Centralized AGV Control Systems based on OutsealESP32 PLC and ESP-NOW Protocol

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Abstract. In this paper, a centralized wireless AGV control system is presented using the OE32-PLC board. The OutsealESP32 PLC (O32-PLC) is a combination of the Outseal PLC Mega and the ESP32. Wireless communication is carried out using the ESP-NOW protocol. The system is divided into three sections according to their functions: the planning layer, the routing layer, and the AGV layer. Some of these features include the addition of a DB9 port and integrated WiFi connectivity. The addition of features of the ESP-NOW communication protocol to the proposed OE32-PLC makes it possible to control it wirelessly. The longest data transmission time occurred on the OE32-PLC routing at 877 ms, which is the sampling time of ESP-NOW and the duration of Modbus RTU serial communication.

Keywords: AGV, Outseal32-PLC, ESP32, ESP-NOW protocol, routing planner, Outseal PLC.

1 Introduction

Industry 4.0 is a method for improving system uptime and boosting production efficiency. The key prerequisite for achieving these objectives is building an automated and reliable infrastructure. For instance, implementing automated guided vehicle (AGV) systems for the transportation of materials enables plant owners to improve operational effectiveness and boost output [1].

In the industrial manufacturing field, a variety of devices are required to be able to work with wireless controls and compact designs. With wireless data transmission, a device can be controlled more flexibly without considering communication cables between devices, and it allows the transmission of control data to devices that require movement, such as an AGV [2].

A programmable logic controller (PLC) is a controller used to handle various automation processes in the industry, such as the supervision of production processes and the control of actuators in factories [3]. To this day, there are at least a few well-known and often used PLC brands in the industry, such as Siemens, Omron, Allen Bradley, and Delta [4]. Outseal PLC is an Arduino that is programmed with the Ladder language using the Outseal Studio software. Compared to often used brands, Outseal PLC offers a wide range of advantages,

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such as being a small and lightweight PLC and having a much lower price than other PLCs [5].

The Outseal PLC can communicate with other control devices via a serial port. All communication processes with other control devices must be carried out with the RTU Modbus protocol [6]. The compulsion to use this Modbus protocol is a weakness when the Outseal PLC wants to communicate with other devices in series that cannot recognize the Modbus protocol at all. The same problem occurs when the Outseal PLC wants to communicate wirelessly via a WiFi network, but other devices do not recognize the Modbus protocol. From these issues, this research is expected to be able to provide a solution to the serial communication weaknesses of Outseal PLC. Therefore, the research aims to design a new Outseal PLC model that is integrated with ESP-NOW to become a new PLC called OE32-PLC and implement it in wireless AGV control applications.

2 Background and Preliminaries

2.1 Outseal PLC

Outseal PLC is an Arduino-based PLC that can be programmed with ladder language. Of the various types of Arduino boards available, Arduino Nano and Arduino Uno are Arduino boards that can be directly used as an Outseal PLC. Outseal has two types of PLC products that are still being developed, namely, the Outseal PLC Nano and the Outseal PLC Mega [7]. Outseal Studio is Outseal-built software that is used to program Outseal PLCs with the ladder language. Like PLC software in general, Outseal Studio is able to simulate the ladder program that has been created. Outseal Studio can display ladder streams online. The advantage of Outseal Studio is the ability to streamline downloads of ladder programs that have been stored in the Outseal PLC microcontroller. Until now, Outseal Studio version 2.4 was the latest version that supported programming on its latest product, the Outseal PLC Mega V1.1 [7].

2.2 Modbus RTU

Modbus is a communication protocol developed by Modicon, which has now changed its name to Schneider Electric. Modbus has become one of the most common standard communication protocols on many industrial devices, such as PLCs, because it is open to the public and royalty-free. There are various types of communication media and data types; Modbus protocols also have various types, one of which is Modbus RTU (Remote Terminal Unit) [6].

2.3 ESP32 Microcontroller

The ESP32 is one of the variants of the microcontroller board developed by Espressif System. The ESP32 can be programmed using the Arduino IDE by first performing an update board on the Arduino IDE. The ESP32 system has two Harvard Architecture Xtensa LX6 CPUs and is dual-core. Either an external crystal or the ESP32's internal Phase Lock Loop (PLL) with a 320 MHz frequency can be used. The ESP32 microcontroller is built to work with the complete 802.11 b/g/n/e/i WLAN MAC specification, TCP/IP, and Wi-Fi Direct standards. FreeRTOS is the real-time operating system on the ESP32. It is open source, made for embedded systems, and gives lower-level applications fundamental operations [8].

2.4 ESP-NOW

ESP-NOW is an ESP communication protocol developed by Expressive. ESP-NOW has been integrated into a library published by Expressif and can be used on the Arduino IDE platform. It is compatible with both the ESP32 and the ESP8266. ESP-NOW works on the same frequency as Wi-Fi, i.e., at 2.4 GHz. ESP-NOW does not use Wi-Fi networks as a transmission medium but rather local networks created by themselves to communicate with each other. Communication between ESPs using the ESP-NOW protocol occurs connectively, meaning the sender and recipient do not need a connection before communicating. By default, ESP-NOW has a bit rate of 1 Mbps when performing data transmission. Another important feature is that ESP-NOW communication can be done in one direction or in two directions.

3 System Design

A centralized wireless AGV control system using the OE32-PLC board is presented in this paper. The OutsealESP32 PLC (O32-PLC) is a combination of the Outseal PLC Mega and the ESP32. Wireless communication is carried out via the ESP-NOW protocol. The OE32-PLC will be implemented on four devices. The first device is implemented as a human-machine interface (HMI) control unit and will be called the OE32-PLC UI. The second device is implemented as a travel route control unit distributed to both AGVs and will be called OE32-PLC Routing. The third and fourth devices will be implemented on both AGVs and will be called the OE32-PLC AGV. The overall block diagram can be seen in Fig. 1. The block diagram is divided into three sections according to their functions: the planning layer, the routing layer, and the AGV layer. ESP32 on the O32-PLC AGV layer will be connected to several types of sensors that can monitor the conditions of the environment in which AGV works. Sensor values are then displayed on the HMI screen as additional information.

3.1 OE32-PLC Design

The OE32-PLC is a fusion of the Outseal PLC Mega version 1 board with the ESP32S WROOM. Outseal PLC Mega was chosen because of its better performance than other types of Outseal PLC, such as its larger flash memory and higher I/O amounts. To get the ESP-NOW feature, you can actually use the

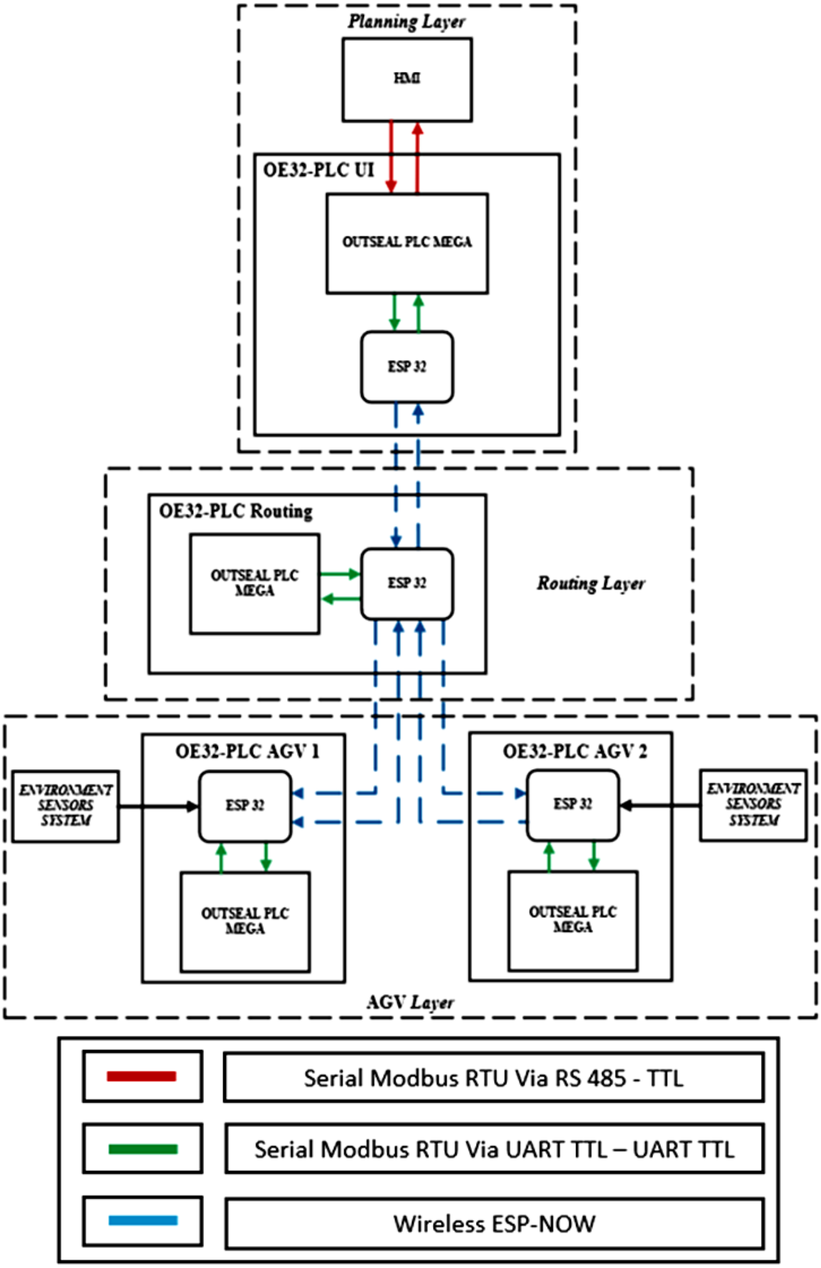

Fig. 1. Block diagram system

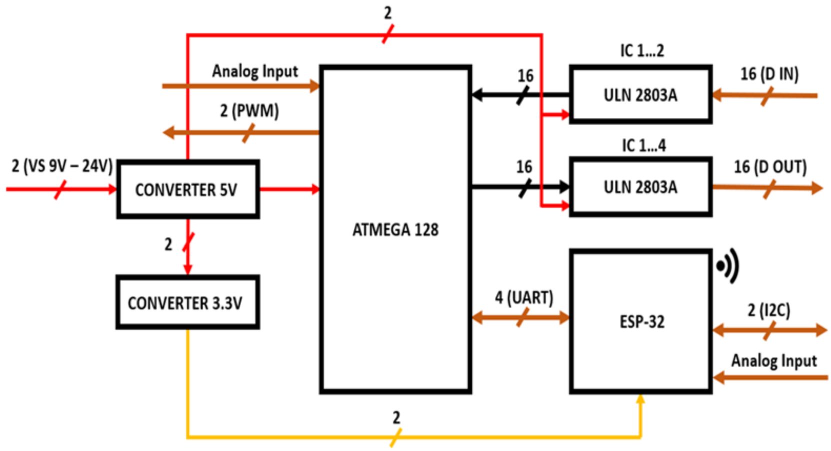

Fig. 2. Hardware diagram

ESP8266 type, which has a slightly cheaper price. However, when viewed from a performance and subsequent development point of view, the ESP32 board is considered more suitable than the ESP8266. The OE32-PLC is designed using the well-known Diptrace PCB design application. The design process begins with the design of the hardware diagram, as seen in Fig. 2. The diagram is a simplified diagram.

3.2 HMI Interface Design

To monitor and give commands on the movement of each AGV, the HMI Weintek 8071 IE is used. An HMI interface is designed as shown in Fig. 3. In the design, the station, cancel, replay, and go buttons use the set bit button. The stop button is designed using the combo button. In HMI Weintek, the combo button is a button that gives many instructions in a single button-press process. In fact, each stop button consists of two buttons that are stacked: stop and resume, but when the stop button is not pressed, the resume button is still hidden. When the stop button is pressed, the button gives three commands at once: remove the display of the stop button, display the resume button, and give a set of bits. The last button is a historical button that is useful to open the historical sensor page of each AGV.

3.3 AGV Design

The AGV was designed by adopting the line-follower robot design with a differential drive system. The propulsion wheels are located in the middle of the AGV, while at both ends of the AGV, there are four castor wheels that can move freely. The propulsion wheel has a size of 7.5 cm, while the remaining four castor wheels are 1 inch. The designed frame has dimensions of 22 cm by 28 cm and is

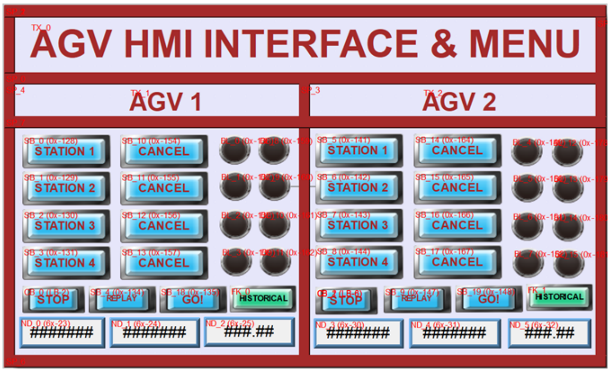

Fig. 3. Main window of HMI

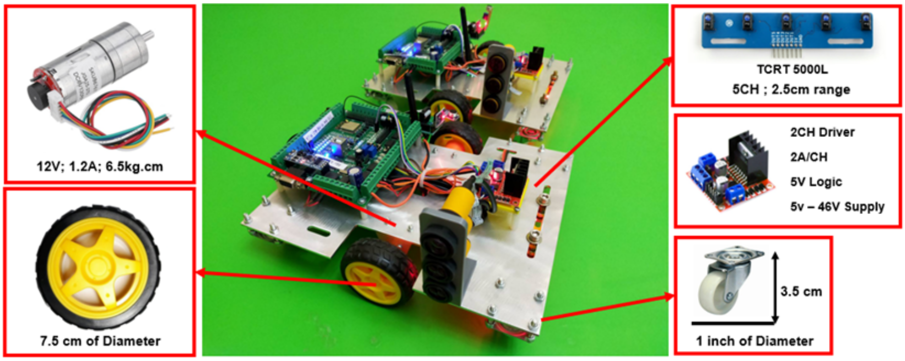

Fig. 4. Miniature of an AGV

made of 3 mm aluminum material. As the AGV's mid-wheel drive, a DC 25GA 370 motor is used. The DC motor is able to provide a maximum torque of 6.5 kg/cm with a maximum current of 1.2 A at a voltage of 12 V. Based on current requirements, an L298N driver is selected. The L298N driver is a dual-channel driver engine, and each channel can provide a current drive of up to 2 A with a voltage of 46 V. Since AGV works with the line follower robot concept, it needs to be equipped with a line sensor to read the track as a black line on the floor. The line sensor used is the TCRT 5000L line sensor module, which is a 5-channel line sensor. The sensor is then mounted on the front of the AGV. All mechanical parts are then joined into the frame of each AGV so that the AGV looks like Fig. 4.

All sensors and actuators are programmed in ladder language using Outseal Studio software. To drive the motor, which is connected to the motor driver, an OE32-PLC PWM signal is required. PWM signals can be regulated by enabling the PWM function overlay column on the device settings menu and the timer submenu on the PLC Outseal Studio programming software. Once the PWM

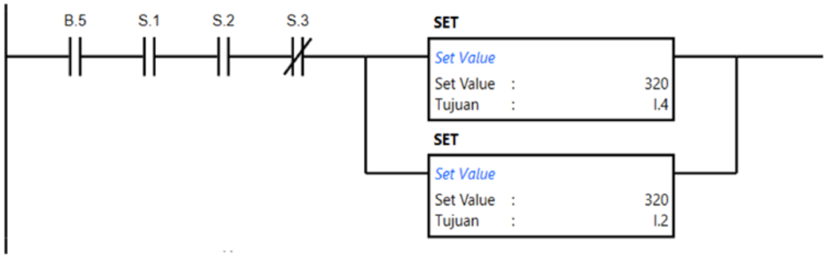

Fig. 5. Examples of duty cycle PWM and ladder sensor lines ladder diagram

menu is activated, there are two important parameters that need to be set, namely the PWM frequency and PWM duty cycle. Outseal Studio provides only 5 frequency menus, and menu no. 4 (977 Hz) was selected by giving the set value 4 on the memory integers I1 and I3 for each PWM OE32-PLC. This is located on output ports 7 and 8 (Addresses R7 and R8). The duty cycle value is then programmed depending on the line sensor reading outcome on the S1 to S5 addresses and also depends on the commands from the OE32-PLC routing subsequently. The duty cycle value can be given by giving the program a ladder set on I2 and I4 for each output port 7 and output port 8, as shown in Fig. 5.

3.4 HMI OE32-PLC Communication Design

Communication from the OE32-PLC to the others can only be done with other devices via the UART TTL or RS-485 media with the RTU Modbus protocol. Therefore, the HMI must be configured to communicate with the Modbus RTU protocol. On the HMI Easy Builder Pro software designer, HMI Weintek 8071 IE serial communication settings can only be done through RS-485 or RS-232 communication; in this design, it is selected for RS-485 communication. As for other settings, baud rate is 115200, parity is none, data is 8 bits, and stop is 1 bit. When an HMI communicates with the PLC, the HMI will act as a master while the PLC acts as a slave. As a master device, HMI also requires a timeout setting to provide the maximum duration of request and response from the slave and a turn-around delay setting to give a delay from one communication process to the next.

The OE32-PLC is a fusion of the Outseal PLC Mega and the ESP32. The Outseal PLC Mega uses the ATMega128 microcontroller, serves as the primary controller of the OE32-PLC, and is programmed with ladder language. ESP32 plays a role in the ESP-NOW communication process. To send data from the Outseal PLC Mega with ESP-NOW, the data must first be sent to ESP32. Outseal PLC Mega and ESP32 communications are carried out with TTL UART media via the RTU Modbus protocol. On the OE32-PLC AGV and OE32-PLC Routing, the ESP32 acts as the master device sending the request, while the Outseal PLC Mega acts like the slave sending a response. The reason for making the ESP32 a master device is that the Outseal PLC Mega program execution process is not interrupted by the possibility of timeout that occurs due to failure of delivery when Outseal PLC Mega is used as the master device. Of the entire program that has been designed, there are only two types of Modbus function codes used: function code 3 (read multiple holding registers) and function code 6 (write a single register).

Unlike the OE32-PLC AGV and OE32-PLC Routing, the OE32-PLC HMI has a configuration where the ESP32 acts as a slave and the Outseal PLC Mega acts like a master. This is due to the fact that the UART TTL port of the slave Outseal PLC Mega has been used to communicate with HMI, so there is no other choice than to use the UART TTL port of the master Outseal PLC Mega to communicate with ESP32. In order for communication between the Outseal PLC Mega and ESP32 to take place, ESP32 must also be programmed as a slave with suitable slave and baudrate parameters.

3.5 ESP-NOW Communication Design

The OE32-PLC's communication is wireless via the ESP-NOW protocol. From Fig. 1, it can be seen that ESP-NOW communication is designed in a star topology where OE32-PLC routing acts as the center. The OE32-PLC Routing has an ESP-NOW configuration that receives from many devices and sends to many devices, while the AGV and PLC UI only communicate with the OE32-PLC Routing peer-to-peer. ESP-NOW uses the MAC address as the shipping address. Therefore, before performing the ESP-NOW programming, the first thing to do is find each MAC address of the ESP32 installed on the OE32-PLC using the program. After the program is transferred to the ESP32 OE32-PLC, the "EN" button is pressed, and on the serial monitor will appear the MAC address information from the ESP32.

4 Experimental Results and Analysis

4.1 The Proposed OE32-PLC Dimension

Table 1 shows a comparison of the Outseal PLC Mega with the OE32-PLC design results.

Table 1. Comparison between OE32-PLC and Outseal PLC Mega features

Features	OE32-PLC	Old Outseal PLC
DB9 Port	1 port via RS-485	N/A
Integrated WiFi	using ESP32	N/A
Dimensions	132 x 105 mm	93 x 87 mm

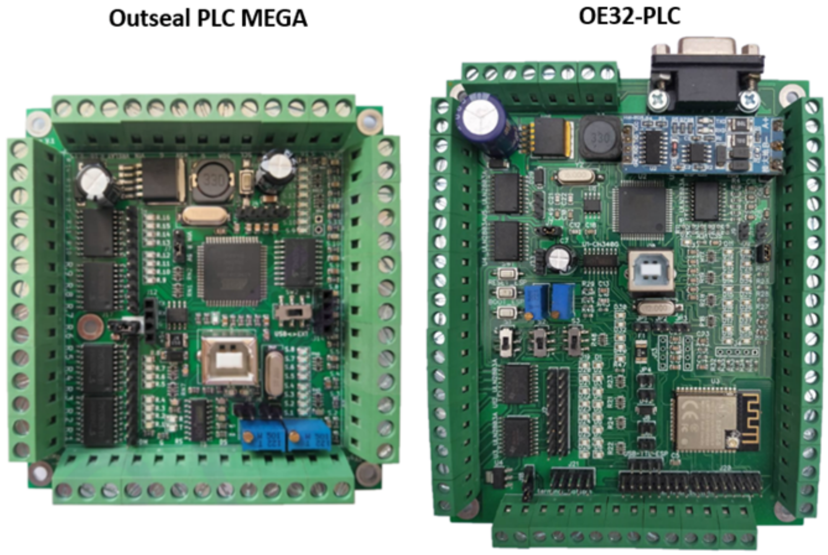

Fig. 6. Dimensional comparison of the old Outseal PLC and the proposed OE32-PLC

In Table 1, it can be seen that the proposed OE32-PLC does not experience a reduction in features but instead has features added. Some of these features include the addition of a DB9 port and integrated WiFi connectivity. In addition, the OE32-PLC also has the wireless communication protocol ESP-NOW. Compared to the Outseal PLC Mega (the old Outseal PLC), the OE32-PLC has a larger dimension because of additional features. Fig. 6 shows a comparison of the old Outseal PLC with the proposed OE32-PLC dimensional results.

4.2 The Experimental Arena

To test the reliability of ESP-NOW communications, the arena from the miniature industry with four stations was used, which can be seen in Fig. 7. On the arena, there can be seen four stations, whereas on each station there are two branched paths. On the upper side, there is another crossroad, but it is not used as a station but as a home route for AGV 1 and AGV 2. The outermost home side will be used for AGV 1, while the home that is printed on the inner side will be used for AGV 2. Magnetic tapes on the side of the track are used to map the position of each AGV. The AGV then moves clockwise. The track is made using black tape that has a width of 1.8 cm. The magnetic tape used has a thickness of 2 mm. All stations are made of assembled wood and cardboard materials. Each station has a different design, which is intended so that each AGV can distinguish each station.

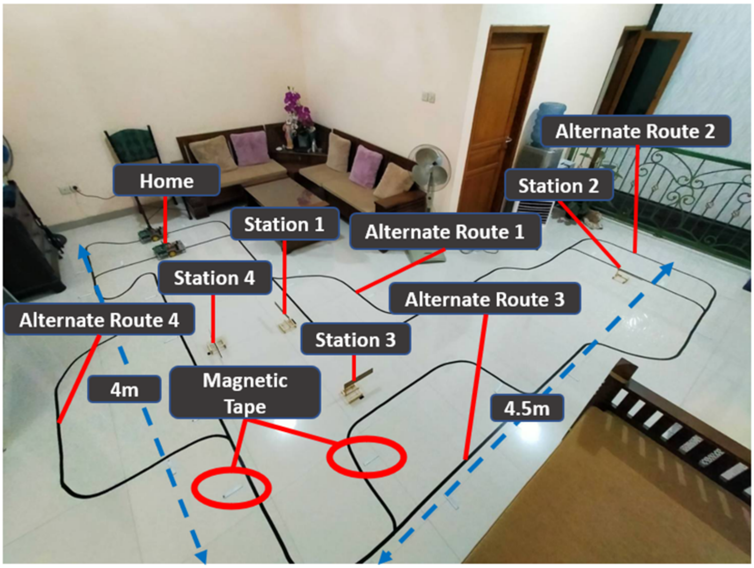

Fig. 7. Experimental AGV arena

4.3 Communication Evaluations

The purpose of this evaluation is to know the size of the data confirmed by each OE32-PLC as a whole and to estimate the duration of data transmission from one OE32-PLC to another, as well as the time of communication between the OE32-PLC UI and HMI. The size of the data transmitted between OE32-PLCs here is the size of the data sent during the ESP-NOW communication process. Fig. 8 shows a diagram of the size of the data transmitted between the OE32-PLC and the HMI. The duration of OE32-PLC data transmission can be determined by adding the duration of RTU Modbus communication between the Outseal PLC and ESP32 present in the OE32-PLC to the ESP-NOW communication sampling duration. The duration diagram of data communication between OE32-PLC and HMI, as shown in Fig. 9.

4.4 Routing Algorithms Evaluations

The next evaluation is the routing algorithm test; this test is divided into six according to the number of cases that have been designed. The routing algorithms in cases 1 and 2 are simple routing algorithms that involve only one AGV. Routing algorithms 3 to 6 involve two AGVs where one AGV is blocked by another AGV with a range of four possibilities along with its algorithm solution. The six scenarios are shown in Fig. 10. (1) Case 1 routing algorithm occurs when AGV 1 does not get the order to go to station 1 but instead goes to another station, but the main route to station 1 is empty, so AGV 1 selects the right route. After

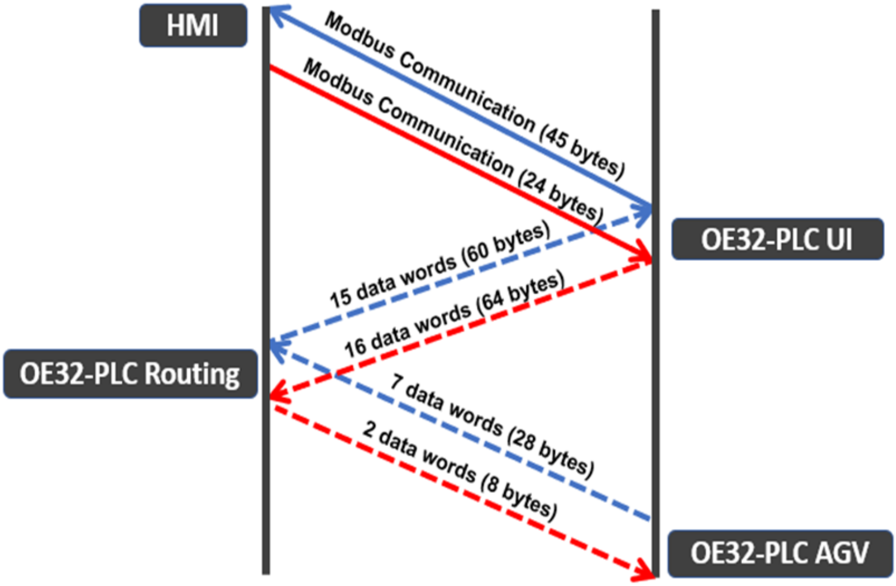

Fig. 8. Data size diagram in communication between OE32-PLC and HMI

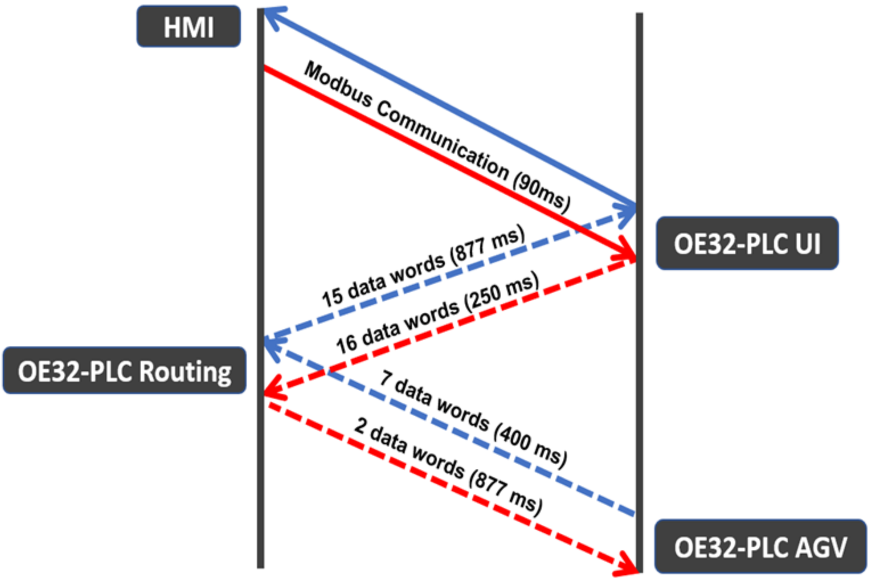

Fig. 9. Communication duration diagram between OE32-PLC and HMI

passing the magnetic tape a label, then straight forward passing the c label, AGV 1 continues to move straight without stopping even if it detects the presence of station 1. This algorithm applies to AGV 2. (2) In the routing case 2 algorithm, AGV 1 gets an order to go to station 1, and station 1 is empty, so AGV 1 selects the right route. After passing the magnetic tape a label, then straight forward passing the c label, AGV 1 continues to move straight and stops when it detects the presence of station 1. Then, stop at station 1 and finish the task. (3) In case 3, AGV 2 wants to go to station 1, but on station 1, there is still AGV 1, so AGV 2 takes the right line. After detecting magnetic tape on a label, it will stop on the c-tape. AGV 2 moves straight after AGV 1 detects the presence of the next magnetic tape. After AGV 2 runs straight, it stops for 50 seconds when it detects station 1. This applied to AGV 2, with the same situation. (4) The routing case 4 algorithm occurs when AGV 2 does not get the order to go to station 1, and on station 1, there is AGV 1. When this happens, AGV 2 takes the left route to take the alternate route after detecting magnetic tape label a. AGV 2 continues to move after detecting magnetic tape b. (5) Routing case 5 is an algorithm that avoids the possibility of collisions when there are two AGVs each leaving an alternate route and station. The routing case 5 algorithm occurs when AGV 2 first passes through the magnetic tape f label instead of AGV 1 passing through the tape e, so that AGV 2 is preceded to continue running while AGV 1 stops at the tape e. AGV 1 returns to move after AGV 2 passes through the magnetic tape. (6) The routing case 6 algorithm has the same purpose as routing case 5, i.e., to avoid the possibility of a collision that occurs when there are two AGVs each leaving alternate route 1 and station 1 at the same time. However, in case 6, AGV 1 must first pass the magnetic tape e as opposed to AGV 2 passing the tape f, so that AGV 1 is to continue while AGV 2 must stop first on the tape f until AGV 1 passes the tape g. This algorithm also applies the opposite when AGV 2 is in the station direction while AGV 1 is on the alternate route. Due to paper limitations, only the routing case 6 evaluation sequential results were presented in Fig. 11.

5 Conclusion and Future Works

The development of an AGV control system based on the OutsealESP32 PLC (OE32-PLC) using the ESP-NOW protocol has been presented. The addition of features of the ESP-NOW communication protocol to the proposed OE32-PLC makes it possible to control it wirelessly. The longest data transmission time occurred on the OE32-PLC routing at 877 ms, which is the sampling time of ESP-NOW and the duration of Modbus RTU serial communication. For further development, the AGV travel duration data should be displayed on the HMI screen as a prediction of the travel time of each AGV in completing its task.

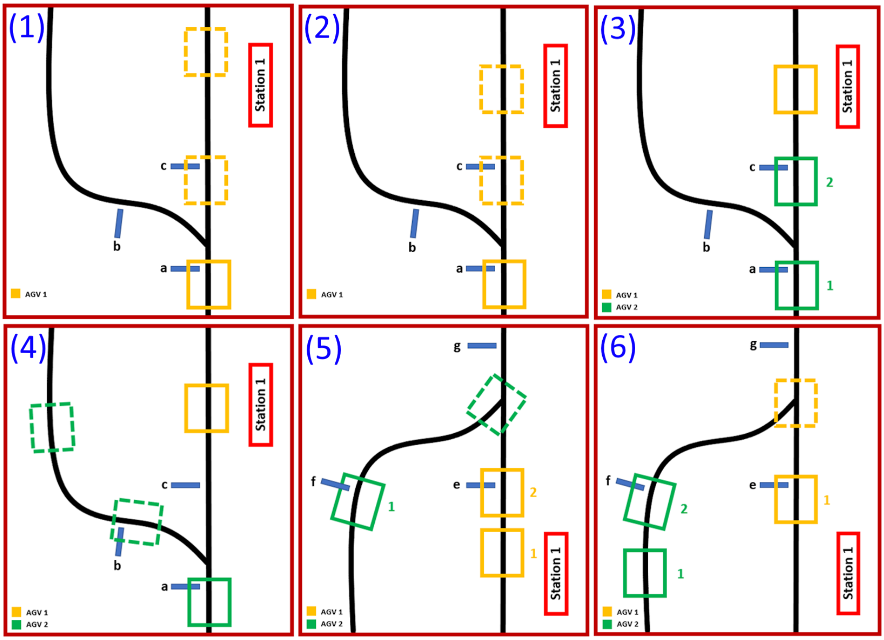

Fig. 10. Routing cases

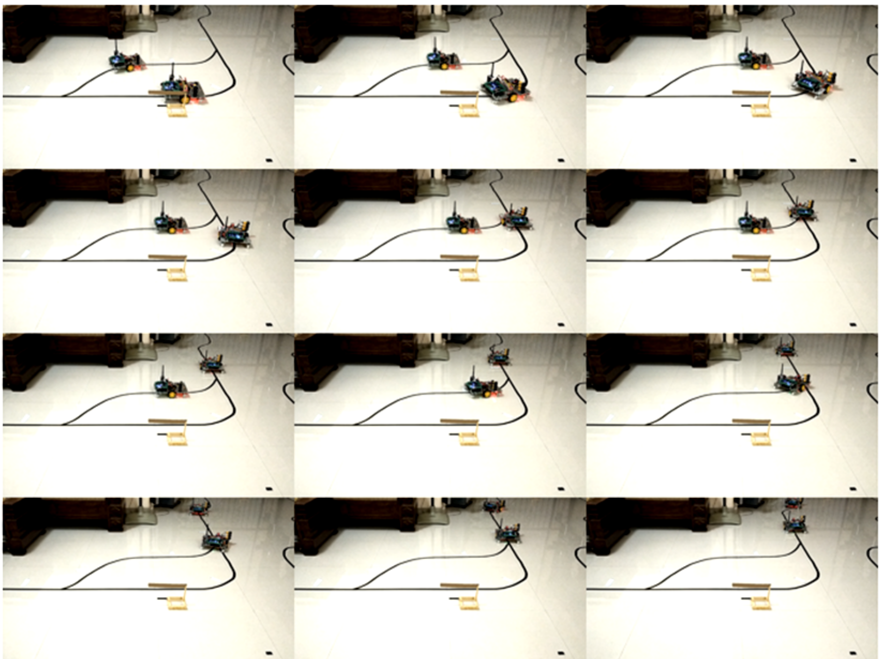

Fig. 11. The 6th routing case sequential

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