

3.2. Sensor Units

The detection unit created to control the position, obstacle avoidance and movement processes in the cargo carrier robot consists of 3 sensors (compass sensor, ultrasonic sensor, Bluetooth sensor). The HMC5883L compass sensor is a digital sensor used to measure movements in the X, Y and Z axes. The 3-axis sensor, manufactured by Honeywell Company, communicates with the I2C serial communication protocol. The HMC5883L compass sensor is shown in Figure 3.a. The HC-SR04 distance sensor is one of the popular ultrasonic sensors used to measure distances between 2-400 mm, with a receiver and transmitter eye on it. In order to measure the distance of an object around, the ultrasonic sensor detects the distance with the signal during the return of the sound wave sent from the output unit after hitting the object. The HC-SR04 distance sensor is shown in Figure 3.b.

The HC-05 Bluetooth sensor is a sensor used for wireless communication and supports the Bluetooth 2.0 protocol. With the sensor, which has a range of about 10 meters in the open area, Arduino-based systems can be easily controlled remotely. The HC-05 Bluetooth sensor is shown in Figure 3.c.

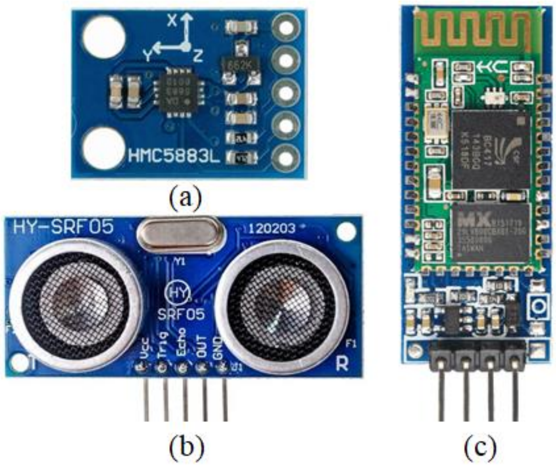

Figure 3. Cargo Carrier Robot Sensing Unit

3.3. Software Architecture

Two different software processes are discussed for the autonomous cargo carrier robot. In the first stage, controlling the data coming from the Bluetooth sensor is discussed. The target point sent via Bluetooth via the mobile application is detected and the movement of the vehicle is started. In the second step, the process from the beginning to the end of the movement is discussed. In this process, operations are carried out to ensure that the cargo vehicle can avoid obstacles that may come in its way, and to constantly control the status of arriving at the determined target point. The flow diagram of the working structure of the cargo transport vehicle is given in Figure 4. When the working structure is examined through the flow chart;

1. Firstly, a connection is expected between the mobile application and the Bluetooth sensor. After the Bluetooth connection, information about the target location is sent via the mobile application.
2. If the incoming location information is “B”, “C” or “D”, while operations are being performed to go to the relevant location, if “A” or a different command is sent, a warning is given and a command is expected to be sent again.
3. When one of the "B", "C" or "D" positions comes, the distance information is calculated in

meters according to the target location sent in the Arduino Uno microcontroller.

4. After the distance of the current location is determined, the compass sensor is expected to find its direction. Then the movement process is started.
5. Whether the robot should turn left or right is determined by the distance measured by the ultrasonic sensor. The distance is detected 10 cm before the obstacle and the motor rotation directions are determined according to the position of the obstacle.
6. The movement of the carrier robot continues along the route determined based on the obstacles encountered during the movement.
7. Whether the robot reaches its target point is determined by the threshold level value (Threshold Level, 15 cm selected).
8. If the threshold level is not reached, the robot tries to reach the target by recalculating the target direction, the current direction angle and the angle to the target. This process continues until the goal is reached.
9. The cargo carrier robot waits for 10 seconds after reaching the target point. This hold was chosen to represent the release of cargo.
10. After the waiting period, the cargo carrier robot returns to its starting point "A" and ends its movement.

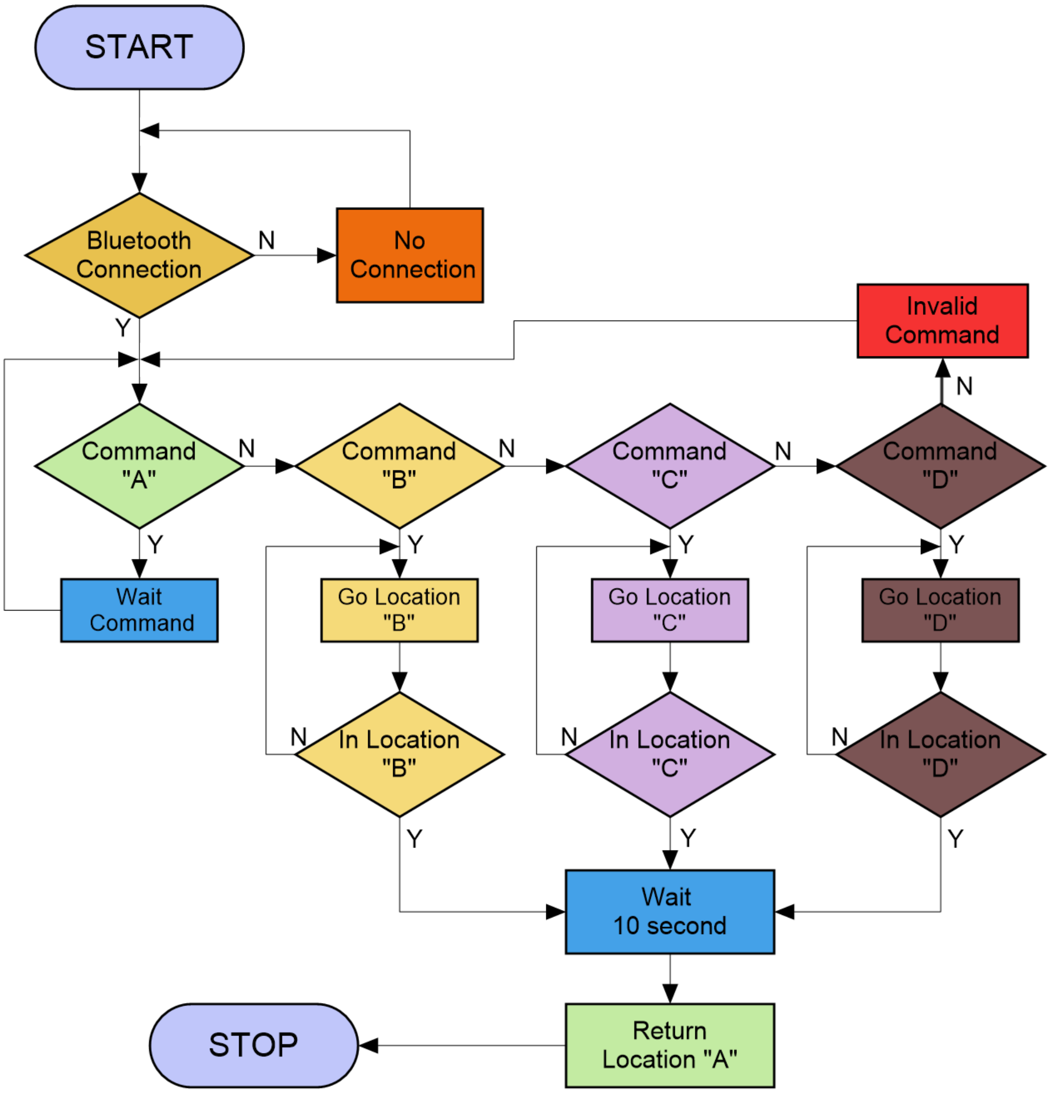

Figure 4. Flow Diagram of the Working Structure

3.4. Software Architecture

Cargo robots are used to perform delivery tasks, an important example of automation systems. In terms of working area, these robots can generally work in indoor environments or complex areas where GPS cannot be used. The cargo vehicle developed within the scope of the study was designed to operate in such an indoor environment. In the developed direction detection algorithm, map-based guidance and obstacle avoidance operations were performed for the cargo robot. The flow diagram of the working structure of the direction detection algorithm is given in Figure 5.

Since the cargo robot will be operated in an environment where GPS is not used, a data set containing map information of the task area has been prepared. In the created map structure, location information is determined for each corner point (A, B, C, and D). The task area used in the studies carried out in the test environment was prepared as 1.5 * 1.5 meters in size and the coordinates of the corner points were determined. The coordinates were set as point A (0, 0), point B (1.5, 0), point C (1.5, 1.5) and point D (0, 1.5). During the movement from the starting point to the target point, the direction information on the x and y coordinate axis is checked with the compass sensor and the direction of the cargo robot is determined in this way. Whether the cargo robot reaches the target point or not is checked by comparing the instantaneous x and y coordinates of the robot in motion with the x and y coordinates of the target point.

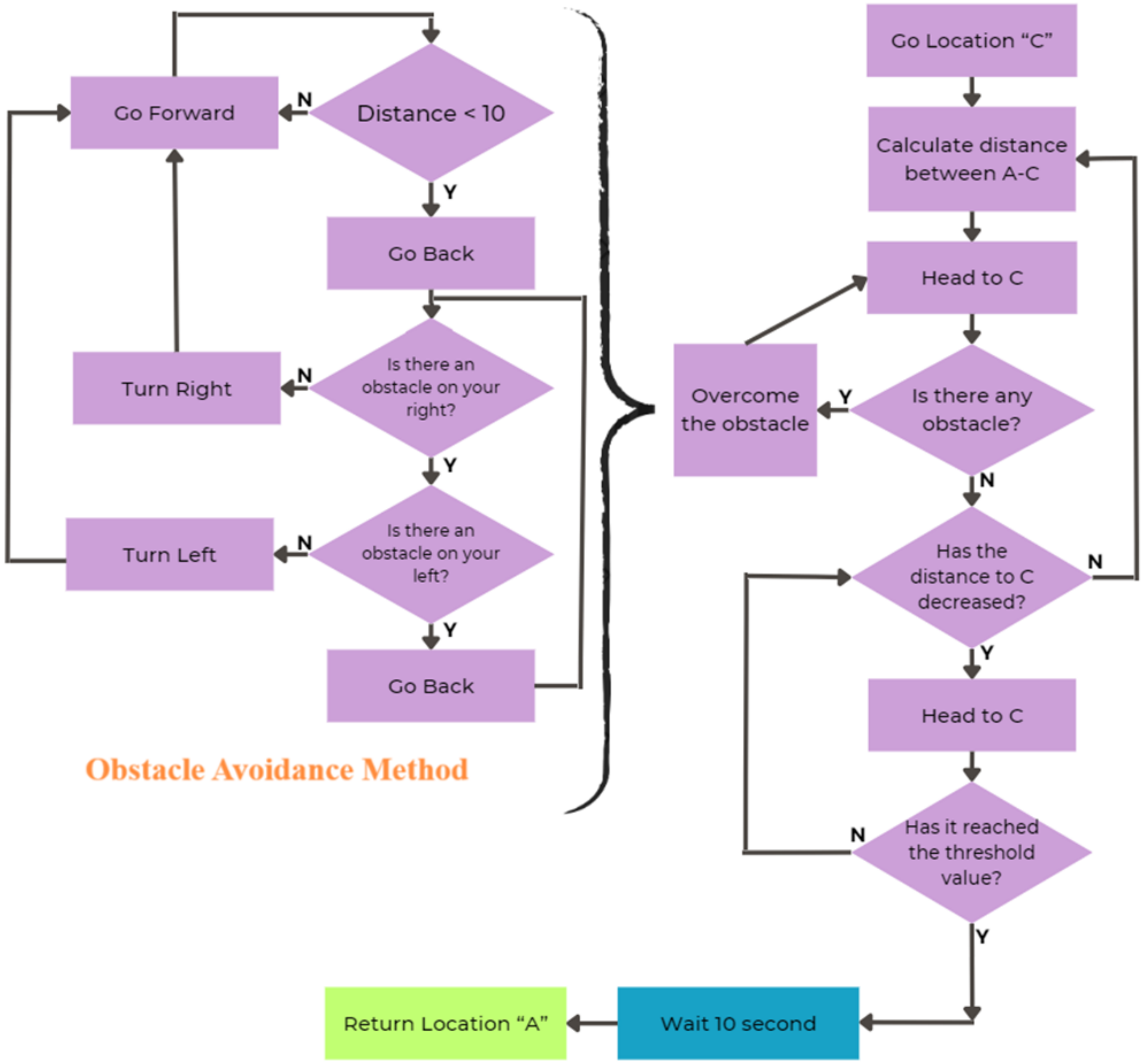

Figure 5. Flow Diagram of the Direction Detection Algorithm

When the cargo vehicle starts its movement, first the coordinate information between the starting point and the target point is taken into account and the distance between these two points is calculated. After this process, movement towards the target point is carried out. An ultrasonic sensor has used to detect obstacles and avoid these obstacles that may appear in front of the cargo robot during its movement. If there is an obstacle in front of the cargo vehicle, the ultrasonic sensor connected to the servo motor controls the right side of the robot, and if there is no obstacle, the robot turns to the right side. If there is any obstacle on the right side, the robot turns to the left side. If there is an obstacle on both the right and left sides at the same time, the robot goes back and continues on its way by making the same checks again. After overcoming the obstacles, distance checks based on coordinate information are made again while moving towards the target location. The decision as to whether the target point has been reached or not is made based on the threshold level value of the relevant target point. In making this decision, the proximity of the x and y coordinates of the target point and the instantaneous x and y coordinates of the robot (threshold 15 cm) is taken into consideration. After the cargo robot reaches the target point, it moves towards the starting point by repeating the same steps algorithmically. As a result, the direction detection algorithm developed enables the cargo robot that will operate in indoor environments to operate via a map-based guidance system, independent of GPS

3.5. Mobile Application Platform

A mobile application has been developed to remotely control the cargo carrier robot and send information about the destination point. The interface of the developed mobile application is shown in Figure 6. In the mobile application developed with the MIT App Inventor interface, Bluetooth connection is first performed. The information of the relevant Bluetooth sensor is selected via the mobile application and the wireless connection process is performed. After the connection process, one of the 3 destination points ("B", "C", "D") determined to carry cargo through the application is selected, and the cargo carrier robot is activated. Information about the relevant target location is sent to the Arduino Uno microcontroller board via the Bluetooth sensor. The robot starts its movement by making calculations about the received target information.

During the cargo transportation process, informational messages are also sent through the application depending on the destination points. After reaching the target, a return to the starting point is performed after a certain period of time, and the movement of the vehicle is terminated until the next command is received. If a different command is received via Bluetooth while the cargo carrier robot is going to the destination, it is not allowed to make any changes in the robot's movement route. In this way, it is aimed to prevent erroneous location detections that may occur.

Figure 6. Mobile Application Interface

4. Indoor Environment Experimental Tests

During the development process of the autonomous cargo carrier robot, various tests were carried out. Firstly, test procedures were made for the individual operation of electronic components (Servo motor, DC motor driver, Bluetooth Sensor, Compass Sensor, Ultrasonic Sensor) with the Arduino Uno board, and each component was controlled. After the control of the electronic components, the tests related to the communication of the mobile application and the Arduino Uno board were started. In these test processes, test operations such as sending and receiving data to Arduino Uno via the mobile application were carried out. After controlling the carrier robot manually via the mobile interface, autonomous driving tests were started.

In autonomous driving tests, individually tests were performed such as for detecting objects around the vehicle and moving without hitting these objects, direction determination accurately moving to a given target point, and returning to the starting position. Finally, in the integrated system tests, tests were carried out to reach the target point and return to the starting point again without hitting the obstacles in front of the cargo carrier robot, which moves autonomously towards the target received via the mobile interface. The block diagram showing the hardware connection of the Arduino Uno board and electronic components is given in Figure 7.

The pin connections between the hardware components used in the cargo carrier robot and the Arduino Uno microcontroller are given in Table 2. A 4WD model car frame was used for the robot to carry the hardware components. Three pieces 1S LiPo batteries were used to meet the energy need of the system. Before moving to the integrated system, test work was carried out on each hardware. After the related hardware studies were successful, we were passed to the next hardware. In this way, hardware connection problems that may occur in the integrated system of the cargo carrier robot are prevented.

Table 2. Pin Connections

Arduino Uno	Hardware Component
D0	RX (Bluetooth)
D1	TX (Bluetooth)
D5	ENB (L298N)
D6	IN4 (L298N)
D7	IN3 (L298N)
D8	IN2 (L298N)
D9	IN1 (L298N)
D10	ENA (L298N)
D11	Servo Motor
D12	Echo Pin (Ultrasonic)
D13	Trig Pin (Ultrasonic)
A4	SDA (Compass)
A5	SCL (Compass)
VCC	Common +5V
GND	Common Ground

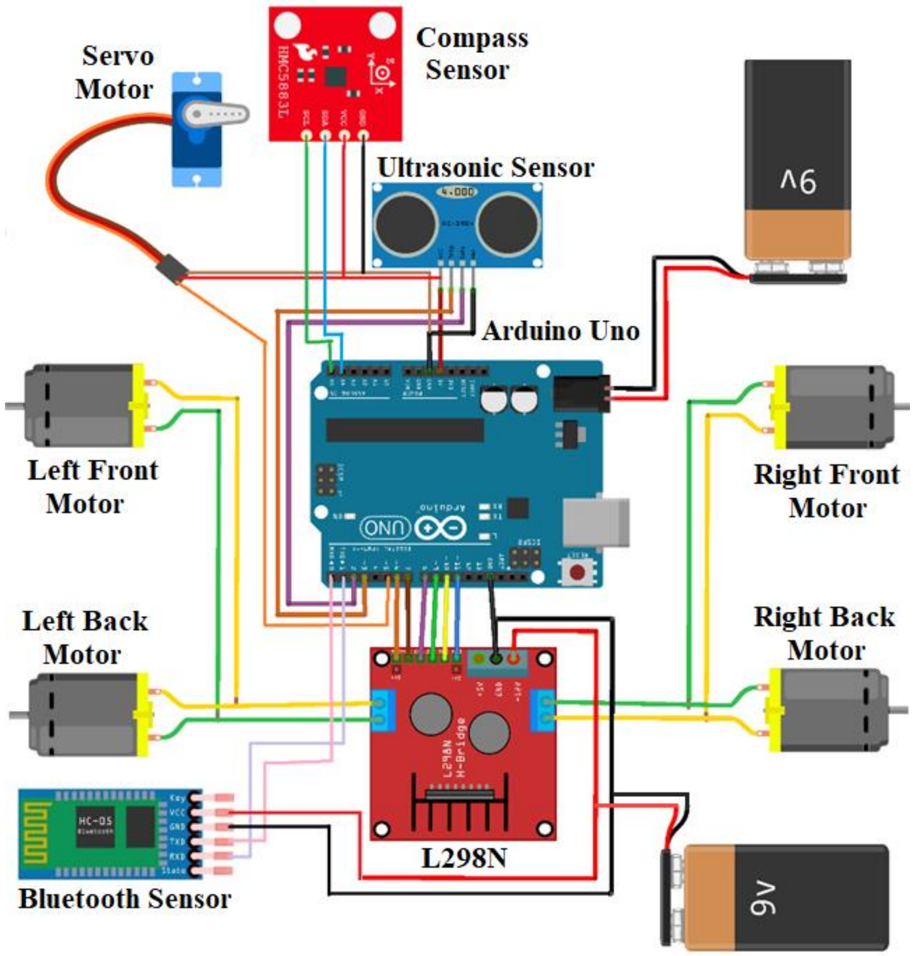

Figure 7. Block Diagram of Cargo Carrier Robot

A test environment has been prepared in order to conduct driving tests of the cargo carrier robot developed within the scope of the study and to control the status of going to the determined destination points. With the environment developed similar to the interface controlled via the mobile application, tests were carried out for the cargo transport vehicle to go to the given destination points. In Figure 8, the visuals of the test environment created and the visuals of the test process are given. During the test operations, it was observed that the robot went to all 3 determined locations and did not hit the obstacles that it encountered during its movement. With the test processes, navigation was carried out independently of GPS, which is one of the cargo transportation processes that can be done indoor environment.

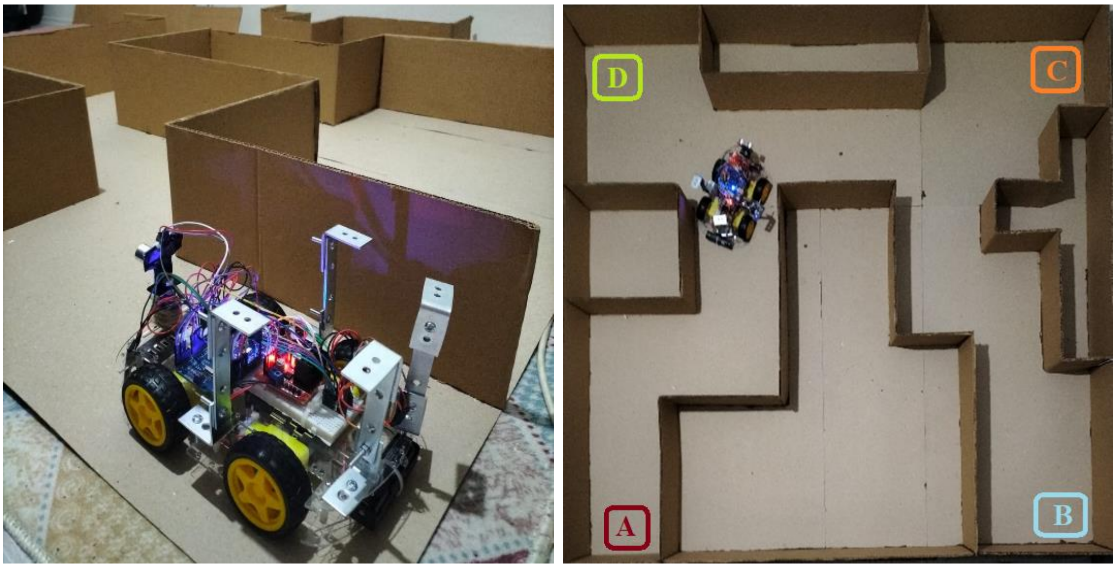

Figure 8. Test Environment

In the test processes, the cargo robot was enabled to change its direction of movement depending on the obstacles it encountered and to continue its movement in this way and move towards the target point. The angle-time graph of the servo motor is given in Figure 9 in order to observe the rotation movements of the robot as it moves from the starting position to the target position. In the given graph, the movement time to destination points B, C and D and the return time from these points to the starting point are shown separately. For example; During the cargo robot's movement towards point C, it took approximately 2 minutes to reach the target point, approximately 2 minutes to return to the starting point, and the total time was 4 minutes (B => ~3.20 min - ~3.30 min, D => ~1 min - ~1 min).

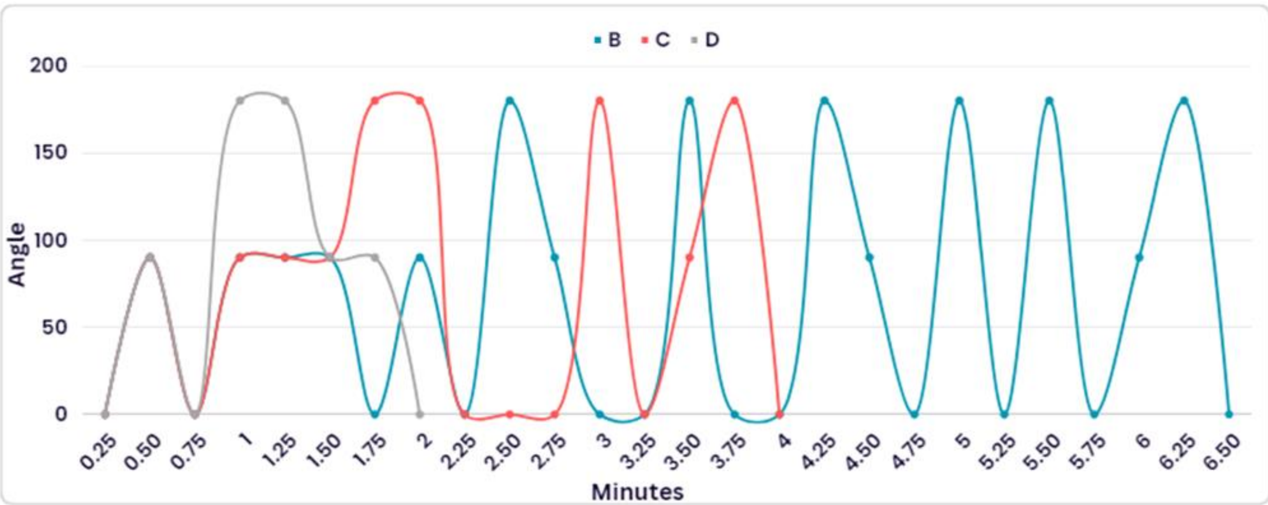

Figure 9. Angle-Time Graph of the Servo Motor

In the angle time graph for the servo motor, there are angles of 0º, 90º and 180º. At the beginning of the movement, the angle value of the servo motor was initially taken as 0o. When an obstacle appears in front of the robot, the servo motor first turns to the right and the angle value is recorded as 90º. If there is an obstacle on the right side, the servo motor rotates to the left and the angle is recorded as 180º (-90º). In this way, the movement process of the cargo robot was discussed by taking samples step by step while moving from the starting point to the target point.

5. Conclusion

Robot technologies, which are in their golden age with the Industry 4.0 revolution, are increasing their popularity in the service industry day by day, thanks to their high efficiency, reliability and low cost. Robots, whose assigned tasks are performed quickly and independently, provide many conveniences to their users in areas such as the service sector, transportation, delivery, food service, laboratory work, and household cleaning. Robots working indoors may encounter problems such as poor navigation, narrow spaces and obstacles in general. Intelligent algorithms and sensor systems are used to eliminate such problems.

In this study, a cargo carrier robot has been developed to move products between different locations in indoor environments. The specially designed cargo robot carries out its transportation operations autonomously. The developed robot can move easily indoors, thanks to its small size and ability to quickly turn in different directions. In this way, it can easily continue its movement on narrow and disabled roads.

The cargo carrier robot starts to move depending on the information about the target location coming from the mobile application prepared within the scope of the study. A navigation process independent of GPS signals was carried out in the path detection process of the cargo robot used in the indoor environment. For this process, axis informations was obtained from the compass sensor and the cargo robot was allowed to move towards the target location. During the movement of the cargo robot, obstacles were detected with the ultrasonic sensor integrated into the servo motor in front the robot and the movement continued without hitting these obstacles. After reaching the target point, the cargo robot waits for a certain time and then moves towards the starting point again. A test environment has been prepared to test the developed system. In the test environment, it was checked whether the vehicle autonomously went to the given target point. In addition to being more cost-effective compared to other studies, the application has advantages in terms of features such as being able to move autonomously and having a return to home feature.

Contributions of the authors

All authors contributed equally to the study.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

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