A Framework of IoT Platform for Autonomous Mobile Robot in Hospital Logistics Applications

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***Abstract*—Hospital Logistics deals with effective and efficient ways to transport items in hospitals. Autonomous Mobile Robot (AMR) is one of the most widely used automated systems to improve the transportation process. In this research, AMRs are used for delivering food and medical supplies to individual patients. Especially in COVID-19 pandemic situation, AMRs are important tools for keeping physical distance between patients and health workers to prevent infection. In this research, the AMR is equipped with Internet of Things (IoT) module which can be connected to the IoT platform on the server side. As a result, the health workers are able to monitor can control the robots effectively via a web application.**

Keywords—Autonomous Mobile Robot, Internet of Things, Hospital Logistics

I. Introduction

A. *Autonomous mobile robots in COVID-19 situation*

Logistics management in hospital deals with effective and efficient ways to transportation of various items, e.g. food, medicine, medical devices, clothes and etc. in a hospital [1]. Most of the transportation processes are still performed manually by health workers these days. In most cases, the health workers need to deal with heavy items, for example 100 - 200 kg food cart. This can be difficult be handled by a single person and result in a serious problem in long term. Robotics and automation technology can be concerned one of the possible solutions to improve the transportation process. Not only performance but workplace safety is also improved by using this technology. In addition, the concern about safety issue has arisen significantly during the pandemic situation.

Autonomous Mobile Robot (AMR) is concerned one of the solutions for improving logistic system. AMRs are used to automatically transport items between particular locations. They are widely used in industry for decades and started to apply in other working environments, including hospitals [2], [3] During pandemic situation, COVID-19, implementation of AMRs in hospital is not only for improving work efficiency but also for the infection control purpose. Direct contact between health workers and patients should be minimized in order to reduce the risk of infection. Therefore, the new way of communication and interaction between patients and health workers must be considered. To avoid the direct contact, mobile robots are used to interact with patients while the health workers can operate them remotely from outside the contamination area. AMRs have been applied in many of these cases, e.g. tele-medicine, items delivery, UVC disinfection, and etc.[4].

B. *Remote monitoring and control*

In pandemic situation, COVID-19, dedicated patients wards are set up with infection control protocol. The robots operating in these wards need to be treated carefully in order to prevent the contamination with environment. In practice, a special cleaning protocol and disinfection are required for the robots. Remote operation is also required for service and maintenances.

In this research, an AMR system, named "CARVER" [5], is developed for transporting items in hospitals. The AMR is equipped with a special designed food storage for bulk delivery to particular patients in COVID-19 wards. For item dispensing, in this case, the system is designed in the way that the patients are allowed to take their personal items from their particular slots on the storage by themselves. The safety and security have become a serious concerned when the items are food or medicine. Therefore, the system must be able to prevent the dispensing mistake by using locking mechanism for each slot. However, according to the current hospital safety protocol, the health workers need to be able to control and monitor the system, regardless. As a result, *Internet of Things* (IoT) platform is implemented on the system to enable the ability to control and monitor the AMR and related activities remotely.

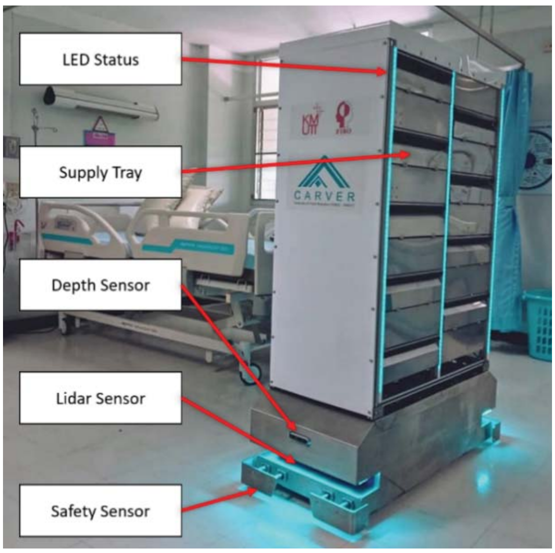

Fig. 1. Main components of Carver-Cap robot [5]

This article is organized as follows: IoT in hospitals, cloud service, and communication system are reviewed in *Section II*. Methodology for system development is described in *Section III*. Detailed implementation of IoT platform with AMRs is explained in *Section IV*. Results are in *Section V.* Conclusion and discussion are in *Section VI.*

II. Literature review

A. *Internet of Things for Hospital Service Robot*

IoT is related to the system that integrates between many things – e.g. sensors, device, actuator, decision process, people, technology – where the related information can be transferred via network. The IoT platform allows the users to easily access the system and real-time monitor their devices. In hospitals, Medical-IoT (M-IoT) platform allows the health workers, namely doctors and nurses, to interact with patients' information more effectively.

A number of research works are presented recently. [6] proposed an IoT platform which is a web / mobile application for on-line monitoring anesthesia with cloud-based network. [7] proposed IoT system deployed in hospitals for various application and supports Lo-Ra, Wi-Fi, and etc. This system uploads the data to the cloud service from devices - such as electrocardiogram (ECG) detection, environmental monitor, and people flow statistics - and then feeds back to the user in real-time via user interface. [8] proposed prototype of IoT Based remote health monitoring system for patients. This prototype monitoring three health sensors: heart pulse sensor, body temperature sensor and galvanic skin response sensor. The sensor data can be uploaded to the cloud storage and updated in real-time database. The system allows the doctors to monitor patients via android application. [9] developed an on-bed monitoring and alarming system for detecting abnormal activities of patients while being on bed. The information is sent to the caretaker's mobile device and a control panel at nurse station via an IoT platform.

In this research, IoT platform is presented in 4 parts: hardware, network, IoT cloud service, and application.

B. *Cloud Service for robotics*

Recently, IoT cloud platforms are generally provided as a service by many companies. The key service providers in the market are Microsoft Azure, Amazon Web Services (AWS), and Google Cloud. [10] reviewed IoT cloud platform vendors using the constraints of hubs, analytics, and security. [11] surveyed on various cloud services used in an integration with IoT and studied about cloud computing for data management, storage, and analysis. [12] did a comparison between three aforementioned cloud platforms in regard to the cost analysis on different of load and performance.

In this research, the AMR monitoring and control platform is developed on Cloud. AWS and AZURE servers are selected based on cost, performance, and ease of use.

C. *System communication*

In this section, communication protocols of IoT used are reviewed. Nowadays, a number of protocols are available for development, including MQTT, CoAP, XMPP, RESTFUL Services, 6LoWAN, RPL, and etc. [13] reviewed of IoT protocols used for data transfer between cloud service and a large number of connected IoT devices. [14] presented an insight review on various protocols applied at different layers of IoT protocols, such as CoAP, MQTT, AMQP, and XMPP. The efficacy and reliability of these protocols are analyzed.

In this research, the system allows the users to control and monitor AMRs from anywhere via the client web application. To enable these functions, real-time data transfer between AMRs and cloud server is required. MQTT protocol is selected to be used in CARVER platform.

III. Methodology

A. *Study of hospital procedures and functions requirements*

CARVER platform is used for logistics related process in hospitals, so that most of the users are health workers. The survey on the function requirements was done with the health workers who are in-charge of this service.

The original transportation procedures of food and medicines to patients are observed and studied. The service schedule is assigned to each patient according to the treatment recommendation. Food and medicine are served correctly for individual patients at specific time and location. Patient's identity - i.e. name, surname, date of birth must be verified every time by the officers according to hospital safety protocols. Originally, the information sheets are carried by the officer (in this case, a nurse) at all times during the service. In this project, the sheets are converted to be a CSV file and the data will be imported to the system. Therefore, the AMRs can operate accurately according to the assigned schedule.

In regard to modes of control, "*manual*" and "*automatic*", the AMRs automatically operate throughout the hospital floors in general. However, the robots need to be able to controlled manually in certain situations due to the safety issues. From the distance, the users need to be able to monitor real-time position of the robots on the map and control the robot to move between assigned target positions. The concept of tele-operation is applied in this case. In regard to User Experience / User Interface (UX/UI), alarm and descriptions are required to inform on the system. Words and symbols on the UI must be clear and easy to understand.

In summary, the requirements are pointed out in 4 categories (a) automatic and manual modes, (b) Traceability of robots' positions, (c) CSV for service scheduling, and (d) proper UX/UI on graphical user interface (GUI).

B. *Conceptual Design*

From the requirements explained in the previous section, the system is designed for the user to control the AMRs with various devices, such as smartphones, tablets and computers. The system is designed according to the following functions:

- Able to input the information by using CSV file;
- Able to control robot's position control;
- Able to add new location points easily;
- Able to monitor the state and status of the robot;
- Able to perform the tasks according to the user assigned schedule; and,
- Having procedure for safely dispensing and storing the items for individual patients.

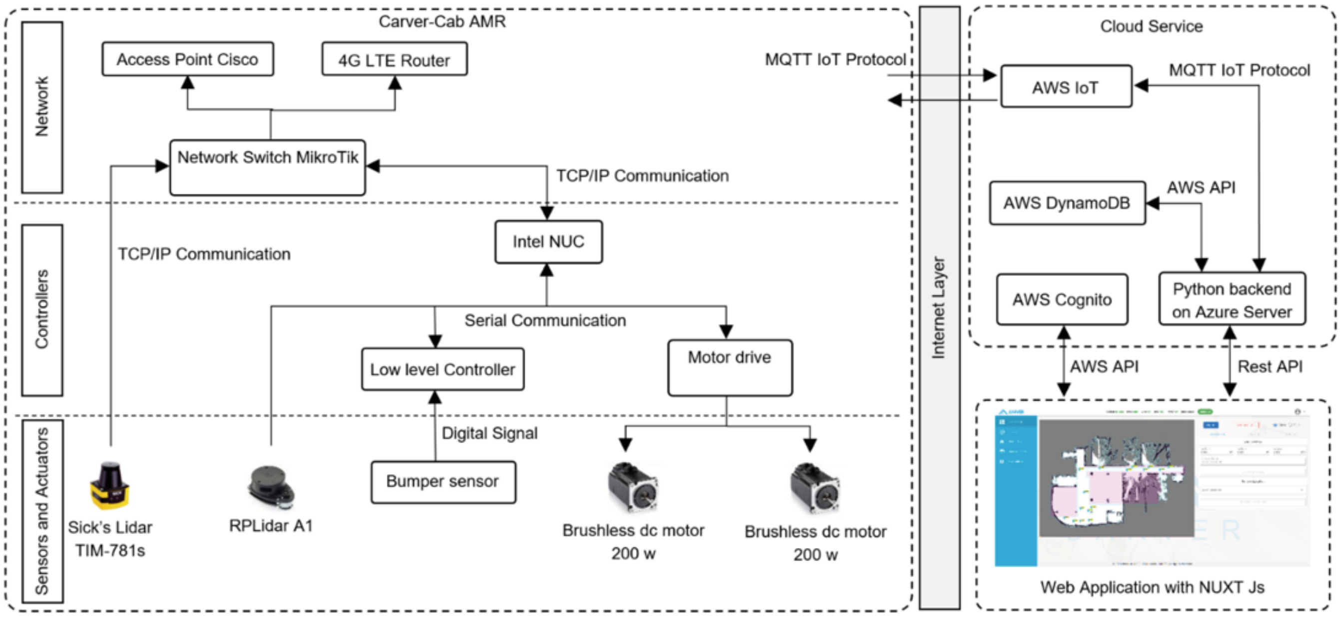

Fig. 1. System diagram on CARVER and Cloud service side

IV. IMPLEMENTATION

A. System Architecture

The system architecture is consist of 3 parts frontend, backend, and robot (see Fig. 3).

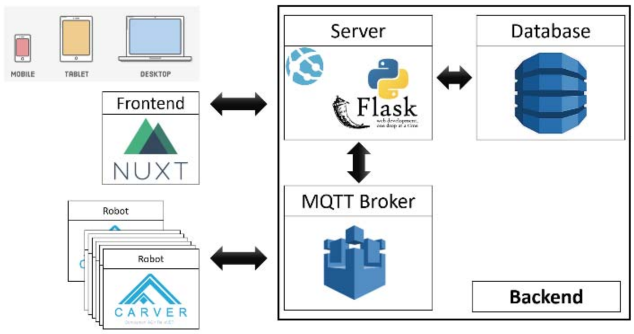

Fig. 4. System overview of Carver platform web application

The platform is running reliably on cloud service on AWS and AZURE server. The platform is a hybrid structure control with the *global manager* to schedule the task of the robot and *local state machines* to perform local tasks. Users can control the robot via the web application (frontend) with multiple devices such as mobile phones, tablets, and laptops. The *frontend* uses HTTP protocol to communicate between the server by GET/POST method. The *backend* consists of the cloud service: MQTT broker, Web App Service, and DynamoDB. On each robot, Robot Operation System (ROS) is running on the middle control layer of the robot to control the operation and to communicate with MQTT Broker.

As shown in a system diagram in Fig. 2, the system is divided into 2 main sections: *AMR* and *Cloud service with web application*.

(a) *AMR section* is an integration of sensors and actuators layer, controllers' layer, and Network layer. The details of each layer is as follows:

On the *sensor layer:* the components consists of an industrial grade Lidar SICK TiM-781s and RP Lidar A1 for front and rear side, bumper sensor in front and rear side.

On the *controller layer,* the components consists of a Brushless DC motor driver interfacing with RS232 bus. A programmable logic controller (PLC) is used for low level control interfacing with RS232 bus. The main controller is programmed with ROS under UBUNTU 18.04 LTS running on an Intel NUC i7-8559U with 8 GB RAM.

On the *network layer,* the components consists of an access point to receive Wi-Fi signal and 4G LTE router to receive 4G signal. A network switch MikroTik is used to manage the internet signal between Wi-Fi and 4G LTE. In general, the main network is operated on Wi-Fi signal. It will switch to 4G while the Wi-Fi fails.

(b) *Cloud service with web application section* operates running a backend program on AZURE web application service and interfaces with AWS API, for example AWS DynamoDB, AWS Cognito, AWS IoT and S3.

For multiple robots operation (Fig. 5) CARVER can be connected to each other via server. User can control robots via the GUI on the web application. This connectivity uses intermediary server to transfer data. The data is transferred to the server and then to robots.

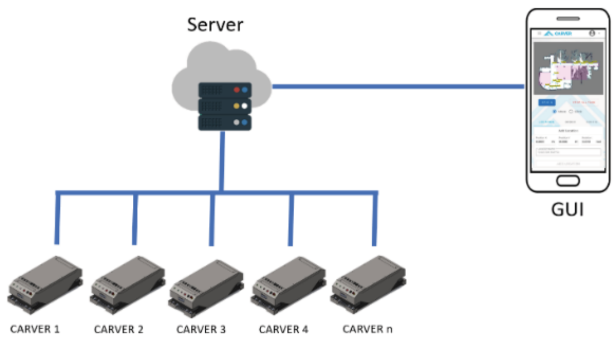

Fig. 5. System diagram on multiple AMR robot

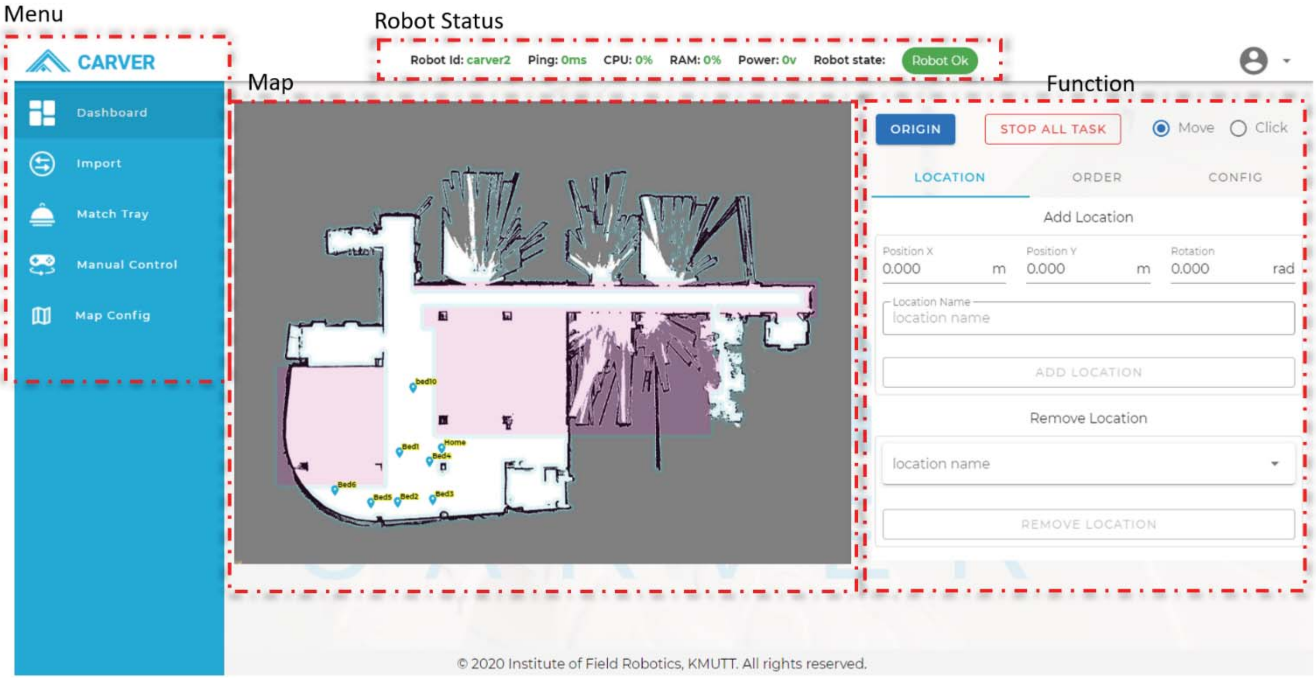

Fig. 6. Example page of Carver platform web application [5]

B. CARVER-Cab

CARVER-Cab is an AMR designed for bulk delivery of items (i.e. food, medicine, and medical supplies) to patients with safety and personal authentication (see Fig. 1). The robot is running on ROS with state machine. It is able to fully navigate in specific areas with known map by using multiple sensors for safety and obstacle avoidance (Fig. 1). The items are stored in the storage with 18-slot lockers with light status display in front of each slot. The communication node is developed to communicate between robot and server with AWS IoT service. This node is streaming all sensor data and robot status to server.

C. Frontend GUI

Web application of the system consists of five main parts:

(a) *Dashboard* is a collection of the data to visualize and monitoring the robot (see Fig. 5), such as %CPU, %RAM, robot state and current position of robot. User can drag and drop the pointer to easily set target positions.

(b) *Import scheduling* is a function to set the schedule of the robot to move to target locations (e.g. patient beds, charging station, and etc.) at specific time. The schedule can be imported from a CSV file (see data format, Fig. 7) where the data is exported from *Hospital Information System* (HIS). CSV is converted to JSON format and sent to the robot. User is able to change the schedule on the fly in web application.

(c) *Matching Tray* is a function helping the users matching the items to be stored in each specific slot with a specific patient. The status light at the specific slot will be shown according to the selected patient's name. Therefore, this function can prevent the mistake in the process of storing personal items. The users can check and verify it in web application.

(d) *Manual control* can be used to move the AMR to specific position manually by using a virtual joystick in the web application. This function is crucial during emergency.

(e) *Map configuration* is function for adding / removing / editing the location on the fly. The location point consists of position along x-axis, y-axis, heading, and name.

D. Backend

The backend side is developed on FLASK Micro Web Framework. The main function of server is to bridge between client and robot. The server is connecting the cloud service.

(a) *Database*: AWS DynamoDB is used as the database. is used Key-value is used to access data in NoSQL.

(b) MQTT Broker: AWS IoT is one of services on AWS service providing multi-layer protocol with encryption data. MQTT protocol is the lightweight messaging protocol design for IoT device with low bandwidth and high latency.

location	hn	barcode	name	surname	birthday
Bed1	HN8342821722	8766686863	DUMMY	Dummy	20/11/2537
Bed2	HN2483033673	8766686863	DUMMY	Dummy	29/11/2537
Bed3	HN2573676027	8766686863	DUMMY	Dummy	20/10/2537
Bed4	HN2573676028	8766686863	DUMMY	Dummy	20/10/2538
Bed5	HN2573676029	8766686863	DUMMY	Dummy	20/10/2539
Bed6	HN2573676030	8766686863	DUMMY	Dummy	20/10/2540

Fig. 7. Example CSV file for input

V. Experiment & Discussion

A. Testing and results

Several logistic services are implemented in this platform. The system is tested by using web application and cloud service. The test was initially conducted in lab environment. Robot home, a charging station, and 18 mock-up patient beds were setup over the approximately 100 m^2 space. The space had full coverage of Wi-Fi signal. In this test, only one AMR was used at a time.

From the result, the health worker can control an AMR in the delivery process with scheduling task. The state machine of this system is expanded in Fig. 6 for better understanding. First, the health worker imports the schedule and sends it to the server. The server processes the task, sends the command to the AMR with MQTT broker, and logs to the database. The

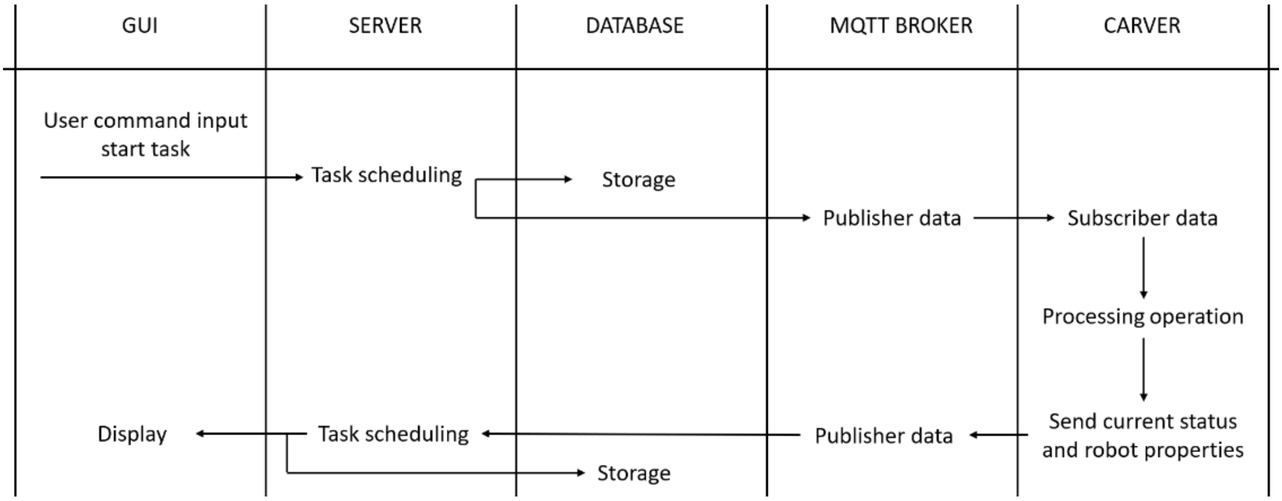

Fig. 2 The state machine of the system

AMR receives the command and do the local state machine. Then, the AMR sends the robot properties and robot state to the server with MQTT broker. The server receives a feedback from the AMR and then saves it to the database.

The health worker can visualize the AMR on dashboard, where an example is shown in Fig. 9. The dashboard shows the *start position*, *current position*, and *target position* of current task. While the robot is moving to the target position, the AMR will update the current position and robot status (e.g. Position X, Position Y, header) which will be displayed on the dashboard. The bed locations are predefined on the map as the labels of bed number displayed on the dashboard.

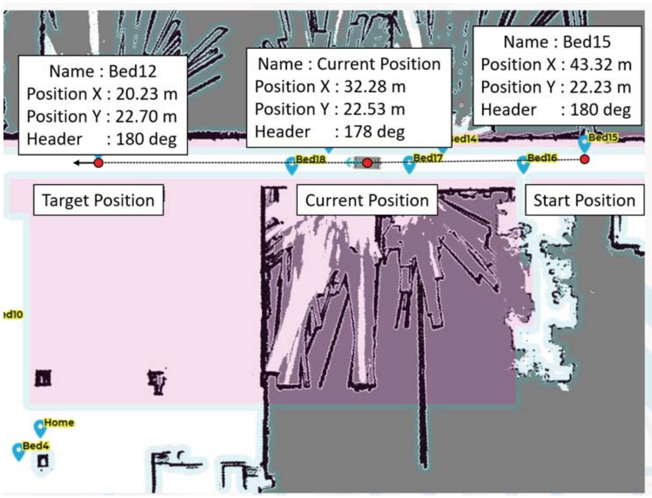

Fig. 9 Mapping in GUI shown about path and target point of navigation.

B. Discussion

The AMR was able to completed all assigned target positions which are located along 40 m path within around 5 mins. Minor signal lost was occurred but the AMR was able to carried out the operation safely. The result of the testing presents that the platform is able to control and monitor the operation effectively. There are three issues needed to be discussed and improved.

Input Scheduling: In this platform, the user can input scheduling by importing a CSV file to platform. If the schedule can be taken from hospital information service directly, it will be more convenient and faster. However, access permission of HIS from hospitals is required.

Alarm and Error Code: If the robot found unusual situations the platform must send alarm message to the user in real-time. An example of an unusual situation is low battery, obstacle detection, timeout in schedule task, the robot collides with obstacle, the emergency is pressed, and etc. This function must be reliable as they are safety related issues.

The connection has been lost: When the robot moves to a position there is no Wi-Fi signal. The robot must switch the network to others source such as 3G/4G signal. This function must be reliable according to the AMR safety protocol about controllability and traceability.

VI. Conclusion

Hospital Logistics deals with effective and efficient ways to transport items in hospitals. AMR is one of the most widely used solution for the internal transportation in hospitals. In this research, AMRs are used in a COVID-19 in-patient ward for items delivery service. Another important main purpose is to keep physical distance between patients and health workers. To enable remote monitoring and controlling the system, an IoT platform is developed.

Eventually, the AMRs can be successfully controlled via a web application with cloud service. This application can control the robot in autonomous scheduling task and tele-operation in manual control mode.

For future work, CARVER platform will be implemented in a number of hospitals for the field study and experiment. The performance and capability in regard to engineering issues will be improved and aimed for fully automatic operation in the future.

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