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Application of Internet of Things in Online Robotics Class

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Abstract

Distance/online learning is becoming a necessary form at academic institutions, and the growth in distance/online learning has been outpacing enrollment growth. The pandemic has been even further pushing distance/online learning to the peak based on the census from the United States Census Bureau. According to the data of EducationData.org, 98% of the institutions have moved most of the in-person classes to the online sections. The online robotics classes are also currently provided online across the country. Because the robotics class is a kind of intensive hands-on class, the online course prevents the students from implementing various experiments. The student will suffer difficulties in understanding the advanced concepts and theories. Therefore, it is necessary to let the students have equal chances to practice via hands-on projects. The internet of things (IoT) has been integrated into the robotics classes in the Department of Mechanical Engineering Technology (MET). The basic idea is to use the internet to implement IoT-based projects that combine wireless sensor networks, online learning management systems, and remote-control techniques to realize the learners' remote collaboration and immersive feeling. In an IoT-based project, a robot spider is taken to show the implementing procedures. This project combined several cutting-edge techniques, including vision-based simultaneous localization and mapping and object detection. The students can have the chance to broaden their horizons of knowledge by using machine learning libraries and tools. In order to demonstrate the efficiency of the IoT application, the statistics of the students' performance were analyzed after the classes over three semesters. The results show that the students' hands-on skills are acquired as desired, their enthusiasm for robotics is improved, and their performance can compare with the in-person sessions.

Keywords: Distance/online learning, IoT, Robotics, Mechanical Engineering Technology

1. Introduction

Robotics classes require highly intensive hands-on practice and projects. With the pandemic fluctuating, many colleges for both the instructors and students had been suffering from remote teaching and learning due to the shortage of hardware and software that facilitate the implementation of the hands-on projects for robotics classes. As a result, the enrollment in the robotics programs was impacted severely, especially part-time students who are willing to earn an online degree have to give up the robotics engineering/engineering technology programs. Consequently, the diversity of the students in the plan is harmed.

At present, there are some implementations to teach online robotics courses: (1) Coding intensive way to emphasize the algorithms, as being implemented in reference [1, 2]. (2) Use simulation and optimization to familiarize students with the concepts and theories. For example, reference [3] introduced how to give remote robotics lessons by simulation and optimization. (3) Employ multimedia. For example, the reference [4] presented how to use the videos to show the fabrication of robots. More information about online robotics courses and the corresponding websites as mentioned in reference [5]. Besides, the online robotics training also prompts the development of online robotics classes. Although the metrics discussed above make online robotics learning possible, they cannot guarantee collaboration in class. Therefore, it is critical to find a method to foster collective understanding in online robotics classes. Because the sensors and actuators are the essential components for the fabrication of robots, the internet of things (IoT) [6] that can synthesize the sensors and actuators into a practice project is employed to realize the remote collaboration in the robotics classes.

2. Internet of Things in Online Robotics Classes

2.1. Concept of Internet of Things

There are many curiosities about IoT and its impact, but there is no standard definition for it. So, we should discuss IoT based on the basic concept, the working principles, and the roles of modern society [7, 8].

As the name implies, IoT uses information architecture to connect the devices and people (things) with the internet. Therefore, data acquisition and data exchange will be the essential function of IoT. The things to connect include various objects of various appearances and sizes, from energy management [9], which stabilizes the end-users demand, to healthcare, which confronts the challenges of COVID-19 [10], to online education, which increases the users' immersive feeling, IoT has been changing our life-style imperceptibly. The basic working principle of IoT can be narrative as follows: Things with built-in sensors, controllers, and actuators are connected to an IoT platform. Then, valuable information about the status and behaviors of things is collected and exchanged through the IoT platform with specific priorities and needs. Next, the events are addressed based on the given conditions or necessaries. As a result, the role of the IoT will be correspondent and responder. So, it obviously can fulfill the duty of collaboration remotely [11].

2.2. Internet of Things in robotics class

One of the essential hands-on works in the robotics classes is to use the sensors and actuators to fabricate specific applications. Therefore, we will introduce the IoT based on integrating the hardware mentioned above. The hardware-based IoT architecture includes four layers: IoT devices, IoT gateway, processing engine, and application layer (Figure 1). The specific descriptions of these four layers are as follows: IoT devices can exchange information through the internet based on specific protocols. These devices form the base layer. In the IoT framework used in robotics classes, various sensors are compatible with Raspberry Pi, a single-board computer. The IoT gateway is also called the aggregation layer. This layer will collect and pass the data between the devices and the processing engine layers. In the robotics class, the gateway device is a wireless router that will aggregate the data complying with the rules defined by the IoT gateway layer. The processing engine is to process the data received from the IoT gateway layer. Usually, the IoT cloud is taken as the processing layer. So, to facilitate accessibility, the Arduino IoT cloud is selected to be the processing layer in the robotics classes[12]. The application layer comprises various terminal devices, including mobile devices, desktops, laptops, tablets, and other consoles. The layer will identify, manage and control the IoT devices by interfacing the terminal apparatus.

The IoT framework in a senior-level robotics class is shown in Figure 1 (b). The class name is "Robotic Systems Design and Applications" in the department of "Mechanical Engineering Technology" at "CUNY New York City College of Technology". This is one of the project-based courses for B.Tech program [13]. In this class, the students are required to use vision-based algorithms to complete two tasks in their projects: (1) the simultaneous localization and mapping (SLAM); (2) the recognition of objects. In this class, the students are assumed to learn the applications of some cutting-edge techniques, including PID control, additive manufacturing, computer vision, and artificial intelligence. The objectives of the class are to let students explore the practical applications of fundamental theories, foster collaborative ability, and prepare for future careers. So, this course emphasizes the practical applications indirectly instead of delivering the theories directly.

Therefore, the IoT framework used in the online session must have the function to facilitate the students' collaboration on the group projects. In addition, the fabrication cost of the project must be affordable for the students. At the same time, the sensor development kit for Rasberry Pi has been used in this class for several years[14], but the sensors should be integrated into the IoT platform. So, it is better to select a compatible microcontroller board to complete this task. Moreover, a free IoT cloud will be the first choice for educational applications. So, the Arduino IoT cloud[15] and the Arduino IoT devices "Arduino Nano 33 IoT"[16] are employed. Currently, the sensor used in SLAM is a 2D laser scanner RPLIDAR A3[17]. RPLIDAR is a low-cost 'Light Detection and Ranging sensor' suitable for indoor robotic SLAM applications. It provides a 360-degree scan field, 5.5hz/10hz rotating frequency ranging 16000 times per second, and a 25-meter ranger distance for A3. The processed data will be passed to the IoT cloud via the selected "Arduino Nano 33 IoT". The IoT gateway is a wireless router connected to the "Arduino Nano 33 IoT" and the Arduino IoT cloud. The students can use the laptop or desktop to connect to the IoT cloud.

3. Design of Spider with Functions of SLAM and Object Recognition

3.1. Vision-based SLAM

The vision-based SLAM is an autonomous navigation method that employs vision sensing techniques to locate the robot's position and map the environment simultaneously. In reference [18], the characters of SLAM were introduced in detail. There are two SLAM approaches (1) monocular SLAM that uses only one camera (one of the implementations can be found in reference [19, 20]), (2) stereo SLAM that uses a pre-calibrated fixed-baseline stereo camera rig, and a typical application of this method may refer to reference [21].

One of the popular monocular SLAM systems is ORB-SLAM. The pipeline of an ORB-SLAM can be found in Figure 2[22]. The (n-1) and (n-2) keyframes give an initial map, and the n^{th} keyframe will be used to match the initial map to estimate the camera's pose. Then, the new keyframes are obtained the same procedures can expand the map. The current keyframe will be compared with the previous keyframes to eliminate the errors to refine the map. The ORB-SLAM system involves several complicated algorithms, and this derails from the educational objectives of MET, even though it is a relatively mature system.

The triangulation of 2-D feature correspondence must match corresponding components between the map and the query image, so it has much higher complexity in algorithms (the analysis can be found in [23]). In contrast, stereo SLAM can directly compare the point cloud, therefore, reducing the complexity of algorithms. Besides this, the scale between the map and the world can be updated in time. More details of the comparison between the two methods may refer to reference [24]. To simplify the SLAM implementation by skipping the procedures of 3D points generation, stereo

SLAM is used in the vision-based SLAM spider [25]. The pipeline of a stereo SLAM method with signed distance functions (SDF) is shown in Figure 3. The stereo camera directly gets the 3D points. The two consecutive keyframes are paired to develop the map gradually. Besides, the camera's pose is obtained by the SDF-based feature registration method. The errors can be estimated after the camera's projection matrix is identified [26, 27].

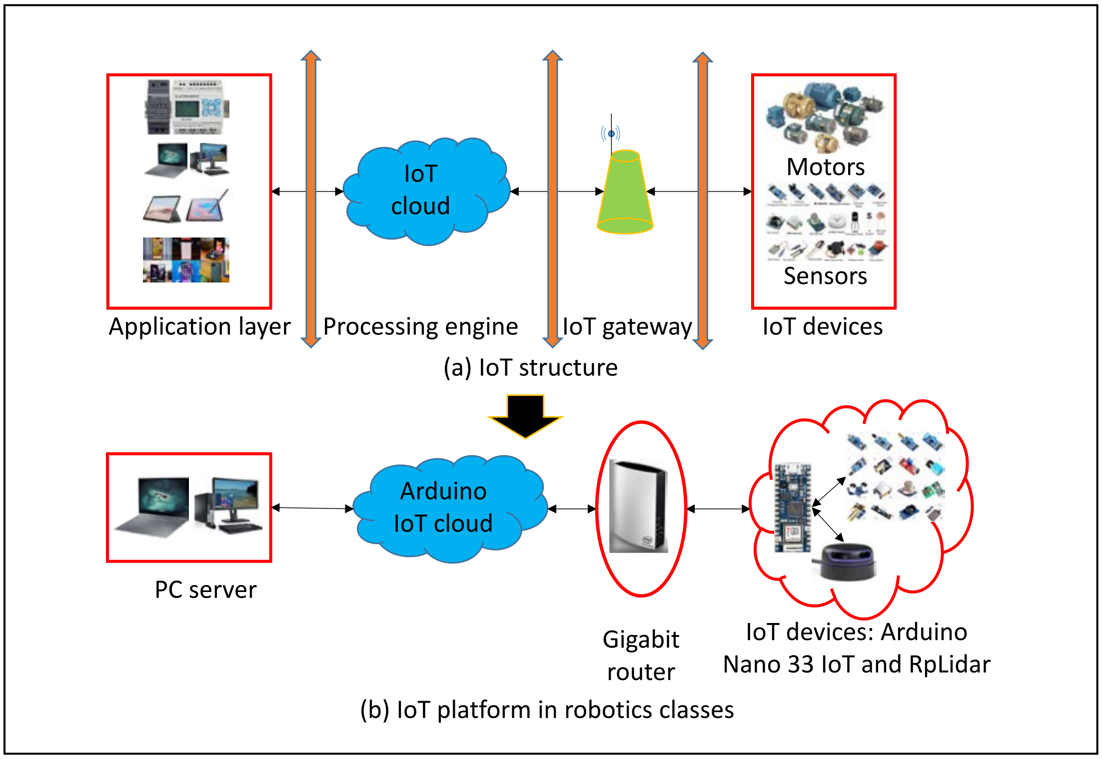


Figure 1: IoT Device Architecture in robotics classes

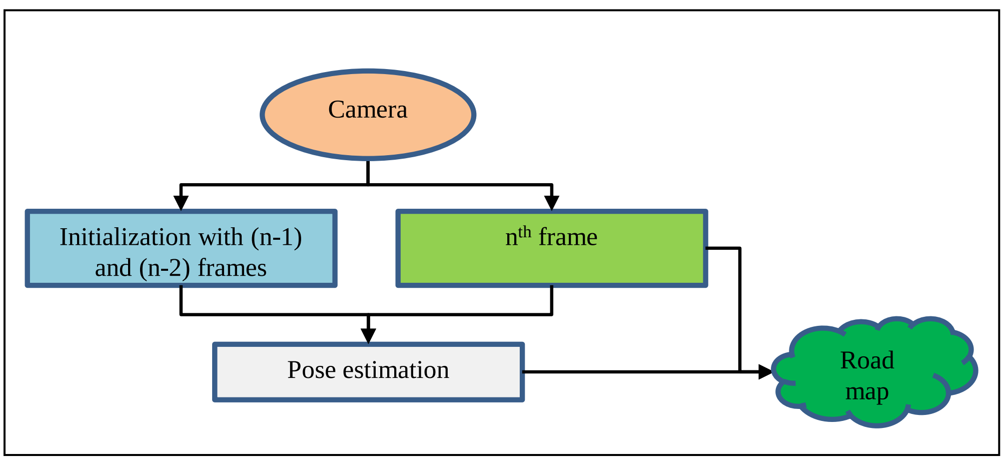


Figure 2: ORB-SLAM system pipeline

3.2. Design of vision-based spider

Figure 4 is the exploding assembly of the project. The spider comprises four main modules: power control module, structure & actuation module, sensors & actuators control module, and communication control module. The whole structure of the spider is fabricated through additive manufacturing by 3D printers. The skeleton of the spider is composed of three main parts: the torso, the six legs, and the head. Each portion of the spider has three joints that are driven by three servo motors. The head has one joint that is also driven by a servo motor to enable the cameras mounted on it to rotate about the vertical axis. Also, the corresponding brackets are designed to mount the power source module, control module, motors, cameras, and communication module.

3.3. Walking control

The walking control strategy is made based on a six-leg pattern, as shown in Figure 5. L1, L2, and L3 are the left-side legs, and R1, R2, and R3 are the right-side legs. The walking pattern can be found in Table 1. Based on the pattern, half of the six legs are supporting the body simultaneously, and the dynamics of the movement should be considered based on the location of the center of mass of the body to make the pace harmonic [28].

Besides, to stabilize the cameras, a double-loop (velocity loop and position loop) the proportional–integral–derivative (PID) controller is used to control the errors. The PID position loop is used to manage the rotation angle of the joints. The velocity loop is used to control the speed of the movement. The proportional gain K_P (rang from 60 to 80), the integral time constant K_i (rang from 60 to 80), and derivative gain K_d(rang from 10 to 16) are designed with the varying duty cycles of PWM, and they are varied based on the external environment.

3.4 Collaborate via IoT framework and implementation

To use the Arduino IoT cloud, the students are directed to sign up to the created environment since the Arduino IoT cloud is part of the created environment. Then, they need to log in to the Arduino IoT cloud to create a thing (register an Arduino device) in which Arduino Nano 33 IoT is specified and configured. After that, they can process and exchange the SLAM data.

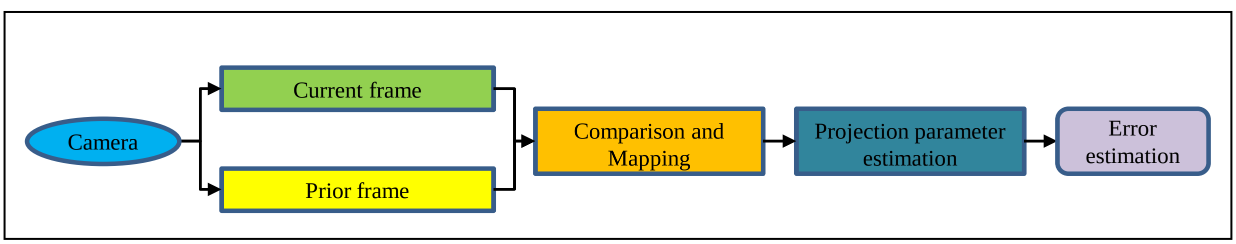


Figure 3: Stereo slam with SDF pipeline

The peripheral devices used in this project include the mouse, keyboard, monitor, ps4 switch controller, and iPad. The mouse, keyboard, and monitor are used for debugging and embedding the programs. The ps4 switch controller is used to control the spider remotely. The mouse and keyboard combo are connected to the Raspberry Pi via USB WIFI modules. The ps4 switch controller and iPad will be connected to the Raspberry Pi via a USB Bluetooth modulus. The monitor is connected to Raspberry Pi via an HDMI port. The Raspberry Pi and the iPad work in a local network to guarantee that they can share the same results of data processing. The iPad is only taken as a display device and does not process any data. The SLAM result will be shown on the iPad through the Bluetooth bus.

In the SLAM map, the spider passes through a simple maze made of cardboard boxes. The area of the maze is about $25\ ft^2$. The gray wall is the reconstructed wall of the maze, and the blue dash line gives the path of the spider. Certainly, the SLAM results obtained here are still coarse, and there is a considerable potential to improve the performance, but it is a successful tentative for the undergraduate students.

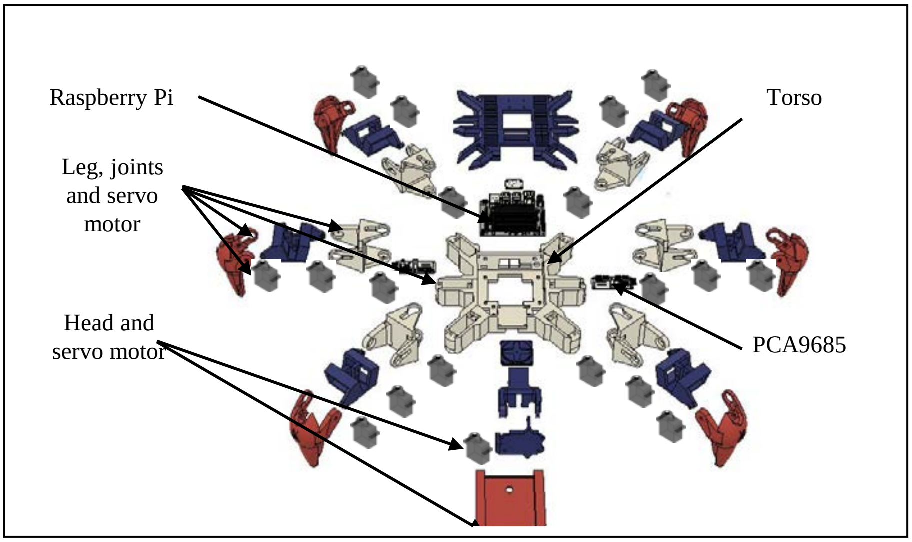


Figure 4 Exploding assembly of spider

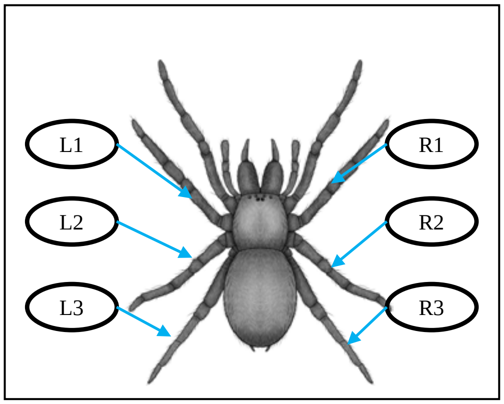


Figure 5 Exploring spider walk

Table 1: Walking pattern

	L1	L2	L3	R1	R2	R3
Step 1	—	|	—	|	—	|
Step 2	|	—	|	—	|	—

3.5 Spider prototype

The final prototype of the spider can be found in Figure 6. The RPLIDAR A3 and Arduino Nano 33 IoT are combined with the spider body. The Arduino Nano 33 IoT is used to communicate among the group members. The gadget is kept by the group leader, and other group members can control this gadget remotely via the IoT Cloud App from computers or mobile devices. The control dashboard can be found in Figure 7. Besides, the group members can have virtual meetings via a "learning management system." Here, the "Blackboard" is employed. Then, the students can enjoy the convenience brought by the free IoT cloud.

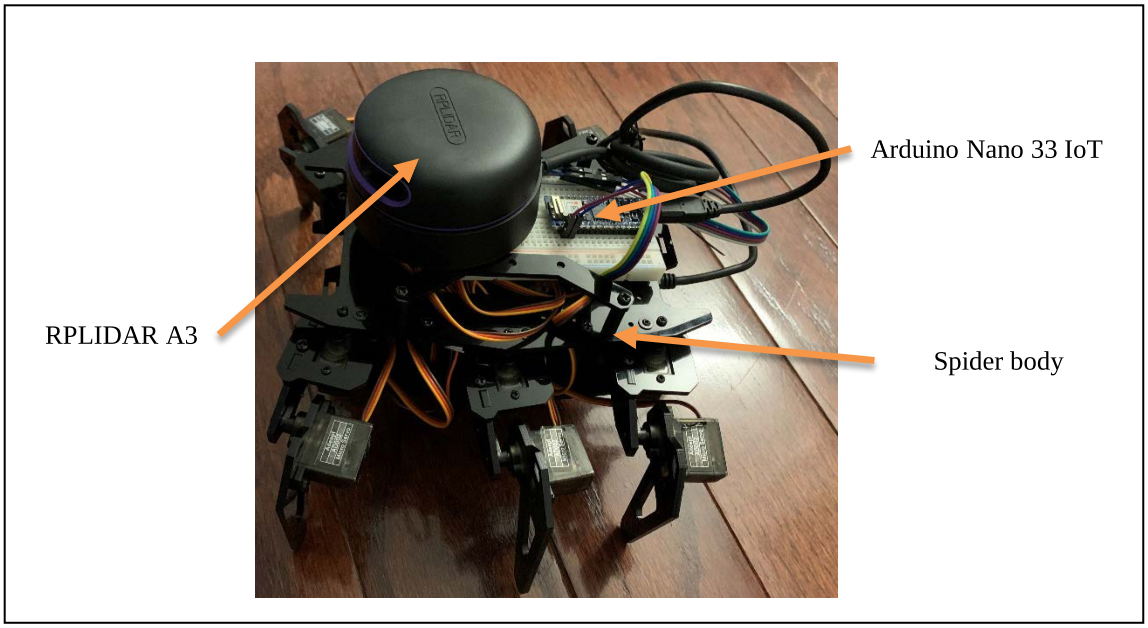
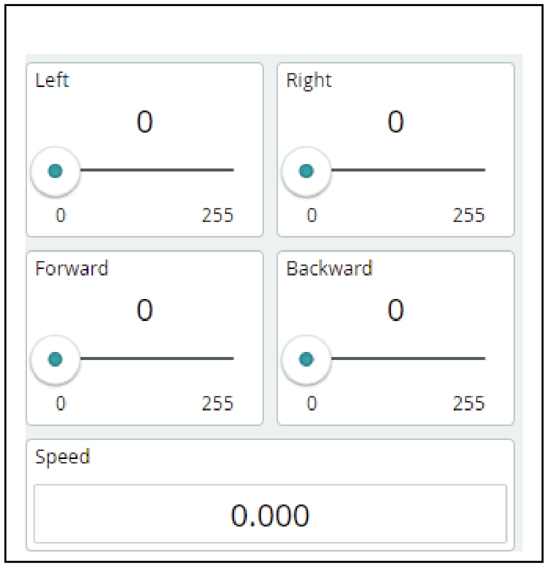


Figure 6 Spider prototype

Figure 7 Control dashboard of spider



4. Evaluation and Discussion

The full online robotics classes at the college have three sessions in which the IoT has been employed. There are 18 students and 20 students in the sessions separately. The courses are administrated by the instructors who take the responsibility of preparing the experiments. Moreover, a peer assessment mechanism is established to evaluate the performance of the students. This mechanism combines the instructors' evaluation (70%) and the evaluation from other students in the class (30%) to decide the final individual grade.

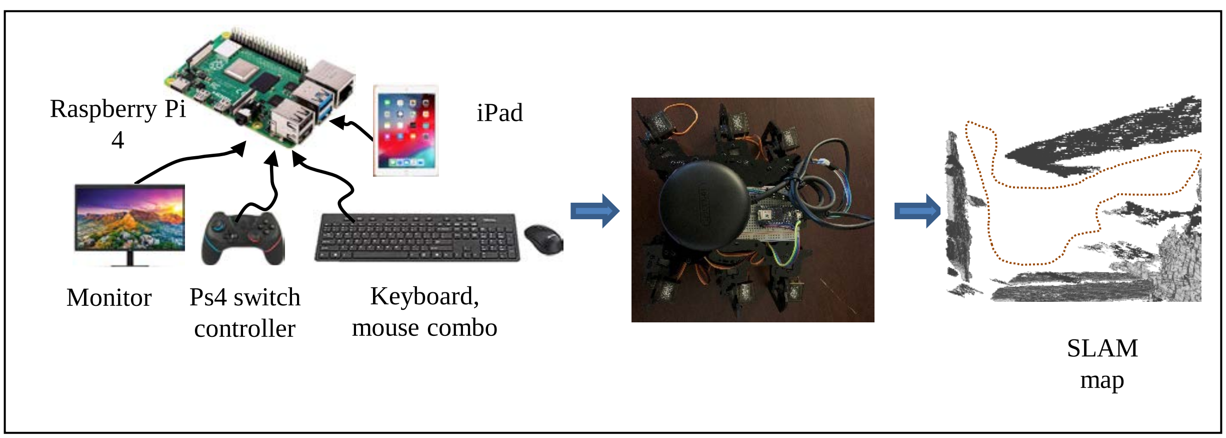


Figure 8: SLAM result

The student's performance is the most crucial standard when evaluating teaching efficiency. The students' performances fall into two catalogs (1) the knowledge and the skills (2) career prospects. With the help of the IoT platform and the corresponding group projects, the students acquire the ability which can compare with the in-person classes. There are five aspects that can show the students' overall performance: (1) combine knowledge and information to identify problems, (2) demonstrate an understanding of all the pieces of the problem, (3) formulate strategies to solve narrowly defined problems, (4) find the correct and detailed solutions to the problems, and (5) solve the problems in the midterm and final. 86% of the students can combine knowledge and information to identify problems, 92% of them demonstrate an understanding of all the pieces of the problem, 82% of them can formulate strategies to solve narrowly defined problems, 88% of them can find the correct and detailed solutions to the problems, and 85% of them can solve the problems in the midterm and final (Refer to Figure 9).

Therefore, the IoT platform combined with the SLAM is helpful for online robotics classes. The students in these classes have demonstrated a competitive ability after the classes.

5. Conclusions and Future Work

In this paper, how to employ the IoT platform and SLAM to promote the online robotics classes is introduced. This work is a tentative practice for an entire online engineering class that is characterized by intensive hands-on projects. To demonstrate the implementation, the usage of IoT platforms and SLAM is discussed. The collaboration among the members of the project group has been shown with a SLAM example. Based on the students' performance, it has been proved that the combination of IoT platforms can improve the students' performance in online robotics classes.

In the future, the IoT platform will be furtherly developed, for example, using ESP8266 to increase the flexibility of the forum. The cloud can be furtherly developed with the SDK provided by the Arduino IoT cloud. The sensors and actuators connected to the IoT cloud will be increased. Besides, the IoT cloud usage is still limited due to the limitation of the account type. Hence, it is necessary to upgrade the account to enable more complicated projects and applications.

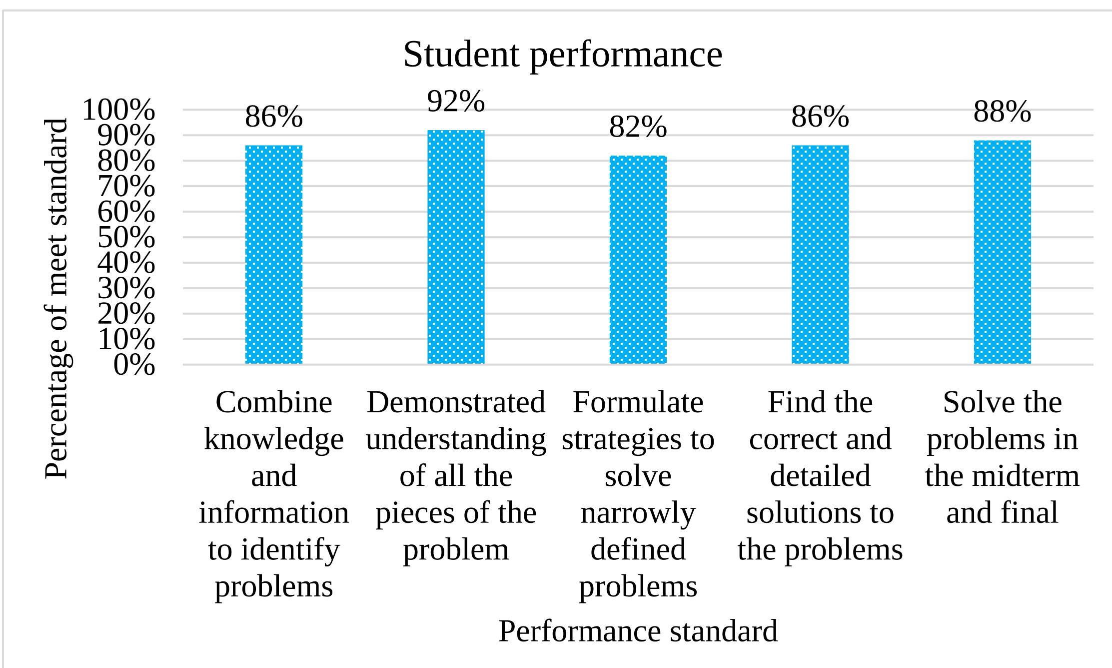


Figure 9 Student performance statistics

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