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A CONCEPTUAL DESIGN OF CLOUD-BASED AUTONOMOUS GROUND VEHICLE ROBOT NAVIGATION CONTROL FOR IR4.0 APPLICATIONS

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Abstract:

Autonomous Ground Vehicle (AGV) type robots are increasingly used in numerous applications nowadays, including as service robots attending to customers in restaurants and shops. They can also seeing increasing applications as surveillance robots. One of the problems the operators of such robots faced is when they need to precisely control the movement of the robot to inspect the robots surrounding over the internet. In this paper, we describe a preliminary design and implementation of a cloud-based navigation control systems for AGV type robots. This allows remote robot supervisors to navigate the robot for precise local positioning over the Internet. The robot's communication system uses the ThingsSentral cloud-based IOT platform to enable communication and navigation control between remote robot supervisor and the local robot over the Internet. The robot's navigation process also involves the use of ultrasonic sensor for assisting local navigation of the robot, assisting the robot's safety system to protect it from unforeseeable accidents. The overall prototype system was designed, developed and tested successfully in this project.

Keywords:

Internet of Things (IoT), Intelligent system, Cloud Computing, Autonomous Ground Vehicle (AGV), IR4.0

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Introduction

Robotics has assisted humans in accomplishing daily tasks. It is designed to operate in almost any environment and carry out human activities (Bonci et al., 2021). Robots are controlled by sensors and actuators with certain physical characteristics. Frequently, these robots are manually operated to move from one area to another. Several studies have been carried out on autonomous robots that lead to the entire potential application of this autonomous robot (Eskandarian et al., 2020; Lam Loong Man et al., 2018; Saleem et al., 2021). Unmanned ground vehicles (UGVs) are vehicles that operate in contact with the ground without the presence of humans on board. Vehicles of this type are controlled remotely. An autonomous ground vehicle (AGV) can track its surroundings and navigate without human assistance (Lynch et al., 2019).

Autonomous vehicles are vehicles that can automatically navigate both long-distance and short-distance routes (Hartono et al., 2020). Humans can choose a destination when driving an autonomous vehicle, but they do not need to perform any mechanical tasks, as the vehicle can detect its environment and move autonomously. However, autonomous vehicles have several issues that consumers must face. One of the issues inherent in controlling autonomous vehicles is navigation control, which includes route planning and tracking control (Rascón-Enríquez et al., 2020). Nowadays, some of the automation systems in the residential sector are increasing rapidly due to various improvements in life such as comfort, convenience, centralised equipment control, cost reduction, energy savings, and safety (Zare & Iqbal, 2020). Nowadays, autonomous vehicles are mostly used in the service sector. There are numerous categories of service robots, including those for cleaning and housekeeping, surveillance, education and entertainment, rehabilitation, and other robots (Fabregat et al., 2020). In Malaysia, service robots have been widely used in restaurants to deliver food to customers' tables.

Supervisory Control and Data Acquisition (SCADA) technology provides a platform that remotely detects and monitors devices, gathers data from them, and transmits restricted control instructions. One of the devices that is especially closely related to SCADA technology is the ESP32. This ESP32 is a general-purpose low-cost microprocessor, a low-power system on a series of micro-controller chips with Wi-Fi and Bluetooth capabilities and a highly integrated structure powered by two Tensilica Xtensa LX6 cores (Barybin et al., 2019; Sabah Ahmed et al., 2021; Tzou & Su, 2008). The use of ESP32 can be attributed to the Internet of Things (IoT). IoT has evolved into an ecosystem that includes hardware, software, physical objects, and even data exchange (Vogel et al., 2020). IoT users, services, and applications are increasing rapidly across a diverse range of industries (Gubbi et al., 2013; Kumar et al., 2019; Laghari et al., 2022; Nord et al., 2019).

Supervisory control technology can be defined as information processing and the role of the operator in a particular task, or as the degree of automation used and the type of interaction of the operator with automated technologies. Humans play various roles in supervisory tasks, including planning, teaching, monitoring, intervention, and learning. Supervision control is developed using a simple point-to-point network between targets, robots, and personal computers. The computer serves as a base station for logging all the data necessary for performance evaluation (Teo et al., 2020).

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In this paper, we present the conceptual design and implementation of a cloud-based autonomous ground vehicle (AGV) navigation control system on a mobile robot. The robot's control system allows it to reach specified and marked coordinate points. The paper is organised as follows: The next Section presents a brief introduction to AGV navigation control systems, the IoT cloud platform (The ThingsSentral) and the process flow. Then, the following Section covers the implementation and testing of an AGV mobile robot prototype, the development of a supervisory control system, and a performance test analysis of the supervisory control system. The last Section gives the conclusion and future work.

Cloud-Based Autonomous Ground Vehicle (AGV) Navigation Control Systems

In mobile robotics, navigation is a fundamental concern (Mouad et al., 2012). The challenge of local navigation involves navigating on a scale of several metres, with obstacle avoidance being the primary concern. Dynamic Artificial Potential Field (DAPF) is an enhanced version of the APF method that uses a dynamic window approach to avoid the local minimum region (Sun et al., 2019). The study developed a cloud-based control system using an IoT platform. 46 IoT platforms have been described as open, whereas 25 systems are deemed to be open by some research but not by the platforms themselves (Vogel et al., 2020). The authors discovered that NodeMCU and ThingSpeak are the most extensively recognised and utilised open IoT platforms, accounting for more than 70% of all open IoT platforms. In this study, the cloud platform to be used is ThingsSentral, which has properties similar to the ThingSpeak cloud platform. ThingsSentral is a cloud platform developed by the CAISER research group at the Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM) (Saad et al, 2021).

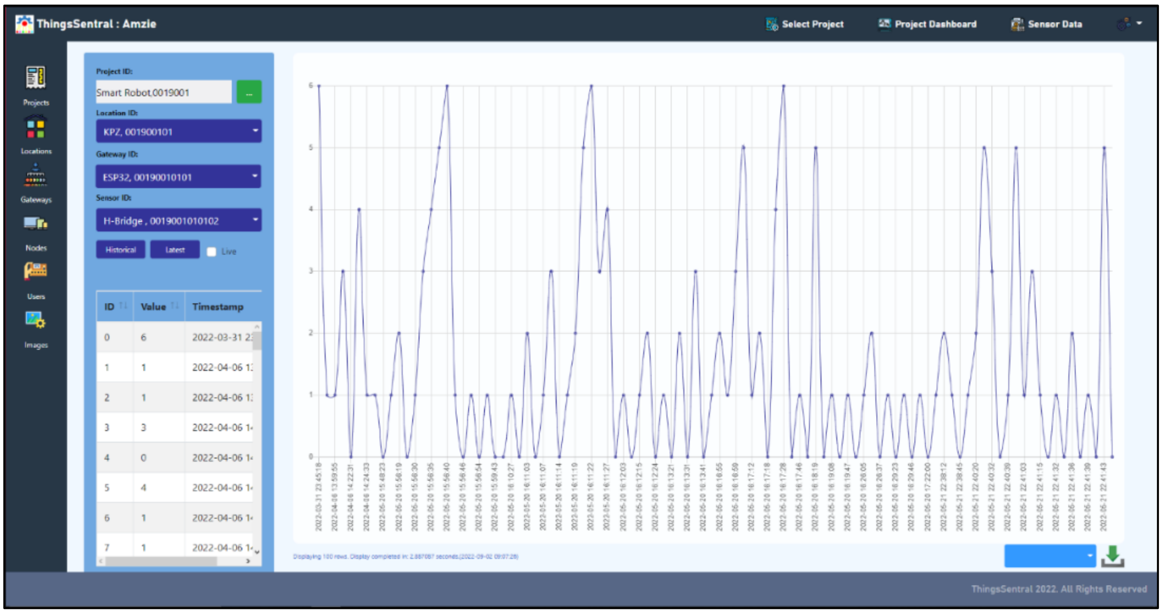

Figure 1: The ThingsSentral Cloud Platform

The software used to develop communication systems between the robot and the ThingsSentral cloud platform is the Arduino IDE and Xojo. The Arduino Integrated Development Environment, also known as Arduino Software (IDE), consists of a text editor for writing code, a message box, a text console, a toolbar with buttons for standard tasks, and a series of menus. It communicates with Arduino and Genuino hardware to upload and

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download programmes. Xojo is multi-platform software that includes an IDE and the object-oriented Xojo programming language for macOS, Windows, Linux, web, iOS, and Pi. The ThingsSentral cloud platform was developed using Xojo software. Figure 1 shows the ThingsSentral web application developed using Xojo software.

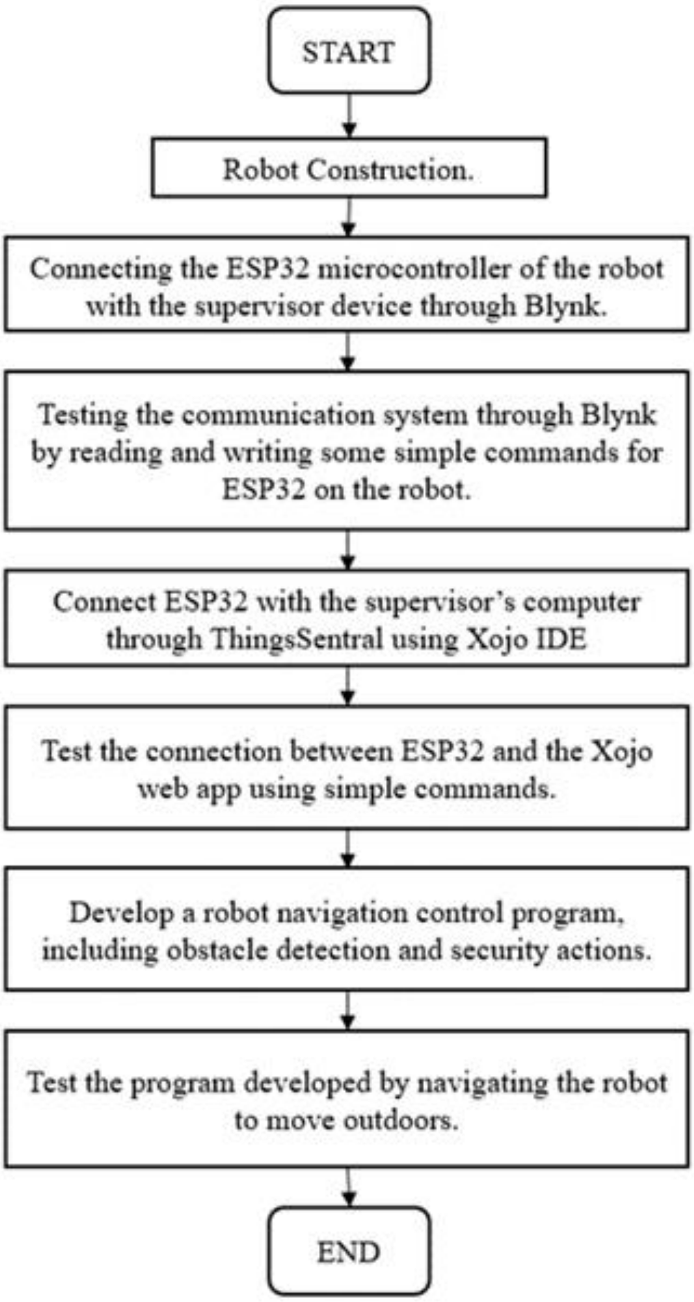

Figure 2: Process Flow of The Proposed AGV Navigation Control Systems on Mobile Robots

Figure 2 shows the flowchart of the AGV navigation control systems on mobile robots. The sensor attached to the robot is an ultrasonic sensor. The robot moves using a direct current motor as its main power source. The motor plugged into the tyre has a battery as a source of

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electricity. The ESP32 is used as the robot's microcontroller. This device uses program memory as well as data memory to store commands and store data.

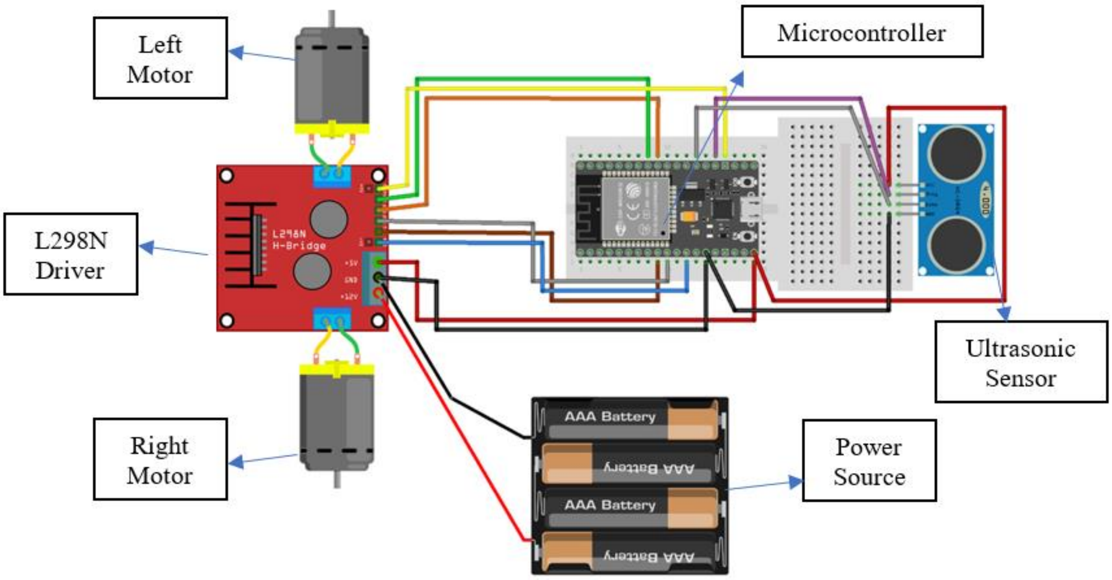

Figure 3: Schematic Diagram of AGV Navigation Control Systems

Figure 3 shows the schematic diagram of the AGV on mobile robots using ESP32 microcontrollers, actuators, and ultrasonic sensors. The communication system using the ThingsSentral platform was designed as a supervisory control system to control the safe movement of the robot remotely and wirelessly. The web application to control the robot is developed using Xojo software. The app developed using this software serves the functions of displaying sensor data and controlling the robot actuator. The difference between communication systems developed using Xojo and Blynk is that the Xojo control application sends and reads data via the ThingsSentral cloud platform, while the data is sent and read directly using Blynk. A web application was developed using Xojo software to serve as an intermediate medium between the ESP32 microcontroller and the ThingsSentral cloud platform.

The use of cloud platforms such as ThingsSentral has several advantages compared to direct communication using the Blynk application. ThingsSentral has a security system available to users. The communication mechanism between the user and the robot can be safely controlled using ThingsSentral without the risk of attackers manipulating the control system. Furthermore, users can control robots created with ThingsSentral using a different network. This is very different from the Blynk application, where the communication system can occur using only the same network. Therefore, the robots developed can be controlled from different locations, no matter how far the user is from the robot. Moreover, this study’s communication system between the robot and the controller needs to be passed through a cloud platform because a cloud platform has its own static IP address to send and read the data from the user. If there is no cloud platform to provide the IP address, the robot must have

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its own IP address for the communication system to function properly. This method has its own limitations due to the limited amount of static IP that can be used for the robot.

The developed robot control system is then tested for its function. The task of the robot during the test is to reach several specified and marked coordinate points. The developed robot has a security system; for example, the robot stops when it almost hits an obstacle on the way despite receiving instructions to continue the journey. The robot is given instructions from the user using the developed control system. While the command is being run by the robot, the robot measures the distance between the robot and the obstacle using sonar readings from the ultrasonic sensor. The user sets the direction to go in and moves to the target. The robot constantly reports the coordinates and status to the supervisor.

AGV Mobile Robot Prototype Implementation and Testing

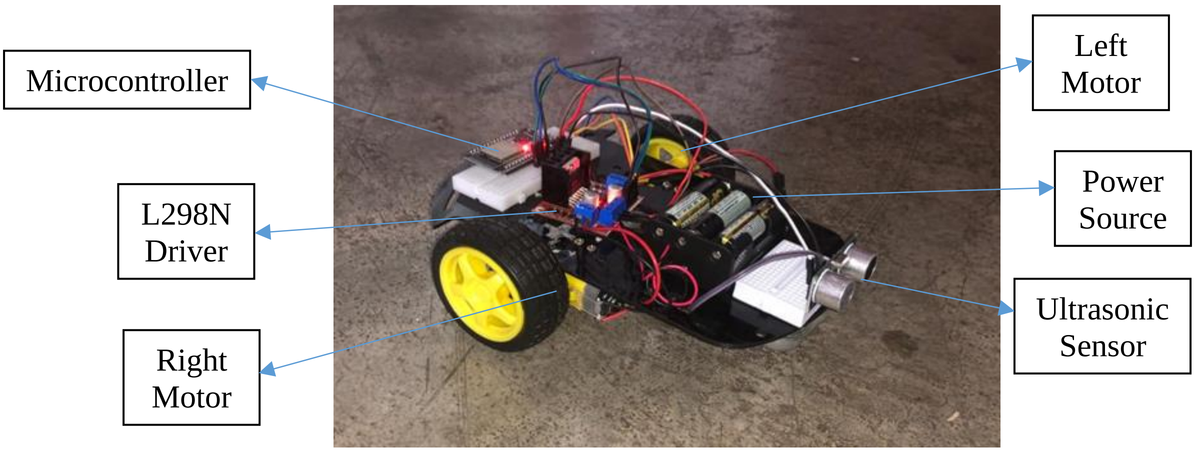

Figure 4: Prototype of AGV Navigation Control Systems on Mobile Robots

Figure 4 shows the prototype of the AGV mobile robots developed based on the schematic diagram. The hardware used is an ESP32 microcontroller, a L298N motor driver, two DC motors, an ultrasonic sensor, and six AA batteries as a power source. The main hardware of the robot developed is the ESP32 micro-controller, which is used as a processor in the communication system between the robot and the ThingsSentral cloud platform. Data received from sensor nodes in this study was sent to the ThingsSentral web application. This transmission requires an intermediary (API) to connect the gateway with the internet.

In this study, HTTP protocols are used for data transmission purposes as well as for receiving data from ThingsSentral. The transmission of the executed data was received from the ultrasonic sensor node. Ultrasonic sensors work by transmitting sound waves at frequencies above the human hearing range. The sensor transducer acts as a microphone to receive and transmit ultrasonic sound. The ultrasonic sensor used has a single transducer to transmit the pulse and receive an echo. The sensor determines the distance to the target by measuring the expiration time between the transmission and the receipt of the ultrasonic pulse. The distance measured by the ultrasonic sensor is used as sensor node data to be sent to ThingsSentral.

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An Arduino IDE software is used to transmit data from sensor nodes to ThingsSentral cloud platforms. This is because the data read from the ultrasonic node is stored by the ESP32 microcontroller first. Using programming, the distance data can be transmitted to ThingsSentral with the help of URLs and internet networks. Data from ultrasonic nodes sent to ThingsSentral is stored in the ThingsSentral database. Each data transmitted by the sensor node is updated in the ThingsSentral database in the 5-second range. The data transmitted by an ultrasonic node is tabulated in Table 1 and Figure 5.

Table 1: Ultrasonic Node Data in ThingsSentral

ID	Sensor Value	Timestamp
0	70	2021-07-14 18:41:01
1	90	2021-07-14 18:41:07
2	99	2021-07-14 18:41:12
3	95	2021-07-14 18:41:18
4	97	2021-07-14 18:41:24
5	100	2021-07-14 18:41:30
6	60	2021-07-14 18:41:36
7	69	2021-07-14 18:41:42
8	55	2021-07-14 18:41:48
9	72	2021-07-14 18:41:53

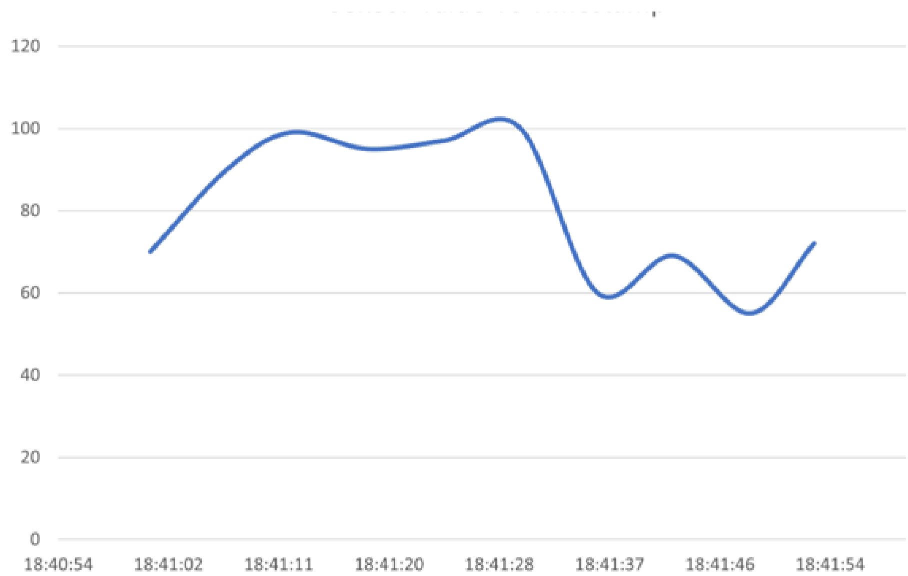

Figure 5: Distance Versus Timestamp Reading in ThingsSentral

Development of Supervisory Control System

Figure 6 displays the supervisory control system that has been developed in this study. It is developed through a web application using Xojo software. There are buttons that have been encoded to give data value to ThingsSentral that are used as instructions for moving the motor on the robot. For example, the "Fwd" button gives a value of 1 when pressed. This

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value of 1 is used as an instruction to the microcontroller to move the motor to drive the robot forward. There are seven buttons that have their own values for controlling the robot's navigation. In addition, the sonar readings of the ultrasonic sensor are also displayed. This ultrasonic sensor reading data is read from the ThingsSentral cloud platform. The HTTP Get protocol is also used to receive ultrasonic sensor node data from the ThingsSentral. The sonar readings on this web app are displayed to users of this navigation control system to inform them of the distance between the robot and the obstacles that are in front of it. Table 2 shows an example of the value sent by the web application to the ThingsSentral cloud platform, along with the timestamp.

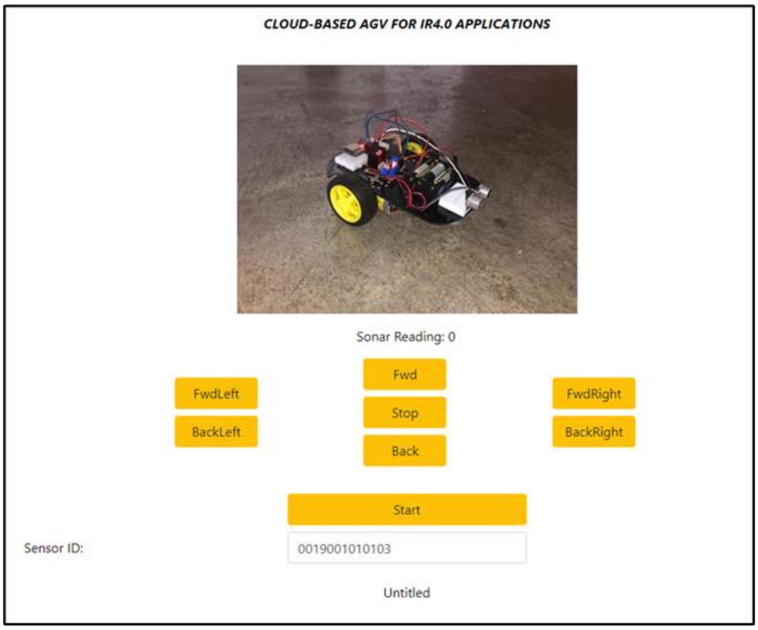

Figure 6: Web Application of Study's Supervisory Control

Table 2: Example of Command Value in Web Application

ID	Command Value	Timestamp
0	1	2021-07-15 05:28:39
1	0	2021-07-15 05:28:42
2	1	2021-07-15 05:28:46
3	3	2021-07-15 05:28:51
4	5	2021-07-15 05:28:55
5	0	2021-07-15 05:28:57
6	2	2021-07-15 05:29:00
7	5	2021-07-15 05:29:05
8	4	2021-07-15 05:29:07
9	0	2021-07-15 05:29:10

Depending on the desired navigation of the robot, each command value causes the motor to move or stop. For example, the robot has been given a command by the supervisor to move forward. Each motor will be assigned a value between 0 and 1 based on the movement of the desired navigation. A positive value was assigned when the motor moved forward, while a

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negative value was assigned when the motor moved backward. Table 3 and Figure 7 show the command value of each motor based on the command value from Table 2.

Table 3: Command Value of Each Motor on The Robot

ID	Desired Navigation	Left Motor	Right Motor	Timestamp
0	Forward	1	1	2021-07-15 05:28:39
1	Stop	0	0	2021-07-15 05:28:42
2	Froward	1	1	2021-07-15 05:28:46
3	Forward Right	1	0	2021-07-15 05:28:51
4	Forward Left	0	1	2021-07-15 05:28:55
5	Stop	0	0	2021-07-15 05:28:57
6	Backward	-1	-1	2021-07-15 05:29:00
7	Forward Left	0	1	2021-07-15 05:29:05
8	Backward Right	-1	0	2021-07-15 05:29:07
9	Stop	0	0	2021-07-15 05:29:10

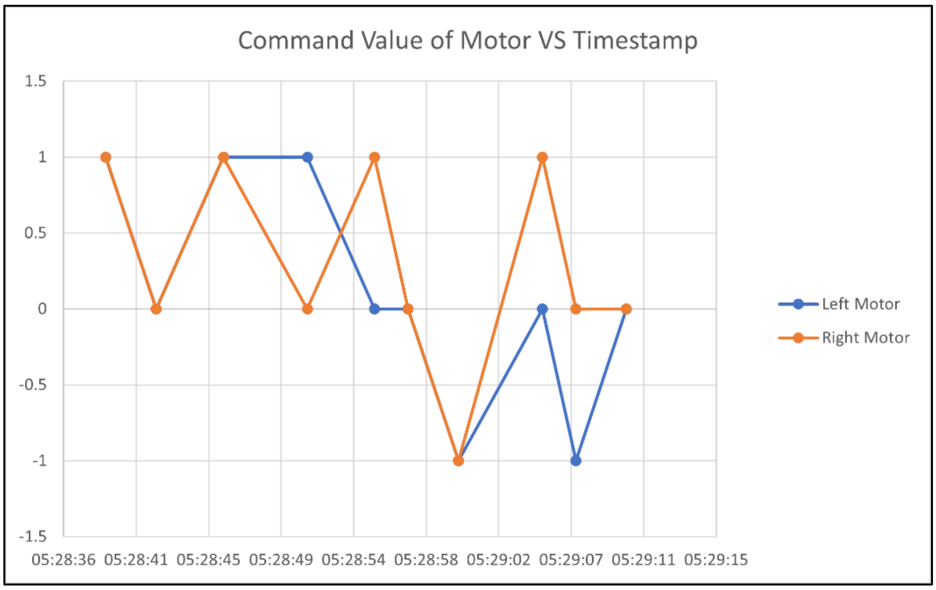

Figure 7: Motor Command Value Versus Timestamp

Supervisory Control System Performance Test Analysis

To test the performance of the study's supervisory control system, the robot prototype is needed to move based on the value of the instructions given by the supervisory control system. The ESP32 microcontroller needs to read the instructions to activate the motor on the robot. The supervisory control system developed using Xojo software is connected to the ESP32 microcontroller based on the code programmed using Arduino IDE software by making the ThingsSentral cloud platform an intermediary. The control system sends the command value to the ThingsSentral database, which is then read by ESP32 to continue the command. The value of the data read instructs the motor driver to activate the robot motor. The HTTP Get protocol also uses ESP32 microcontrollers to read instructions from ThingsSentral.

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After the command value is received, ESP32 uses the value of the command as a command to activate the motor driver. The motor driver moves the robot by giving commands to the motor and determining the direction of rotation as well as the speed of the motor. The developed robot has a security system developed to avoid unexpected breakdowns. The security system developed requires that the robot stop when faced with an obstacle. The robot still stops even when given the command to move forward by the user. The robot can only reverse as well as move left and right to avoid colliding with the obstacle in front of it. The distance between the robot and the obstacle is determined by the ultrasonic sensor. The security system is activated if the distance between the robot and the obstacle is less than 30 cm. The prototype robot always transmits the distance from the ultrasonic sensor node to the user through the developed control system. When the security system is activated, the control system sends a warning message to the user. Figure 8 shows the control system message to the user when the security system is activated.

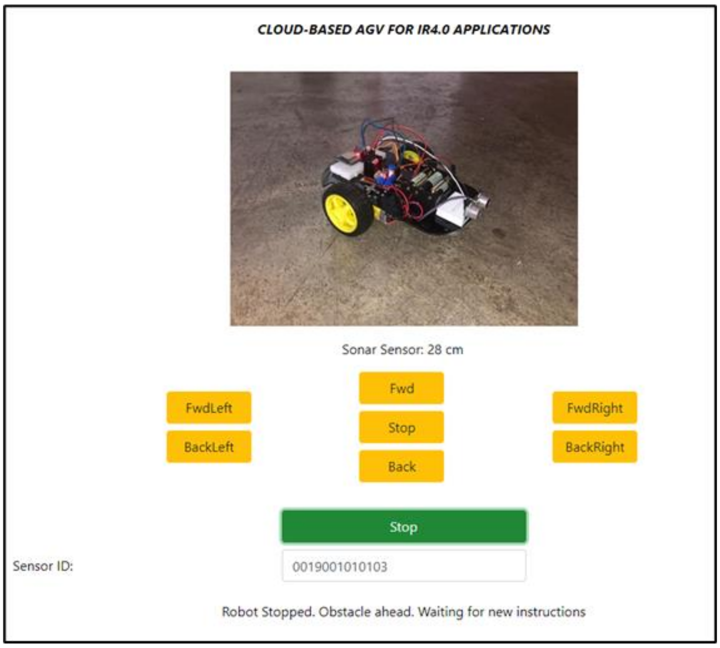

Figure 8: Warning Message When the Security System Is Activated

Conclusion

In this study, a cloud-based AGV navigation control system for IR4.0 applications was developed. The ESP32 is used as a microcontroller, which provides Wi-Fi and Bluetooth functions to facilitate communication between microcontrollers and the cloud platform ThingsSentral. The ESP32 sent ultrasonic sensor node data and read data from ThingsSentral to activate the motor on the AGV developed using the HTTP Get protocol. In addition, a security system was developed to ensure that the robot can be safely controlled. The supervisory control system is developed using web applications programmed through Xojo software. The developed AGV mobile robot was tested to obtain the performance of the developed security system supervisory control system. The task of the robot is to reach several marked coordinate points without colliding with any obstacles in front of it. The robot in this study can be further developed as a service robot that can help the service industry, such as in surveillance or the food and beverage business.

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