Random Walk Application for Autonomous Vacuum Cleaner Robot

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Abstract — **The authors of this project adapted Random Walk Algorithm for domestic cleaning applications specifically vacuuming floors. It is the method of direction employed to the automated vacuum cleaner in order to clean the floor. The robotic vacuum was mainly built on aluminum casing. It used a car vacuum cleaner and a rotating brush underneath the unit to sweep the floor as it passes over it. Two stepper motors are used to accurately drive the robotic vacuum around a room. One free-spinning chair wheel is located at the center of the robot to keep it balanced. The robot is programmed to sense the direction of a collision with an obstacle using contact sensors. It avoids cliffs and edges or any sort of drop-off using two infrared sensors and phototransistors on the front underside of the unit. The sensors constantly send out infrared signals, and the robotic vacuum expects them to immediately bounce back. If all of a sudden the signal gets lost it means that it has approached a cliff and so it heads to another direction. A home base was also designed for auto recharge to compensate for the battery life. While navigating around the room the robotic vacuum constantly checks its battery status and when the battery power is low it will automatically look for the home base and will re-dock to charge its battery. It accomplishes this using the infrared receiver on its front bumper. When the battery power gets low, the vacuum starts looking for the infrared signal emitted by the home base. Once it found the home base location, the robot follows the direction of the signal and attaches itself to the charger. It will head back out to resume cleaning once it is fully recharged.**

I. Introduction

Random walk, as explained in [1], is a random procedure comprising of an array of distinct steps of circumscribed length. Mathematical properties of Random Walks vary greatly depending on the magnitude in which the walk occurs. A random walk is a discrete domain stochastic process. It can be viewed as a domain summation of a Bernoulli process. It is used to model shares prices and other factors. Empirical studies found some deviations from this theoretical model especially in short term and long term correlations. It also describes the statistical properties of genetic drift in population genetics. These are just but some of the many applications of the Random Walk Algorithm.

Another probable application of the Random Walk algorithm is adapting it into a robotic vacuum cleaner. Since cleaning the floor is a tedious and time-consuming process, avoiding this would be a relief to most people; especially those with hectic schedules have very little time to spare for it. Students who live in dormitories and grueling time of reviewing and studying would ignore it for other more pressing priorities. Elderly people who do not have the strength or stamina to do house works would rather hire a maid to do it. However, since it is quite costly to do so, would exert themselves just to maintain a clean abode. This vacuum cleaner can be used to ease the lives of such people. This robot vacuum cleaner can also be used in the industry, nightly office cleaning almost always includes vacuuming of the floor which takes efforts away from other cleanups or becomes an entire person's task. A robot vacuum cleaner can definitely help by automating this task. It can vacuum a floor space on its own without the help of anyone. And the cost of using one has a fixed price rather than paying an escalating wages of workers. The device has to be simple enough for any adult to use. An intensive research and concept integration on Random Walk Algorithm have given this project a ray of light. It is definitely the best algorithm option for the robotic vacuum cleaner since cost-effectiveness is the top priority of the authors of this project study.

II. Methodology

The robotic vacuum is composed of several components designed to meet the specifications of the project. It consists of the following circuits; contact switches and IR sensors, digital random noise source, battery monitor, IR transmitter and receiver, squarewave generator, delay timer, power supply, voltage regulator, and current limiter. Others essential parts of the robotic vacuum are the z8Mulator microcontroller which is the brain of the system, vacuum, geared DC motor for the brush, stepper motor and driver, battery and the circuit for the battery charger on the homebase station.

A. Design Considerations

Every factor that might affect the project in any aspect was all taken into consideration. The preferences of all the components were based on practicality and its importance and usability in the whole system. The application of Random Walk Algorithm into the robotic vacuum was simulated using software that does random walks to construe its efficiency. The battery was based on its ampere rating, durability and low cost that would yet give an acceptable performance. The basis of choosing the stepper motor was its high torque and a compatible motor driver to be able to drive a heavy load. The casing was designed to be lightweight so as to lessen motor load.

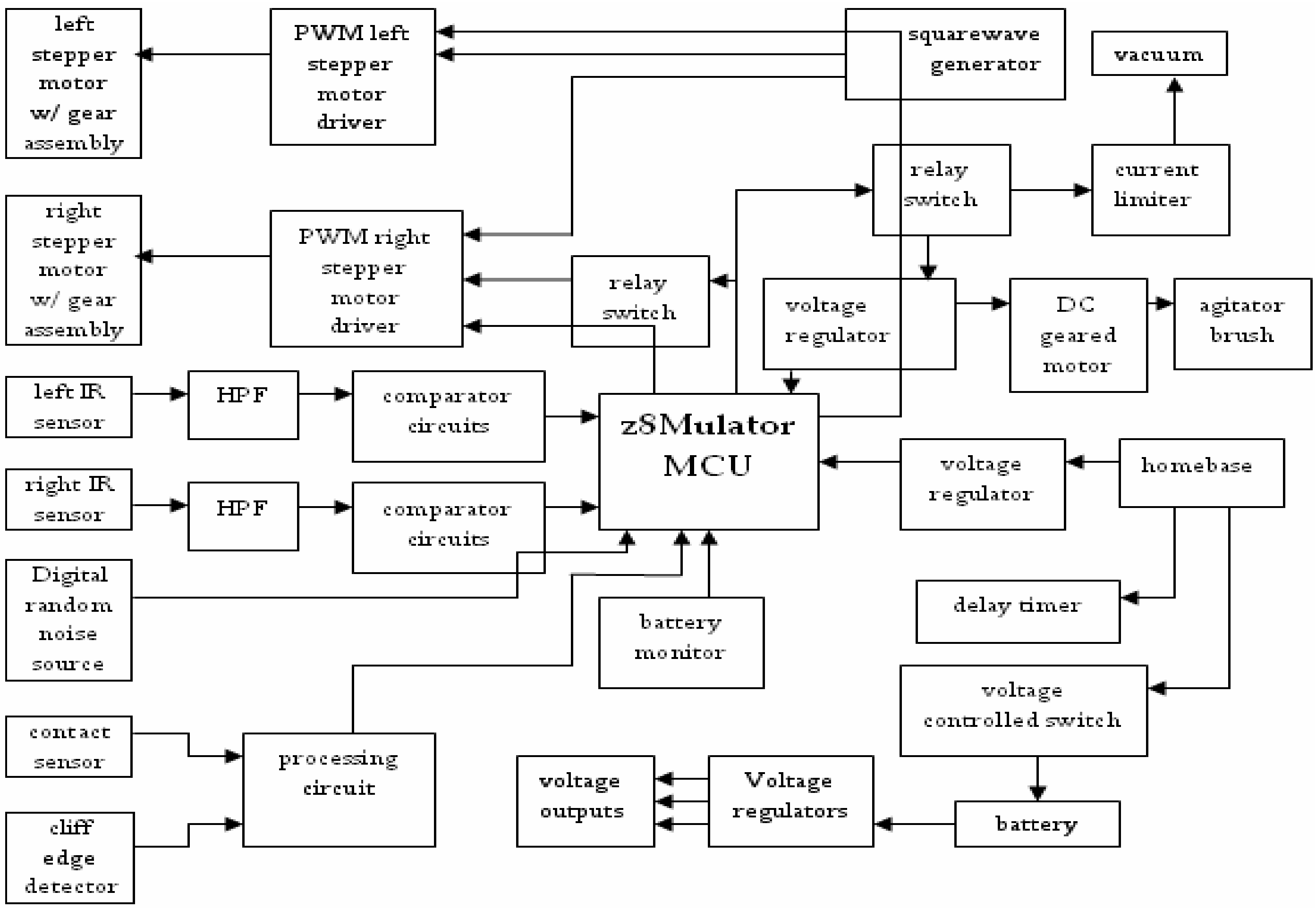

Fig. 1. Block diagram of the whole system

B. Implementation

The whole system of this project comprises generally hardware with a little of microprocessor programming that uses Zilog software.

1) Main Driving System: The driving systems of the robotic vacuum are the stepper motor with gear assembly and the PWM stepping motor driver. The stepper motor with gears shown in Fig. 2 was used in this project. It has a more precise and repeatable position control. It is ideal to the robotic vacuum application because of its power and durability which can drive a load at up to 10kg. So it has enough power to drive the whole system around the room.

Fig. 2. Stepper motor with gear assembly

2) Square Wave Generator: The Square Wave Generator Circuit shown in Fig. 3 is used to generate pulses to be inputted to the stepping motor driver since it is the main driving signal of the stepping motor system. Each pulse input rotates the motor by one full step. The clock input rate sets the rotational speed rpm of the motor. Higher frequency will run the motor faster.

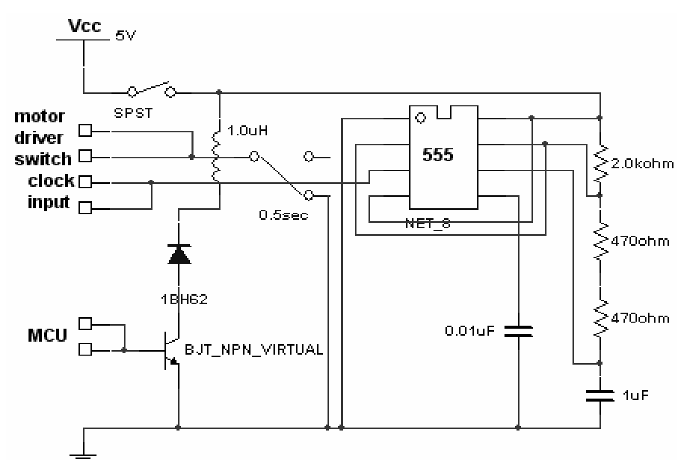

Fig. 3. Square wave generator circuit

3) PWM Stepping Motor Driver: The PWM Stepping Motor Driver Circuit in Fig. 4 is the best match for the stepper motor because it eliminates the major disadvantage of a stepper motor which is the power loss as the motor is revved up. The PWM circuitry keeps the current drawn by the motor constant at all speed. PWM technique assures efficient power utilization. With this kind of motor driver, you get the maximum power your motor can deliver even at different speeds.

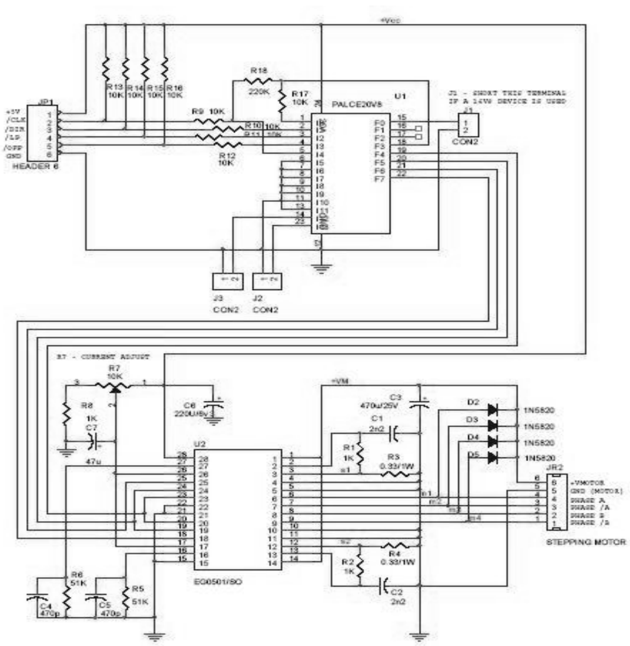

Fig. 4. PWM stepping motor driver circuit

4) Delay Timer: The circuit in Fig. 5 was designed to time the battery charging of the robotic vacuum. The circuit delay time was based on the estimated charging time of the lead-acid battery which is three hours. The value of the capacitor or resistor varies depending on the desired delay time.

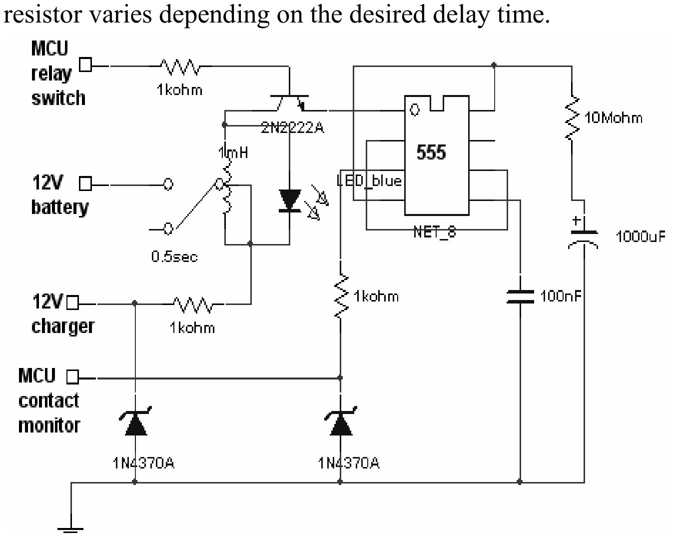

Fig. 5. Delay timer

5) Infrared Receiver: The IR receiver is a significant part of the system because it is the reference of the microcontroller that would give signal if the IR signal is received from the charging station. The first part of the circuit is a phototransistor that will serve as the receiving component of the system. In this project WPT440F from Alexan was used. When the phototransistor receives a pulsating signal, it will give varying voltage output on the collector which is proportional to the pulsed IR signal received. The pulsed output voltage is then fed to simple high pass filter. A high pass filter is important so as to receive the exact frequency transmitted by the homebase. This is achieved by C1 which is shown in the schematic diagram shown in Fig. 6. The transmitted signal is a pulsed signal so that it would not be affected by other IR sources or by indirect sunlight. Then the signal is fed to a series of comparator circuits and last, a voltage regulator that gives 5 volts output to the MCU that means the signal transmitted by the homebase is received. An LED is also used for the troubleshooting purposes so that it is easily seen if the system is working without using a Voltmeter. Two receiver circuits are used that serves as left and right signal that will be the navigating reference for the system to reach the homebase.

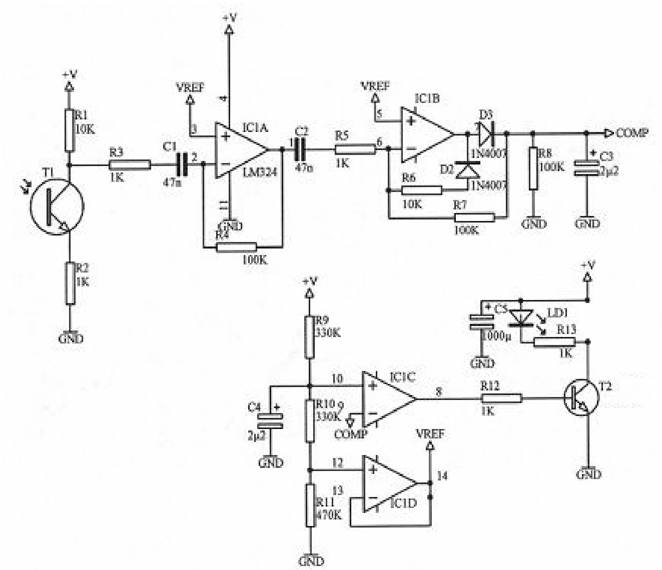

Fig. 6. Schematic diagram of IR receiver

6) 12Volts Lead Acid Battery Meter: The circuit shown in Fig. 7 is used to monitor the voltage level of the lead acid battery in the robotic vacuum. This circuit used a quad voltage comparator as a bar graph meter to indicate the charge level of the 12V lead acid battery. It also used 4 LEDs to determine the charge level of the battery. Each LED represents an approximate 25% change in the charge condition of the battery. The battery is considered fully charged when all three green LEDS are illuminated. When the red LED starts to blink, this means that the battery has only 25% remaining charge. This circuit will then send a signal to the microcontroller which tells the robot that it needs to recharge.

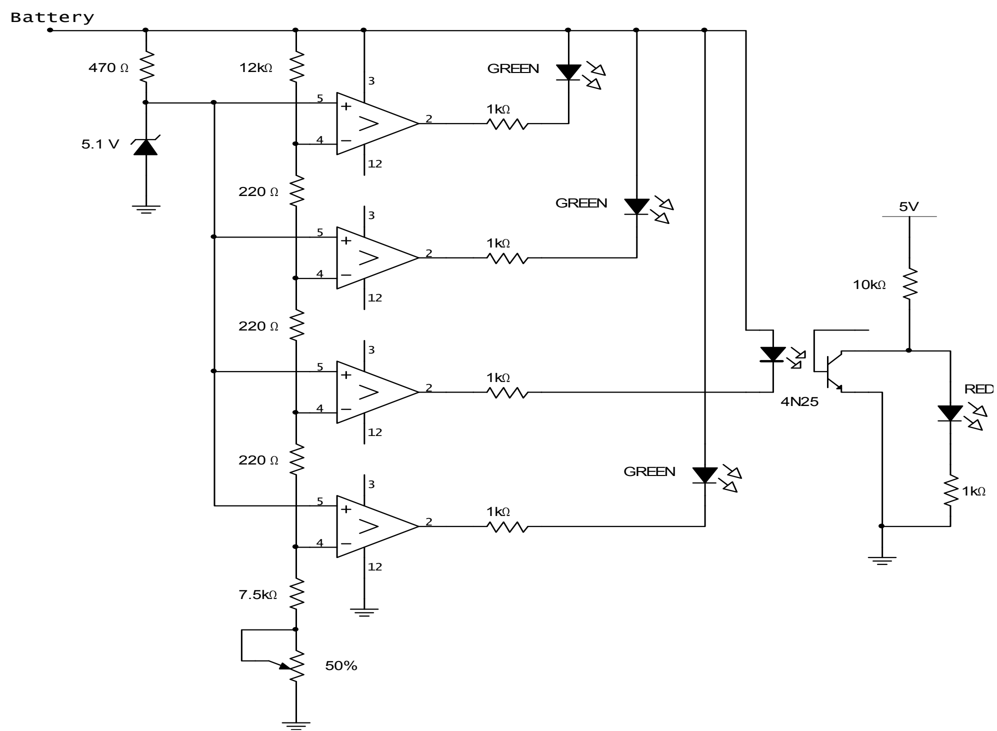

Fig. 7. Battery meter schematic diagram

7) Digital Noise Source: The circuit shown in Fig. 8 is the circuit which generates digital random numbers. These random numbers are fed to the microcontroller to determine the angle of rotation by the robot whenever it hits an obstacle or detects a cliff. It also determines whether the robot will rotate left or right.

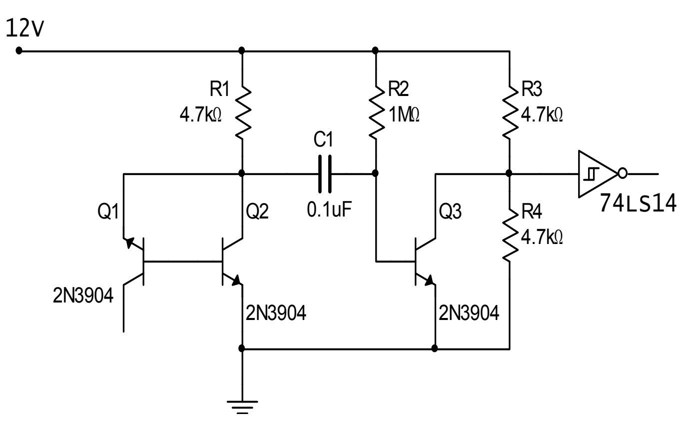

Fig. 8. Digital random noise source

8) Power Supply: The main power supply of the robot is illustrated in Figure 5-11. It has 4 different voltage level outputs which are 5V, 6V, 9V, and 12V. It uses 4 different voltage regulator ICs for the desired regulated output voltage. These are 7805, 7806, 7809, and 7812.

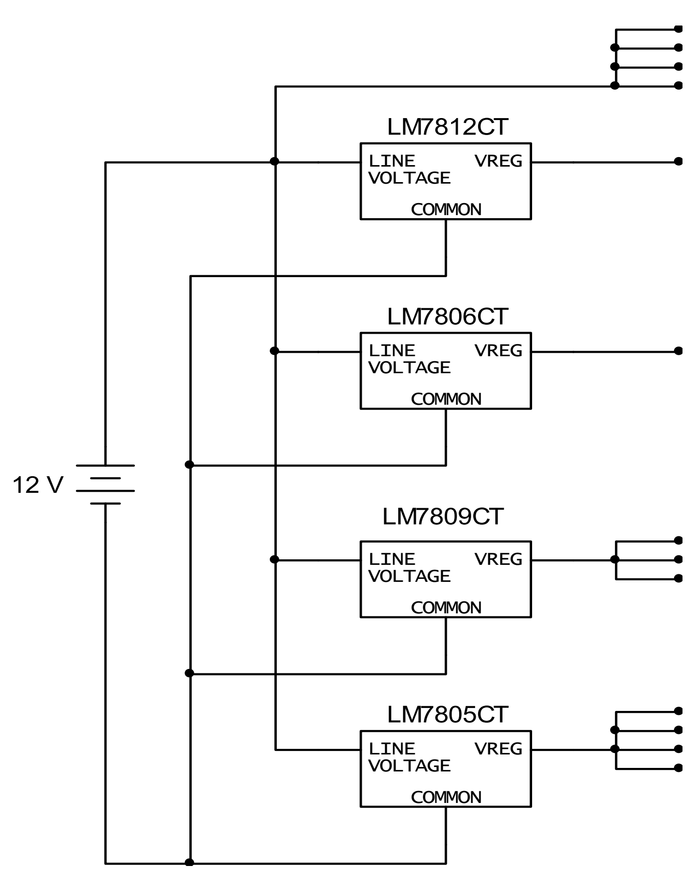

Fig. 9. Power Supply Circuit

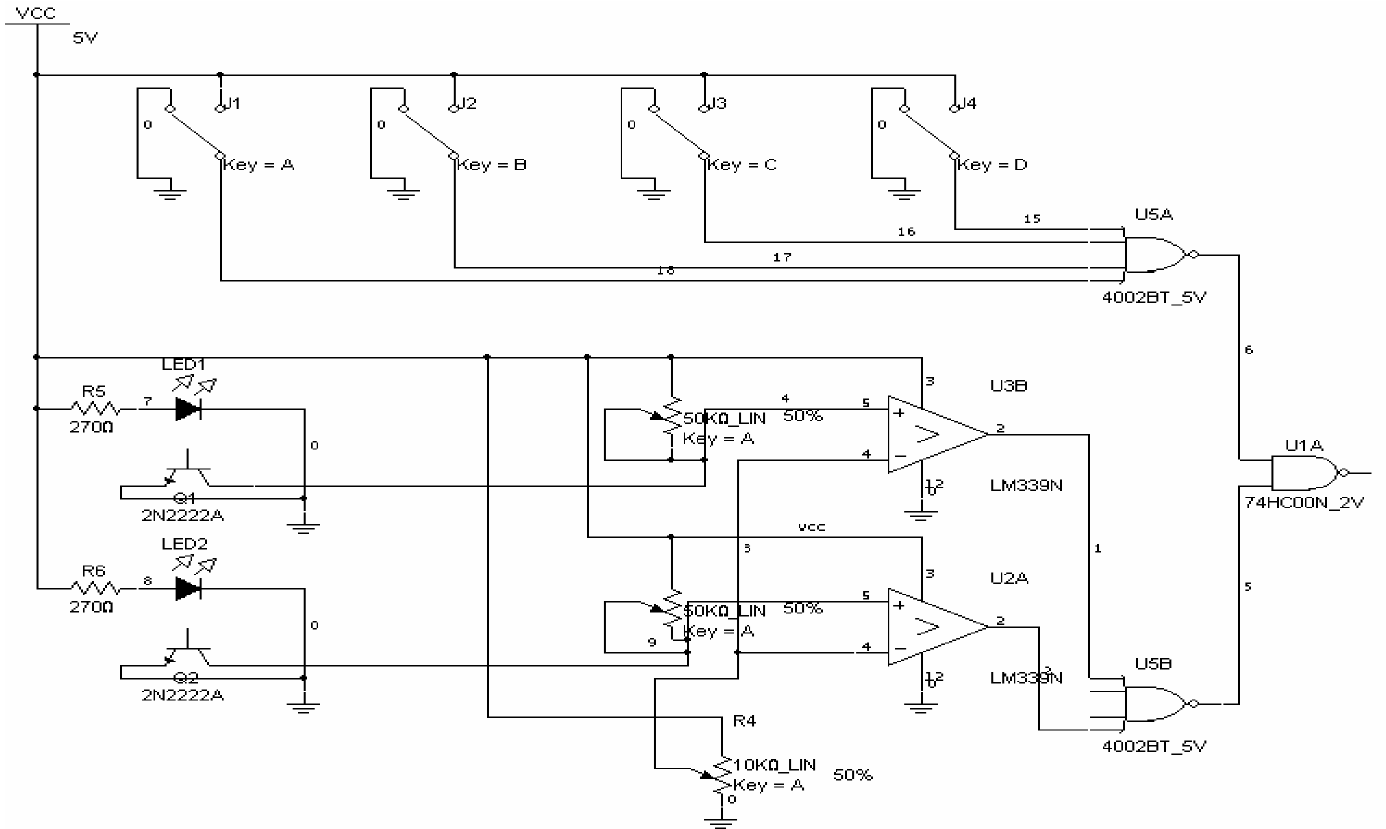

Fig. 10. Obstacle and cliff detection circuit

9) Obstacle & Cliff Sensors: This part of the system is the combined circuits of the contact switch for the obstacles and the IR sensors for the cliff detection. Contact switches with a supply of 5 volts are used to detect an obstacle or a wall. As it bumps or hit an obstacle it sends signal to the microprocessor. When the signal is high (5 volts), it tells the microprocessor to move backward then generate random signal as the basis of the motors to head to another direction.

The contact switch has a good performance tact switch rating which is 50mA 12V DC with strict quality control and high efficient electronic component in compact size.

The cliff detection circuit is a combination of a phototransistor and infrared emitter to detect cliff or edges that keeps the whole cleaner from falling. The infrared emitter sends infrared signal directly to the floor. As it bounces from the floor, the phototransistor receives signal signifying that cleaner is in the right path. Until the phototransistor no longer receives infrared signal, that is the time the output signal of phototransistor goes high (ideally 3-5 volts). Then comparator sends signal telling the microprocessor that an edge is reach. The microprocessor sends to move backward then generate random signal to head to another direction.

The output of Cliff Detection System and Contact Switch is combined through logic gates in order to have one output that is connected to the processor as shown in Fig. 10. Whenever of this two is high, it will send a high signal to the microprocessor. The logic gates used are NOR and NAND gates. These are the available logic gates in the market as the designing started. Combining these gates is just the same as of ordinary OR gate. There was no available OR gate with 6-8 input when the designing began. The circuit would be simpler if only one logic is used.

10) Current Limiter: Fig. 11 is also known as the constant current source because this circuit delivers a constant electric current. This circuit was used in the robotic vacuum to limit the current being absorb by the vacuum. Thus, it enables the robot to conserve battery.

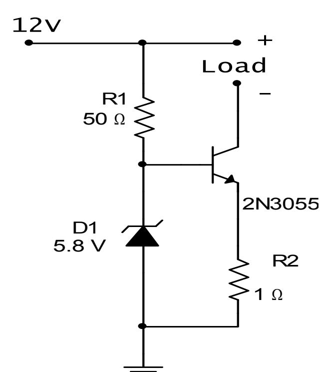

Fig. 11. Current limiter circuit

11) Battery: There are two Lead-acid batteries connected in parallel to supply the whole system of the project. This is to prolong the battery life of the robotic vacuum. Lead acid battery is the oldest type of rechargeable battery. Despite having the second lowest energy-to-weight ratio (next to the nickel-iron battery) and a correspondingly low energy-to-volume ratio, their ability to supply high surge currents means that the cells maintain a relatively large power-to-weight ratio. This, along with its low cost, makes this battery ideal for use in the project as this battery can provide the high current required by the whole system.

12) Vacuum Cleaner: This project uses a Black & Decker AV1260 Dustbuster Auto Vac. Its versatility and high suction power results to effective floor cleaning. It has double action filtration system designed to perform better and last longer. With the help of current limiter circuit, the vacuum performs with the required current to pick up dirt from the floor. It helps the battery to supply longer.

13) Homebase Lead Acid Battery Charger: The schematic diagram for the lead acid battery charger is illustrated in Fig. 12. It is a simple dc power supply cascaded to a transistor voltage regulator that uses a 220V to 15V 6A transformer and employs full wave rectification. A voltage regulator was used to regulate the charging voltage so as not to be too high for the rated voltage of the battery.

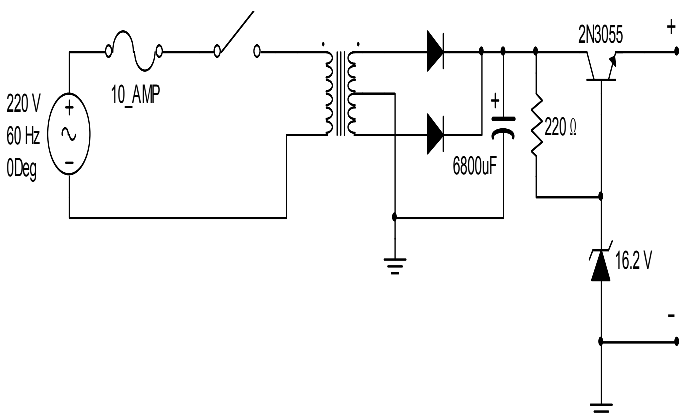

Fig. 12. Lead acid battery charger

14) Homebase Infrared Transmitter: Fig. 13 shows the block diagram of the IR transmitter circuit used in the homebase. The homebase infrared transmitter is a simple circuit that uses a transistorized astable Multivibrator that is connected to a transistor that will vary the light emitted by the IR LED connected to its collector. The astable Multivibrator is designed to give a pulsed output with 9.5 KHz frequency. Its output is designed to feed the base of a transistor with varying voltage with the above computed frequency. The base voltage will be indirectly proportional to the collector voltage that will cause the LED to emit pulsed IR light.

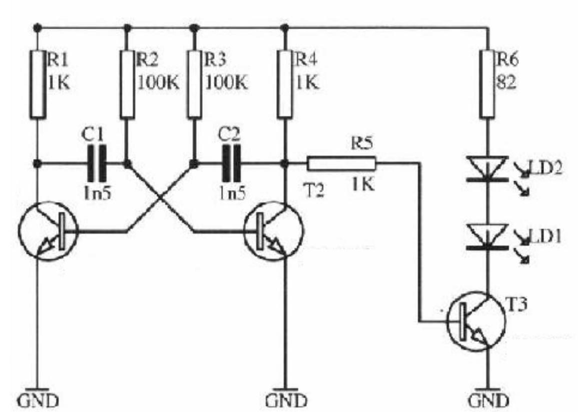

Fig. 13. IR transmitter

15) Casing: The materials for the design of casing are mainly composed of aluminum. This is in consideration of weight of the whole project. Aluminum is a lightweight material that best suit the design of the casing.

There was an original design of the case of this project. It was a rounded shape. It has an advantage of getting dirt in corners as well as its maneuvers on the floor but due to its complexity for fabrication the main design has been changed. The rounded shape can not easily be made for the unavailability of machines to shape the curves. Nobody has accepted the design. The designers have decided to redesign the casing in accordance with accessibility of the materials to be used. These are materials that can easily be shaped like the counter trim that really helps the maker to create the design in a given time. The solid wire is used for recharging because of its flexibility (adjustable) and its good conductance.

Fig. 14. The robotic vacuum

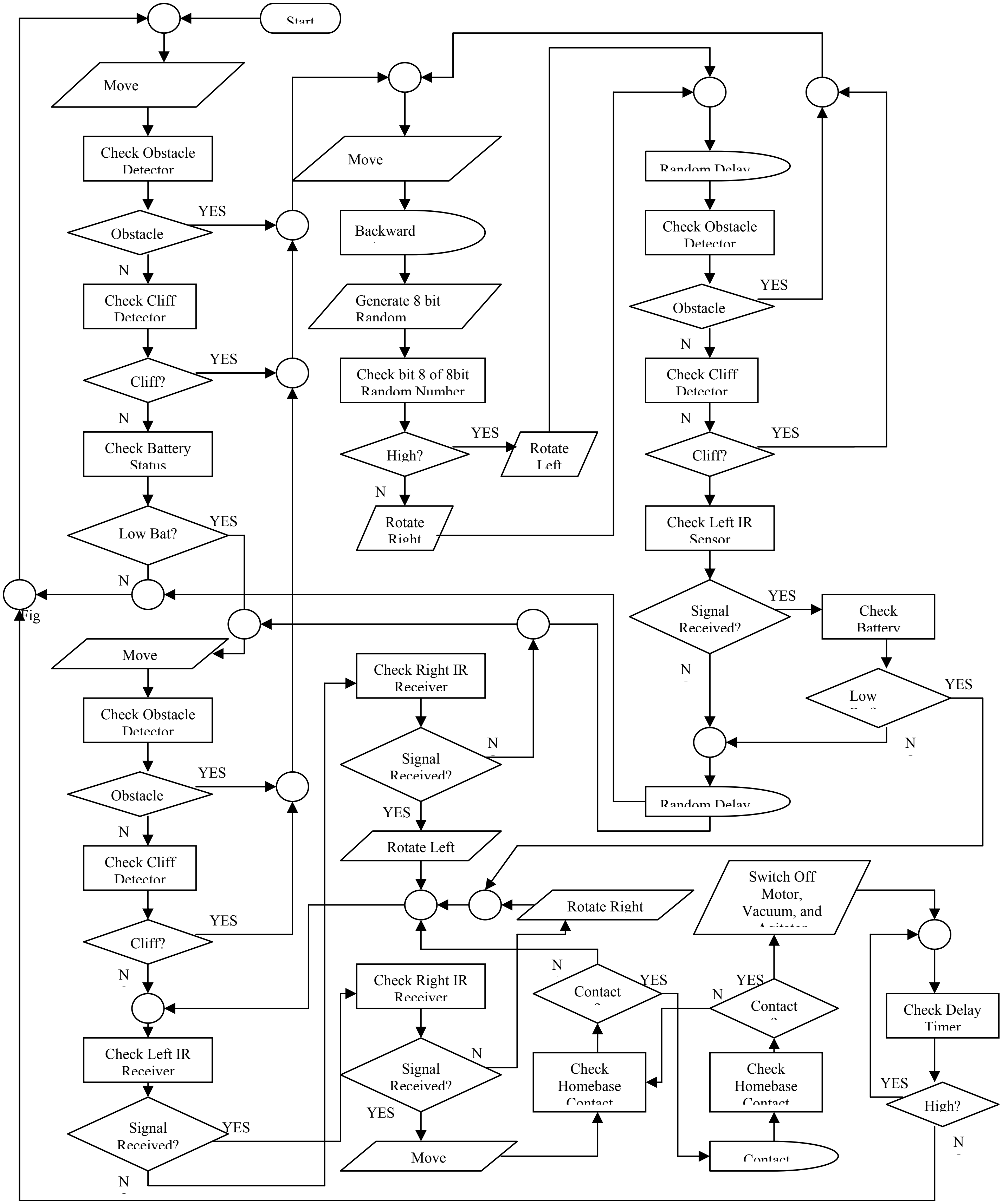

Fig. 15. Program’s flowchart

C. *Testing*

The purpose of testing the robotic vacuum was to gather data in order to know the average cleaning time of the robotic vacuum in a 20 square meter floor area. An uninterrupted power supply was used to supply the robotic vacuum during the testing and salt was used as dirt to be cleaned. The timing of the robotic vacuum starts eventually when its power is turned on. We let it run around the 20 square meter room until such time that approximately 90% of the room was cleaned by the robotic vacuum. During the testing we assumed that there is a homebase and every 30 minutes, as it bumps into an obstacle and rotates 180 degrees where it can detect the IR transmitter from the homebase, we direct the robotic vacuum to the position of the assumed homebase and then it will head to where the homebase is located. In reality, the battery life of the robotic vacuum is good for only 45 minutes that is the reason we set the 30-minute scheme to allot the remaining 15 minutes in searching for the homebase location in case the robotic vacuum was not able to immediately locate the IR transmitter.

The 90 percent approximation that was cleaned by the robotic vacuum was done through comparison with a 2 square meter floor. The floor area where the robotic vacuum cleaner was tested was entirely spread with salt. Then, we keenly observed the lines the robotic vacuum crossed as it vacuums the floor. Until such time that it has navigated almost everywhere around the area. But there are still small areas left unclean, we approximated by combining these left area if it would be less than 10 percent of the whole area by comparing it to the 2 square meter area. If the resulting area left is very minimal and would be less than 10 percent of the whole area cleaned, we then conclude that the automated vacuum cleaner had cleaned 90 percent of the floor.

III. RESULTS AND ANALYSIS

The application of Random Walk Algorithm in a robotic vacuum was first simulated using software to know how efficient the algorithm is. The simulation had somehow proven it. Though each circuit that comprises the whole system seems to be simple, yet putting it together as one creates complexity. Generally all the circuits have somehow performed according to their design although some circuits had different output compared to the expected computed values.

The cliff detector has a minor problem wherein its sensitivity is inconsistent. It varies depending on the floor color so it should be calibrated in accordance with the floor color. Another drawback of the sensor is that it is affected by direct sunlight. We also encounter a problem from the stepper motor, in the beginning it was not able to drive the whole system but we found out eventually that gears are needed to be able to drive the whole package. The square wave generator also generates very high frequency that makes the rotation of the motor quite fast which is inappropriate for the design since it is more favorable if its movement is slow to effectively vacuum the dirt.

Among those encountered circuits problems we came across with two major problems that we considered in our project. First was the vacuum cleaner that we originally bought can not suck up dirt if not closely placed to the location of the dirt. We had to buy another vacuum with better features and specifications hence we were able to solve it. But since vacuum cleaner has a very high power consumption a battery with high ampere rating is needed to compensate for its consumption, this lead us to the major drawback of the project which is the battery span. The first design of the robotic vacuum has a very short battery life. In fact its battery life lasted for only 10 minutes, not enough time to clean the whole area. The choice of replacing the lead acid battery into lithium ion battery would be very impractical since it would cost thousands to buy a lithium ion with high ampere rating. To prolong the battery life we decided to add another lead acid battery in parallel connection with the other to increase its ampere rating. This somehow made the life of the battery longer than before. But still the time is not yet enough to be able to clean the whole area. So to compensate for the battery life an autorecharge was added to the system

A. *Test Results*

After the final design with the new circuits installed for the autorecharge, the current consumptions were measured so was the navigation time of the robotic vacuum cleaner. This is due to the additional circuits installed that would complement the robotic vacuum cleaner's design. Table I shows the current consumption of each major subsystem and the overall consumption of the whole system. The total time that the robot navigates has also improved. From 10 minutes, we were able to make the robot navigate for a maximum time of 45 minutes. Table II summarizes the time each algorithm takes to clean.

TABLE I
CURRENT CONSUMPTIONS

System Description	Current
Vacuum Cleaner and Dirt Agitator System	4.5A
Circuits with Stepper Motor	0.86A
Total Current Consumption	5.36A

TABLE II
ALGORITHM BATTERY TIME

Navigation Algorithm	Time
Random Navigation	30 min
IR Signal Search for Recharging	15 min
Total Battery Life	45 min

Table III shows the time comparison for each trial. The tests that we have conducted had acceptable results since all the data that we were able to gather has minimal time differences. The calculation for the average cleaning time is in (1).

TABLE III
TIME MEASUREMENTS IN TESTING OF THE PROTOTYPE

Test	Time
Trial 1	1hr: 23min/1.38hr
Trial 2	1hr: 32min/1.53hr
Trial 3	1hr: 40min/1.66hr
Trial 4	1hr: 37min/1.62hr
Trial 5	1hr: 33min/1.55hr

$$mean = \frac{1.38 + 1.53 + 1.66 + 1.62 + 1.55}{5} \quad (1)$$

$$mean = 1.55hr$$

B. Analysis and Interpretation

The computed mean time for the five trials is 1 hour and 32 minutes which means that it is the average time of the robotic vacuum cleaner to clean approximately 90 percent of a 4m x 5m area. Using the maximum battery life of 45 minutes and a charging time of 3 hours the study implies that it needs two recharge procedures to be able to clean approximately 90 percent of the floor area. With the charging time and total battery life, the robotic vacuum cleaner cleans the area in 7 hours and 30 minutes with the battery initially fully charged.

III. CONCLUSION AND RECOMMENDATIONS

All of the objectives of this study were met accordingly. The prototype was incorporated with the Random Walk Algorithm with the use of the Zilog microcontroller as the main controller of the whole system. It was able to vacuum small solid particles such as salt, sugar and the like. However, the authors of the study had encountered some difficulties with the Zilog µC and found out that it was not easy to use. Some commands did not work as expected which made it difficult to debug the algorithm.

The project study ascertained the theory that the Random Walk Algorithm was able to cover 90% of a certain area specifically $20m^2$. With the acquired result, 1 hr: 32 minutes, the robot successfully covered 90 percent of the floor.

Although the objectives were met, the study was not perfect and needs further improvement. One area that should be improved is the cliff detector. The system adapted in the prototype was flawed. The circuit was dependent on the reflectivity of the floor wherein it had difficulty detecting the difference between a dark colored floor and a cliff. It was also affected by direct sunlight because the sensor used was a phototransistor and the fact that sunlight is a source of IR, it has direct effect on the sensor. Because of these problems, it is recommended to use ultrasonic sensor so as not to encounter the same problems.

The battery played an important role in the prototype because the total cleaning time of the robot is dependent on it. The suction power of the vacuum and the battery life are inversely proportional. Increasing the suction power decreases the battery life. That was the trade off in this design. To compensate for this problem, a better battery type is recommended. Lithium-ion cobalt is strongly recommended since it has 5 times the capacity of a lead acid battery. With Lithium-ion cobalt battery, it will have more suction power and a longer battery life. Moreover, charging will be faster which is only 1.5 hrs. A better case design is also recommended to maximize suction power and enable the prototype to collect larger dirt such as crumpled paper and the like. Smaller case with shorter height is recommended to enable the robot to clean underneath tables, chairs and corners.

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BIBLIOGRAPHY

[1] William Feller, An Introduction to probability Theory and its Applications, vol. 1, Chapter 3, 1968.