IOT-enabled Vacuum Cleaner using Arduino

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***Abstract*— The objective of this study is to develop an IOT-enabled automatic vacuum cleaner using Arduino that can be controlled by using smartphone. This vacuum robot is capable of cleaning the entire floor of homes, rooms, and offices. In this project, Arduino Mega is used as the microcontroller. Additionally, this robot is equipped with HC-SR04 ultrasonic sensors that can detect walls, obstacles, and cliffs. When there are obstacles in front of the robot, its movement will be modified according to the Arduino Mega algorithm. Using these sensors, a path planning algorithm was developed to enable the robot to move and efficiently clean the entire room. With the addition of a wireless ESP8266 receiver module, the robot can be controlled wirelessly via a smartphone running the Blynk application. The user can choose between two modes of automatic cleaning, or they can control it manually. Therefore, this provides a wireless control even when the user is not at home so long as they are connected to wi-fi, and it can also be controlled automatically without the assistance of others.**

Keywords - vacuum cleaner, IOT, Arduino

I. Introduction

Nowadays, more work can be done automatically by using robot and wireless connection. Manual work such as floor cleaning is considered by some people as tedious, boring, and repetitive task that had to be done every single day at home and office. The autonomous home cleaning concept has shown to be an effective technique to help physically impaired persons and save time [1]. IoT-based vacuum cleaners are designed to provide users with a more convenient and efficient way to clean their homes. The vacuum cleaner uses sensors to identify and avoid obstructions, avoid stairs, and alter its cleaning pattern in accordance with the structure of the room. This can help to save time and effort while providing a more thorough cleaning experience.

Various robotic vacuum cleaners are available in the market but most of them are overpriced where the price is higher than RM1500 [2]. Since the technology is quite new in the market, the very high-quality automatic vacuum cleaner is very expensive to certain households. Not all household can afford the expensive automatic vacuum cleaner [3]. Cheap automatic vacuum cleaners are also available, but they are lacks of features that is essential for a good automatic vacuum cleaner such as avoid obstacles and following cleaning path.

Many advancements in autonomous vacuum technology have been made. One method for user and robot communication in a system is the Bluetooth module. They chose this strategy, according to Badri [4], because they underline that Bluetooth can be used for a floor cleaning system, is appropriate for people of all ages, and is very practical in hospitals, homes, and businesses. This method is flawed because the user and machine connection must be cut off when utilising a Bluetooth module. According to the research in [5], Bluetooth connections can be made across a distance of up to 10 metres.

Another approach to connect the vacuum and user is by using wi-fi. Saraf [6] claims that because a robotic vacuum cleaner system may be controlled remotely, it was created with wi-fi. By a straight click at a special created website for the vacuum cleaner, the user can operate the vacuum cleaner, remotely. This method is the most flexible since it uses wi-fi, which connects to the internet and allows for the operation of numerous systems over large distances. In this study, wi-fi could improve the usage of the vacuum cleaner by enabling smartphone-based remote control of the robot.

In order to built a more efficient automated vacuum, Kazi [7] and Ong [8], designed the vacuum robot with algorithm for path planning of the Robot. The algorithm can help the robot to avoid obstacles and walls. They also propose multiple mode of movement for the robot to clean the flat floor. This is all possible because they used Ultrasonic sensor and IR sensor. As a result, the path planning is good for this vacuum cleaner robot which have better efficient cleaning path and save battery power.

There are studies which combined hardware and software in Arduino project. According to Kuo [9], they used Arduino Uno as the platform and they also used hardware like motor-driver (L298N), analog distance sensor and HC-06 Bluetooth module. As for the software, the most common that been used to write programming is Arduino IDE. Programming in Arduino IDE is used to give command to the hardware inside the robot to function properly. They also use Bluetooth module so that the robot can be controlled manually by Android smartphone. This design can be improved by changing Bluetooth module to Wi-fi. According to Shubham in [10], Wi-fi module work on 802.11n/ac layer which offers better range and data transfer rates. It also easy to connect with other devices since all smartphones already have Wi-fi.

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Detecting obstacles and walls are essential in every automatic vacuum cleaner robot. There should be sensors that can detect walls to prevent collision from occurs. Manya et al [11] have used ultrasonic sensor to measure the distance between the robot and obstacles in front. This approach is very good since the range of ultrasonic sensor used (HC-SR04) can provide 2 cm – 400 cm non-contact measurement. The design that they use can be improve if we include three ultrasonic sensors on the robot so it can measure the walls or obstacle from right and left side to. This can provide a smooth transition for the robot to make an adjustment in their movement or to detect if they are about to crash by obstacles left and right. According to Asafa in [12], they use four Ultrasonic sensors in their project. It kind of going overboard with sensor count since we think that use three sensors is already enough to cover front, left and right of the robot.

Another strategy is to develop their vacuum while using infrared sensors to identify walls and other obstructions [13]–[15]. Although ultrasonic sensors operate on the basis of sound waves, infrared sensor operates on the basis of light waves. The drawback of infrared sensors is that using them in sunlight causes a lot of interference. As a result, ultrasonic sensors are more trustworthy than infrared ones.

Taher [16] created the automatic robot sweeper and the analysis the efficiency of sweeping based on the various speed movement of the robot. The result suggests that using lower speed will give good result in cleaning process. Since the robot is a moving object, the reading of ultrasonic sensor can be affected by the speed of wind from the robot movement. Research from Radu[17], shows that as the speed of wind parallel to ultrasonic sensor increase, the relative error of measured distance also increase.

The goal of this study is to design and create an IOT-enabled vacuum system that can effectively clean an entire room in a home or office by sucking up dust and dirt from the floor. In order to avoid walls and obstructions, it is also equipped with sensors and has its own automated path movement algorithms. To improve the robot's cleaning effectiveness, the robot's movement speed will also be studied. The Arduino Mega serves as the robot's microcontroller and be used to control its operation. Moreover, this robot can be controlled via a smartphone and wi-fi. This will allow users to control the robot remotely via a mobile app.

II. METHODOLOGY

A few phases were involved in designing and developing the IOT-enabled vacuum cleaner robot. First phase is to test the components whether they can function properly. Next phase is designing the robot and setting up the sensor to the Arduino Mega. The programming was done after finish designing the robot to test the sensors. The final phase is implementation of IOT into the system.

A. *The Block Diagram*

Fig. 1 shows the block diagram of this system. All the components that were used in this project are explained in this section. The hardware that was used in this project are Arduino Mega, 3 Ultrasonic sensor, Motor Driver L298N, DC motor with gear, 12V DC motor, 2 7.4V as power supply and ESP8266 ESP-01. The microcontroller, Arduino Mega got the distance reading from ultrasonic sensor, HC-SR04. Ultrasonic sensors continuously operated when the robot was turn ON. There were three sensors that were placed in the middle, right and left on the body of the robot. Each sensor was used to detect any walls or obstacles from front, right and left side of the robot.

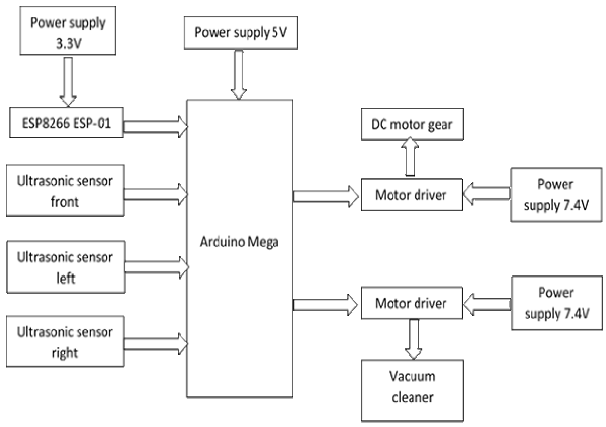

Fig. 1. Block diagram of IOT-enabled vacuum cleaner robot

When the robot is switched ON, both the motor in vacuum cleaner and DC motor gear are turned on. The information will be processed by microcontroller which is Arduino Mega and then it will send the signal to control the motor. User may choose what the movement mode for the robot through Blynk application in their smartphone. Once the mode has been chosen, the robot will move according to algorithm that has been set through each mode. The DC motor gear will be drive by motor driver (L293D).

This robot is connected to the internet and can be control by any smartphone that has been connected with this robot. Fig. 2 shows the block diagram of connection between wi-fi module ESP8266-01 and the smartphone. It allows user to control the robot wirelessly.

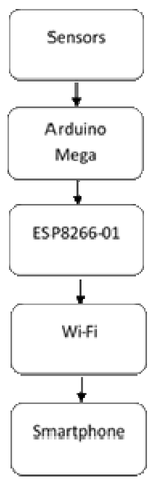

Fig. 2. Mobile Phone Connection's Block Diagram

B. *List of sensors used*

This IOT-enabled vacuum cleaner robot was implemented by using Arduino Mega with 3 ultrasonic sensors (HC-SR04) as shown in Fig. 3. These sensors were placed at the three sides of the robot which is at the front, left and right side of the robot. Ultrasonic sensor works based on the principle of reflected sound waves and are used to measure distance. This type of sensor offers excellent non-contact range detection (2– 400 cm) with high accuracy.

Fig. 3. Ultrasonic sensor HC-SR04

C. *Software Development*

The programming software that was used are Arduino IDE. Programming was important to control the hardware in the system. This programming process was used to setup the input and output pin of components, control the sensor, and implement the movement of the robot. The interface between Blynk and Arduino Mega were also include in the programming process.

D. *Flowchart of the System*

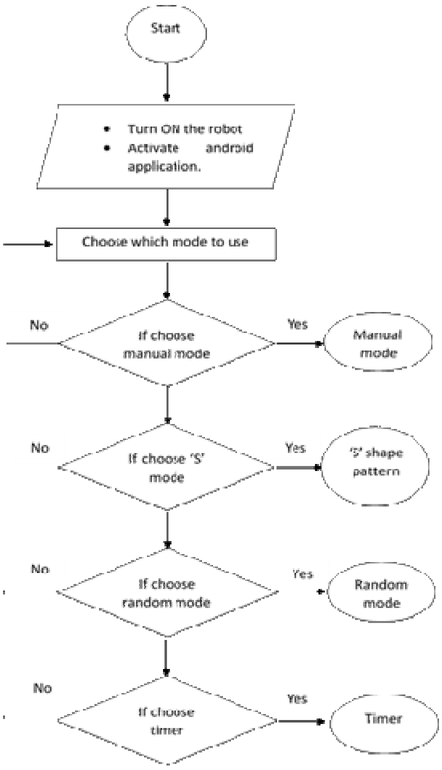

Fig. 4. Flowchart to choose which mode

The vacuum cleaner can be run under 3 modes which Manual mode, Random mode and 'S' shape pattern, as shown in Fig. 4. User can also set a timer to make the robot move according to set of time. By using smartphone, user can connect with the robot through application call Blynk. Vacuum motor, motor wheels and sensor will activate when the robot is On and then the user can choose what mode that they want to use to control the movement of the robot.

1) *Manual mode*

Manual mode allows the user to control the robot's movement. They can make the robot to move in any direction even the place that hard to reach like tight space. They can control manually through their smartphone. All this movement will be controlled wirelessly through Blynk app in the smartphone.

2) *Random mode*

Fig. 5 shows the flowchart of movement for Random mode. A random movement does not require specific pattern of movement based on robot wish. The robot moves forward direction until sensor sense obstacle or barrier, it will check the other side of sensor. If sensor sense obstacle or barrier on the right side, it will back a little bit and turn left for some random time before continuing move forward. If sensor sense obstacle or barrier on the left side, it will back a little bit and turn right for some random time before continuing move forward. All of this movement will be made automatically. User can stop the operation by pressing switch off button on the smartphone.

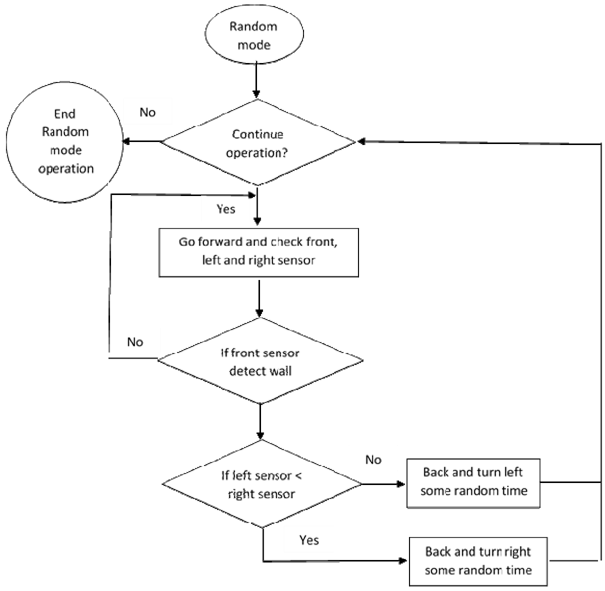

Fig. 5. Flowchart of Random mode

3) *'S' shape pattern*

Fig. 6 shows the flowchart of movement for 'S' shape pattern. By using 'S' shape pattern, it can cover most of the area that robot needs to clean. When the ultrasonic sensors detect obstacle or walls in front of the robot, it will be turning 90 degrees of its direction, go forward a little bit and then turn 90 degrees more to make U-turn. According to the flowchart in Figure 5, the robot will set count to 1 to move forward with sensor detect any obstacle or collision in front. If the sensors detect wall or obstacle, it will go backward a little bit and check the count. If the count is odd, it will make a right U-turn while if the count is not odd, it will make a left U-turn. User can stop the operation by pressing switching off button on the smartphone.

By using timer, user can set a set of time for the robot to perform automatic movement. When the timer has been set, the robot will perform movement of 'S' shape pattern.

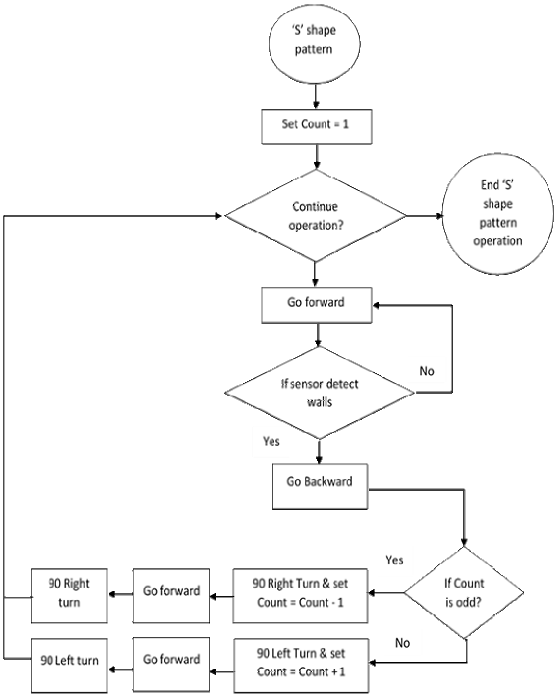

Fig. 6. Flowchart of 'S' shape pattern

Fig. 7 shows the prototype of the vacuum cleaner robot using Arduino Mega as the microcontroller which could be control using handphone via wi-fi.

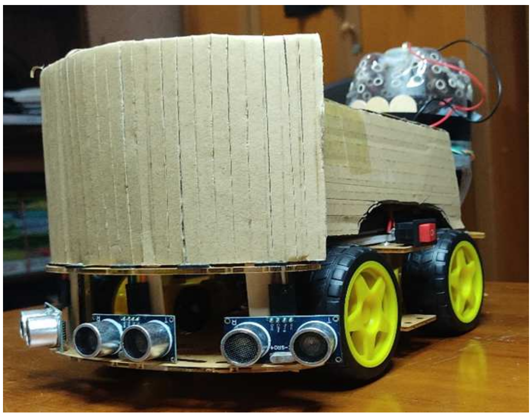
Fig. 7. Prototype of the vacuum cleaner robot

III. RESULT AND DISCUSSION

A. *Experiment data*

The experiment data is to identify on sensor accuracy and consistency on the distance between walls/obstacles and the vacuum robot. There are three ultrasonic sensors used in this vacuum robot to detect the walls in front, on left side and on right side. Then, a data has been collected based on the most efficient speed for the robot to move.

Ultrasonic sensor has been set to take action when the data receive to it is equal or less than 20cm. In this case, it will receive the distance between wall and the robot and send the signal for vacuum robot to stop its movement if the distance between wall and sensor is equal or less than 20cm. Since the robot have three ultrasonic sensors, each of the sensor will detect the wall based on assigned position.

The speed of the robot is based on Pulse-width modulation (PWM). PWM is a method of reducing the average power delivered by an electrical signal, by effectively chopping it up into discrete parts. The speed of the robot is the manipulation variable, and the average error is the response variable. The experiment was done for five times for each speed of the robot.

1) *Accuracy and consistency of Ultrasonic sensor*

Table 1 shows the result based on the distance from the wall to sensor in front of the robot. It shows the relationship between the Speed PWM of the robot and the percentage average error of distance between wall and the front sensor. The speed PWM of 135 has the lowest percentage average error compared to the speed PWM of 255 which has the highest percentage of average error. The result shows that the lower the speed of the robot, the lower the percentage of average error. Standard deviation errors were also calculated and shown in the same table.

TABLE 1. THE ACCURACY OF ULTRASONIC SENSOR ON THE FRONT SIDE OF THE VACUUM ROBOT

Speed PWM	**Average error of distance between wall and sensor (cm)**	**Percentage of average error**	**Sample of standard deviation of error**
135	9.1	46%	0.2236
159	11.1	56%	0.5477
183	11.7	59%	0.7483
207	12.3	62%	1.095
231	12.4	62%	1.084
255	12.7	64%	1.4405

The result is similar to result done by Tarulescu [17]. It stated that as the wind speed parallel to ultrasonic sensor increase, the relative error of reading also increase. When the speed PWM of the robot is increase, it also will increase the wind speed on the ultrasonic sensor, and it can influence the reading of ultrasonic sensor. The lower the standard deviation means that the error of the speed are more consistent. Lowest standard deviation error was shown by lower speed of the vaccum robot.

TABLE 2. THE ACCURACY OF ULTRASONIC SENSOR ON THE LEFT SIDE OF THE VACUUM ROBOT

Speed PWM	**Average error of distance between wall and sensor (cm)**	**Percentage average error**	**Sample of standard deviation of error**
135	7.2	36%	0.2236
159	8.5	43%	0.5477
183	9.9	50%	0.7483
207	11.7	59%	1.095
231	11.7	59%	1.084
255	11.9	60%	1.4405

Table 2 shows the result based on the distance from the wall to sensor on the left side of the robot. The pattern of the result is more or less the same as result from ultrasonic sensor on the front. The result shows that the lower the speed of the robot, the lower the percentage average error of distance from the wall to sensor. The speed of 135 has lower standard deviation compared to other speed. The conclusion can be made from the table above are the higher the speed of the robot, the higher the standard deviation of error.

Table 3 shows the result based on the distance from the wall to sensor on the right side of the robot. The pattern of the result is more or less the same as result from ultrasonic sensor on the front and the left side of the robot. The result shows that the lower the speed of the robot, the lower the percentage average error of distance from the wall to sensor. The speed of 135 has lower standard deviation compared to other speed. The conclusion can be made from the table above are the higher the speed of the robot, the higher the standard deviation error.

TABLE 3. THE ACCURACY OF ULTRASONIC SENSOR ON THE RIGHT SIDE OF THE VACUUM ROBOT

Speed PWM	Average error of distance between wall and sensor (cm)	Sample of standard deviation of error	Percentage average error
135	8	0	40%
159	8.7	0.6708	44%
183	10.3	1.2042	52%
207	11.7	1.3964	59%
231	12.9	1.6355	65%
255	12.8	1.7536	64%

2) *Efficiency of vacuum speed*

It is important to optimize the efficiency of vacuum process. There are many factors that can affect the efficiency of vacuum process such as the suction power of the vacuum or the size of vacuum nozzle of vacuum. Here, the area size of cleaning process was fixed at 1.8 m (w) x 2.2m (l). Pieces of small papers were spreaded out across the test area. Each speed was set for 5 minutes and the results are shown in the table below.

TABLE 3. THE EFFICIENCY OF THE VACUUM ROBOT BASED ON NUMBER OF PIECES COLLECTED AT DIFFERENT SPEED

Speed PWM	Number of paper pieces collected
135	92
159	76
183	68
207	53
231	44
255	38

From Table 3, it shows that the lower speed has the highest number of pieces of rubbish collected. Speed of 135 has collected with 92 pieces while the highest speed which is 255 only managed to collect 38 pieces. The difference is quite big when compared the lowest speed and the highest speed. Therefore, the lowest movement speed of the robot provided the best efficiency of cleaning process.

B. *Mobile Interface*

Blynk application was used to communicate between smartphone and the robot via wi-fi module ESP8266-01. Blynk application is highly customizable to meet the requirement mode for this project.

Fig. 8 illustrates Blynk interface of the IOT-enabled vacuum cleaner robot using Smartphone. The application shows the button for control mode of the robot. There is ‘S’ move and Random move. There also button to turn On or Off motor for vacuum cleaner. The Blynk application has switch for timer. It allows the user to set time to execute automatic floor cleaning. Finally, the Blynk application also have a joystick that allow the user to control the robot movement manually.

Fig. 8. Blynk interface

IV. CONCLUSION

IOT-enabled vaccum cleaner robot using Arduino Mega was successfully implemented. It is proven that the robot system can vacuum dust and dirt on the floor and clean whole room inside houses or offices efficiently. It was equipped with three ultrasonic sensors that can help to achieve its desired movement. To improve accuracy and consistency of movement upon receiving the data from the ultrasonic sensor, the vacuum robot's movement speed has been optimized. The vacuum robot's speed has also been adjusted to increase cleaning effectiveness. One DC motor and a propeller were used to build the vacuum cleaner chamber, which enabled the robot to collect dust and small trash from the floor. Smartphone and robot communication is made possible by the wi-fi module ESP8266-01. The Blynk software on a user's smartphone allows for communication with the robot.

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