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Low Cost Autonomous Robot Cleaner using Mapping Algorithm based on Internet of Things (IoT)

R J Ong¹ and K N F Ku Azir¹

¹ School of Computer and Communication Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.

fazira@unimap.edu.my

Abstract. The objective of this study is to design and develop a low-cost Arduino autonomous robot cleaner using mapping algorithm to clean floor area of houses or offices. The idea is basically to detect any obstacles with the help of sensor and sent its output to microcontroller that will control the autonomous vacuum cleaner movement. A low-cost solution is proposed in this study by using HC-SR04 ultrasonic sensor for obstacle avoidance and control by Arduino UNO. By using an autonomous vacuum cleaner, user can turn ON the autonomous vacuum robot to clean without any help of a human operator. Wall mapping and random mapping is being applied in this study to find the effective mapping algorithm for autonomous robot cleaner. Additionally, instead of using the traditional button or switch to activate the robot, voice recognition through Google Assistant implemented in this project. Hence, this provides a more user friendly platform not only for normal user but also help visually impaired people to activate the robot.

1. Introduction

A robotic vacuum cleaner often referred to as a RoboVac, is an autonomous robotic vacuum cleaner with intelligent programming and an electromechanical control system with high stability and rapid functionality. In 2002, iRobot, an American advanced technology company, launched a robotic vacuum cleaner called Roomba. The Roomba was able to change direction when it encountered an obstacle, spot dirty spots on the floor, and detect steep debris to prevent the stairs from falling down. Additionally, an autonomous robot can also learn new knowledge, e.g. adapting new methods to perform its tasks or adapting to changing environments. The vacuum cleaner robot should have an artificial intelligence mechanism to solve the problem of cleaning the entire environment area, taking into account certain factors such as the number of turns and the length of the trajectory [1]. There have been new variations in robotic vacuum cleaners on the market since 2002. For example, the Canadian bob sweep robot vacuums cleaner, which use both mops and vacuum, or the Neato RoboticsXV-11 robot vacuum cleaner, which uses laser vision instead of conventional ultrasonic models. In 2014, Dyson announced the release of its new robotic vacuum cleaner, Dyson 360 Eye, equipped with a 360-degree camera mounted on the top of the robotic vacuum cleaner or better navigation than other brands. The company is researching robotics and AI to create better robotic vacuum cleaners in the future.

Four requirements should be met by a fully autonomous robot. First, the robot should be able to gain environmental information. For a robot to associate behaviour with a location, it must know where it is and be able to navigate from point to point. Current commercial robots navigate autonomously based on



the recognition of natural features. Second, the robot can move wholly or partially through its operating environment without human support. The advantage of a robot vacuum cleaner compared to conventional vacuum cleaners is more convenient due to its small size and can also be vacuumed by itself. Thirdly, an autonomous cleaner should be able to avoid situations which are harmful to persons, property or itself unless this is part of its design specifications.

In a nutshell, this study aims to develop an autonomous IoT-based vacuum cleaner that uses a low-cost sensor to detect any obstacle and send its output to a microcontroller that controls the robot's movement. With the standalone vacuum cleaner, the user can turn on the robot for cleaning using the remote control or voice recognition through Google Assistant on any Android phones. Once this machine is ON mode, it moves throughout the floor and efficiently covers an entire floor area. In addition, the suction power of this robot must be sufficient to collect dust, sand, human or pet hairs and some tiny rocks that are possible find out indoors. Hence, a small high-speed DC motor with 3000rpm – 10000rpm is used to rotate a fan in order to produce strong air flow from one point to another and archive vacuum function.

2. Literature Review

As robotic technologies have evolved and become imperative, people have tried to alternate human work with new mechanical advances in autonomy, especially where people can take risks at work [1]. Robots have recently emerged as household appliances as human demands increase [10]. Robotics research for household appliances is becoming more active than ever. The market for cleaning robots is expected to grow from USD 1.83 billion in 2017 to USD 4.34 billion in 2023, with CAGR (Compound Annual Growth Rate) at 16.21% between 2018 and 2023, according to semiconductor and electronics market research. Besides, The Medium & Long Term Science and Technology Planning of China (2006 to 2020) have been clearly established that the autonomous will be a primacy enhancement of technology in the future.

It is well known that cleaning a large area is an endlessly boring task that requires a lot of time and effort [3]. Currently, the cleaning robot can be divided into the vacuum cleaner, the wiping robot, etc. according to various functions [4]. The robotic vacuum cleaner was introduced earlier among all these robots. Electrolux introduced the first autonomous vacuum cleaner in 1996. The early robotic vacuum cleaners failed to avoid obstacles and low cleanliness. As a result, this cleaner cannot be successfully brought to market. The UK technology company Dyson developed a robotic vacuum called DC06 in 2001. Due to its high price, however, it was never released on the market.

Since 2002, most of the cleaning robot's research has focused on reducing development costs and developing a highly efficient cleaning robot. There are many improvements made using various sensor and path planning algorithms to archive the goal. In [4], suggested a multifunctional floor cleaner in which can mop and also vacuum the floor. In [5], has developed an independent cleaning robot to remove dust from the solar panel to maximize the solar panel's life and efficiency. In [6], proposed an autonomous robotic vacuum cleaner with 3D vector coordinates for the planning of robot routes. Then, came the idea of Smart Dustbin is to place sensors in the container to detect the level of garbage. When the garbage reaches the threshold, the status of the bin in the cloud is updated and a notification is sent to the user. The garbage that accumulates in garbage bins is collected at the time of day, even if the garbage bins are filled at any time. Therefore, the existing technology is not fruitful as the emerging technology IoT is considered. IoT components such as sensors, detectors and actuators are specifically integrated with the Intelligent System (IS) and inspection system to ensure efficient waste disposal [7].

There are many smart waste disposal projects that are described in the literature today. In [8], Waitkus has implemented a waste bin and garbage collection monitoring system to monitor the capacity of the containers, to notify the garbage trailer, and to schedule the collection of garbage based on customer preferences. In [9], the ultrasonic sensor measures the levels of waste in the dustbin and sends the data through a wireless ad hoc network to the server. In [10] used RFID tags and load cell sensor technology for waste treatment.

Most of the works above require inconvenient operations and/or costly solutions. Therefore, there is essentially to reduce the system design complexity, cost-effective and universal availability of the infrastructure [11]. The growth of information technology and the use of pervasive computing technology have occurred in many applications, including waste disposal [12]. Therefore, in [2] propose fully automated indoor waste disposal to replace conventional disposal facilities by using a mobile waste collection robot. This method is definitely a time effective process than currently used methods.

Mapping and localisation are two closely related activities in the autonomous robot cleaner. The map created can be used in a variety of applications, such as route planning, safety, cleaning, monitoring and just to name a few. Since the autonomous robot does not require any human input for its work. Therefore, the localization and navigation of the robot will be the main concern in the design. High-priced, highly functional sensors such as cameras and laser scanners provide a wealth of information about surrounding environments and are therefore widely used. Both sensor types were successfully used for the creation of raster maps. In particular, 'Kinect' sensors have recently come to the fore, as they are cheaper but provide rich 3D information. In [2] et.al presented a robot navigation system based on the Kinect device and encoder to create a 2D map. Ronny Mardiyanto's system is tested in a laboratory setting. The effective distance is between 60 and 600 cm. Their rotary encoder sensor has an average error of 5.05% on the created 2D map and an error distance of 2.23%. This 2D map creator took 1.46 seconds to create each map in one place. They are disadvantageous, however, because they do not recognize transparent objects like windows. Additionally, high information quality is difficult to develop an algorithm to manage errors and noise. It is therefore not currently possible to promote such sensors to the market. In contrast, ultrasonic sensors are practicable for obstacles avoidance and robot mapping. The HC-SR04 ultrasonic sensor with a range of up to 4 meters is a cost-effective solution for mapping robots, rather than using an expensive laser sensor or camera. In [20] suggest a new approach to creating a raster map for a mobile robot with sonar data. Experimental results and evaluations in the home environment demonstrate the validity of the methods proposed. Complete raster maps, which were created in the way suggested by the research, probably reduce the development cost. In the meantime, Atanas Dimitroy and others presented a prototype of a mobile robot suitable for mapping [16]. It uses a HC-SR04 ultrasonic sensor that is a cost-effective alternative to sensor mapping instead of a costly laser sensor. The proposed robot was tested in the university laboratory and can be improved by visualizing real-time data. In fact, sonar data may not always be accurate because of specular reflective indoor operation. In [17] explains that ultrasonic sensors and compass sensors are used in the mapping algorithm. The sensors used in this document are limited to the environment. Ultrasonic sensors can only detect the distance between 3 cm and 400 cm. Ultrasonic sensors, however, is cheaper compared to another same functionality sensor, and the raster maps created with ultrasonic sensors can most often be reduced by the raster map making methodology proposed in the development of smart robots for low cost.

The current autonomous robotic vacuum cleaner production methods can be classified into three types, namely random walk, video camera location and laser location. In [18] present a new effective global localization approach for residential environments that adapts the notion of free space density to a ceiling - mounted camera. This vacuum cleaner has a camera which captures the ceiling image and uses the lens during transportation. The use of image processing technology creates a map that allows for more efficient cleaning. On the other hand, iRobot Roomba, one of the most popular robotic vacuum cleaners, used an algorithm called iAdapt and used a laser rangefinder to scan around and under furniture, avoid stairs, and clean up very efficiently. In contrast, the random walk algorithm only avoids obstacles with the help of some sensors, and the robot itself does not recognize the work environment. The first two methods, however, are not cost efficient due to the camera module and the cost of the laser rangefinder is relatively higher. In [19] assess a cost-efficient, lightweight, low noise and low maintenance robotic system. It is said that mapping technology is absent in its design because of the cost effective problem. Data shows that the robot covers the whole area more quickly with combined motion algorithms (random walk, s shape and spiral) based on numerous tests. The test result shows that their design is fully adapted to the planning of an effective mode for performing the cleaning task in an unknown environment [20] They also suggest a dynamic return to recharge, including the relative

coordinates of the starting point and the current position. Based on the above research results, path planning is one of the keys to better cleaning robot performance. In this cyber-physical age, the autonomous cleaner can be improved by implementing Internet of Things (IoT) with a number of sensors, with some calculations, to develop a new algorithm to solve the problem in path planning or robotic navigation. For that reason, the motto of this project is to propose a highly efficient and cost-effective cleaning robot using an odometer and with the help of several sensors.

3. Method

The overall of this study is to design an autonomous vacuum cleaner that can perform well without human assistance. In the early stages of design, network connections must be established to ensure that all hardware is connected with each other. This can be done by either check the serial monitor in Arduino IDE or check the list of devices connected to the same local network. Once the system is online, the robotic vacuum cleaner can be either turn on or off by using voice command via Google assistant as shown in Figure 1. Meanwhile figure 2 shows the block diagram of the study. First and foremost, voice command has been implemented with Google Assistant to help the visually impaired. However, there is no way for Google Assistant to connect directly to NodeMCU. Therefore, Blynk and IFTTT are implemented to act as an intermediate bridge to allow the Google Assistant to control the microcontroller to perform as the ON / OFF switch of the robot. To achieve this must have some pre-setting in both IFTTT and also Blynk.

There are two algorithms can be chosen by the user which are wall follow and random walk. By selecting different algorithm, the decision to take will be different when the robotic cleaner deal with obstacle avoidance. After the device is activated, the vacuum pump will start to work. Moreover, all the sensors will begin to collect environment data and process within Arduino UNO. The robot will keep moving around the workplace until it runs out of battery or receives an OFF command from the user.

Figure 3 shows that the subroutine will be called when the random walk algorithm is chosen by the user. First and foremost, the robot will check is the obstacle right in front of the robot. If yes, then the robot will stop for a while in order for the DC motor to take action. The robot is programmed to reverse a bit and following by turn left (reverse the left wheel and forward the right wheel). If no, then the robot will check either the obstacle is at left or at right and apply the same algorithm but rotate in the opposite direction. While there is no obstacle, the robot will keep moving forward.

Figure 4 shows that the subroutine will be called when the wall follow algorithm is chosen by the user. First and foremost, the robot will check is the obstacle right in front of the robot or the robot reaching a corner. If yes, then the robot will stop for a while in order for the DC motor to take action. The robot is programmed to reverse a bit and following by turn right (reverse the right wheel and forward the left wheel). If no, then the robot will check is the robot reaching an edge or not. If yes, the robot will stop for a while and follow by slightly forward and turn left. Furthermore, the ultrasonic sensor at left will always make sure the robot moves along the wall with constant speed.

The backbone of this project is to connect the sensor to the microcontroller to control the actuator to perform certain tasks under certain conditions. Ultrasonic sensor used to avoid obstacles in this project. For instances, the robot is programmed to take action when there is an obstacle 10cm in front of the ultrasonic sensor. The red colour board at the top left in figure 5 is L298N H- bridge motor driver. There are two DC motor connected to this board and power supply by two 3.7V 18650 3000mAh rechargeable li-ion battery. There are two EN pins which are ENA and ENB have to connect to PWM pins from Arduino UNO in order to control the speed of rotation.

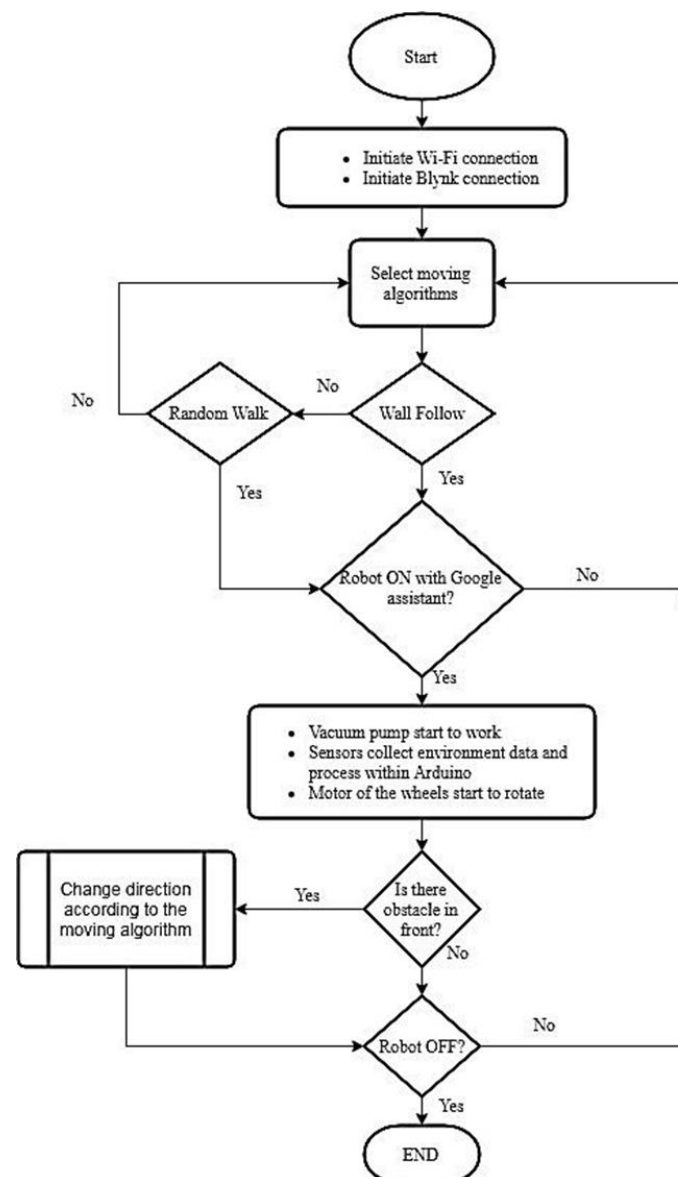


Figure 1. Flow chart of the study.

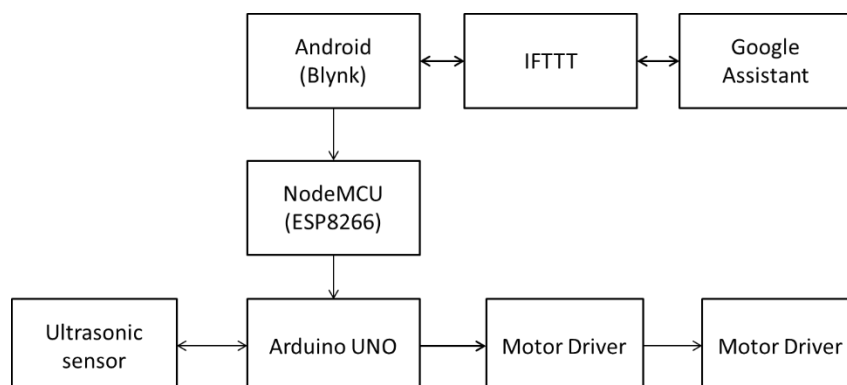
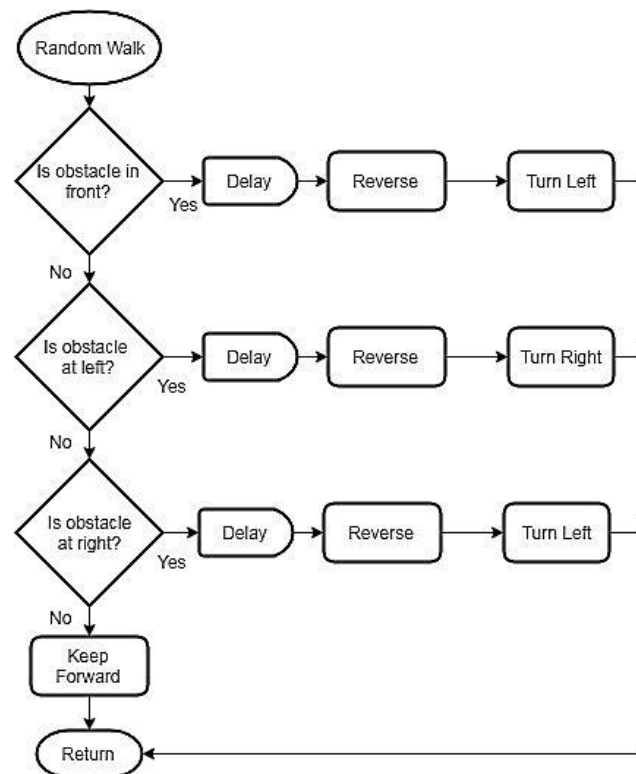
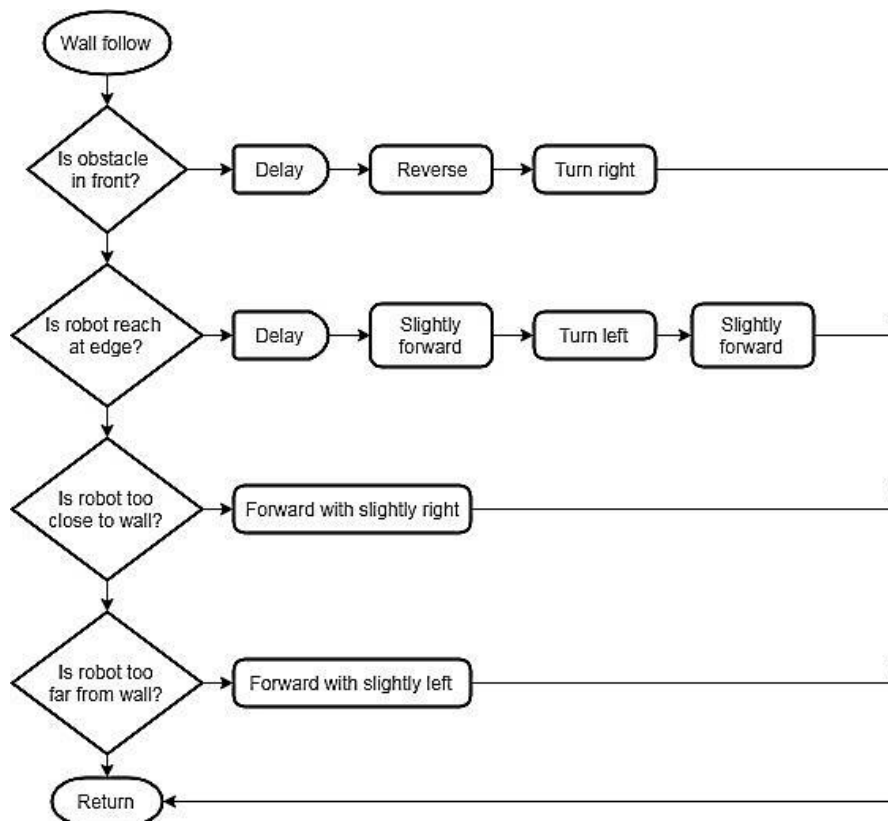


Figure 2. Block diagram of the study.

**Figure 3.** Flow chart of random walk.**Figure 4.** Flow chart of follow algorithm.

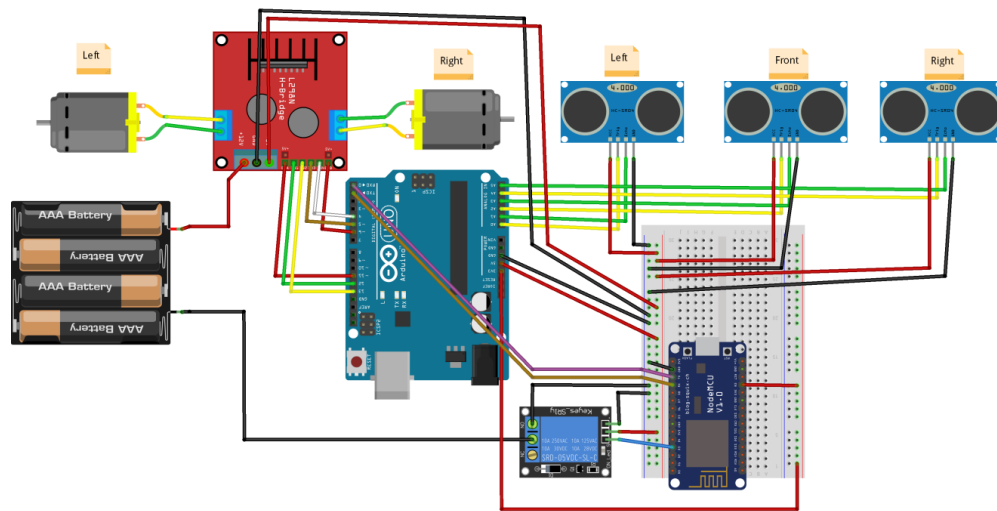


Figure 5. Circuit diagram of the study.

4. Results and Analysis

The testing of the autonomous robot cleaner was done by implementing both of the mapping algorithm to the autonomous robot cleaner. The movement of a robot can be divided into several simple movements as in Table 1. The truth table is generated based on L298N H-bridge motor driver after a few times testing programmed by Arduino UNO. The combinations of these movements are successfully achieved both wall follow and random walk algorithm.

Table 1. Truth table of motor driver

Action	Left Motor	Right Motor	ENA	ENB	IN1	IN2	IN3	IN4
Forward	On	On	Const	Const	1	0	1	0
Reverse	On	On	Const	Const	0	1	0	1
Turn Left	Off	On	0	Const	0	1	1	0
Turn Right	On	Off	Const	0	1	0	0	1
Stop	Off	Off	0	0	0	0	0	0

There are four situations considered during design. Figure 6 shows that the four situations that happened during testing and the robot effectively overcome the problem by itself without human assist. First, the robot is doing well and moving along the wall with a gap of 4cm with the wall. The robot is capable to adjust itself automatically when either going too far from the wall or too close to the wall. Second, the robot escapes from a corner and continue its path to the right intelligently. Third, the robot is doing well when come to the wall edge so that it can close back to the path and continue its task.

For a random walk algorithm, the robot proved that it is smart enough to avoid obstacle before hitting on it. In addition, there are not only static obstacles but also dynamic obstacles such as people walk through the path of the robot as shown in figure 7. Thus, the robot will stop for a while and take action before hitting on such dynamic obstacles.

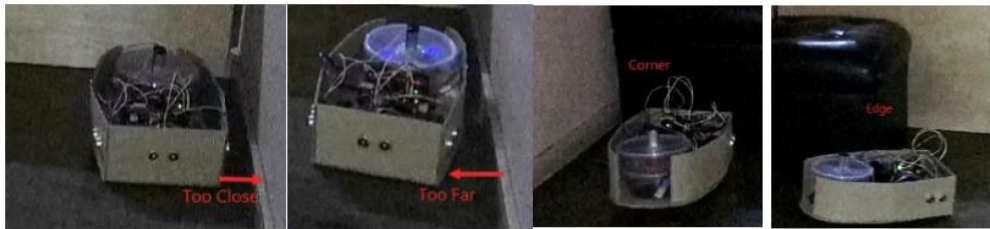


Figure 6. Four situations to overcome by wall follow mapping algorithm.



Figure 7. Random walk mapping algorithm and obstacles avoidance.

Figure 8 shows the screenshot of Google Assistant and Blynk when using voice command. As mentioned earlier in the previous chapter, there are three optional commands in order to activate the robot. When Google Assistant receives a valid command such as “turn off” in the figure 8 then it will reply “Yes sir turning off vacuum cleaner” as an acknowledgement receive command successfully.

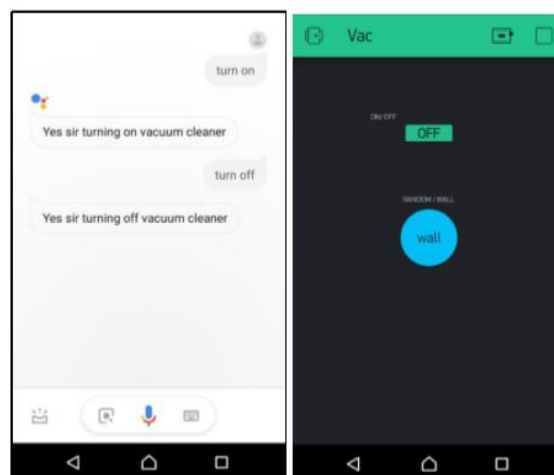


Figure 8. Google Assistant and Blynk for Voice command.

5. Conclusion

The objective of this project was to plan and deployment a cheap and smart Internet of Things (IoT) based autonomous vacuum cleaner that could work in an unknown environment. Although the robot has a minimum number of sensors, this goal has been met by deployed algorithms. Moreover, voice command fulfilled successfully and the output is same as expected. Google Assistant are available on every android smart phone, hence, this can be an ease for development and also provide a more user

friendly platform not only for normal user but also visually impaired people. Walk follow and random walk algorithm implemented successfully which that all the situation considered can be overcome by the robot automatically. Even so, robot development provides endless possibilities to improve the performance and to overcome more situations for unknown environment. Future robot development therefore includes mapping technology, automatic charging algorithm and automatic dirt disposal.

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