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Designing and Optimization of An Autonomous Vacuum Floor Cleaning Robot

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***Abstract*—With the advent of Automation, Robots are seeing widespread use in Industrial manufacturing, Automated retail, Surveillance and Security. In the same breath, home automation has also evoked interest among different user groups. Currently, high-priced floor cleaning robots produced industrially are beyond the purchasing capability of normal households in third world countries. In this paper, we have introduced an initiative to build a cost-effective floor cleaner robot. Using a vacuum cleaning system, we designed and implemented a cleaning robot. The paper has described how an operational floor cleaning robot prototype has been developed along with the techniques of the indoor mapping and positioning system. Raspberry Pi and Arduino Mega were used in unison as the processor of the robot. This robot can map and clean a certain area of a building floor autonomously. One novel contribution of this work is the introduction of a GPS module to the Raspberry Pi so that the robot can be aware of its location and move in the right direction. Human assistance is only required for waste disposal and maintenance. Our future goal is to add a reliable autonomous waste disposal feature in the prototype.**

***Index Terms*—Cleaning Robot, Floor Cleaner, LIDAR, Wall Follow, IR Proximity Sensor, Raspberry Pi 3, GPS, Vacuum Cleaning, Obstacle Avoidance, Magnetic direction Sensor.**

I. Introduction

The last few decades have experienced significant influx of robotic appliances used in household activities. Floor cleaning is one of the most taxing and time consuming chores. And this is where automation comes into play, taking over jobs where manual effort is necessary. Rising level of pollution,increased level of consumption goods followed by humongous amounts of garbage have necessitated a meticulous cleaning of our surroundings in a quotidian manner. Floor cleaning Robot is the best possible technical solution to do this and thus makes life more easier[1].

A vacuum cleaner is an electro-mechanical appliance commonly used for cleaning floors, furniture, rugs and carpets by suction .Nowadays, consumers are paying appreciable attention to Robotic Vacuum Cleaners (RVC). The market size had already grown to 350 million dollars in 2005[2]. While in 2014, The global family vacuum cleaners market size was valued at USD 11200 Million[3]. A new market report published by Transparency Market Research claims that the global household vacuum cleaners market is expected to reach a value of US$18,936.9 Mn by 2026[4]. A high demand for fitting yet affordable dust cleaning appliance is driving this market growth. A fully automated cleaner bot can save both time and money.

Since the late 1990s, better developed cleaners equipped with limited suction power have been developed. Then the footstep of iRobots Roomba vacuum cleaner in 2002 has been followed by many other companies launching similar products. In early 2008, Samsung made the first robotic vacuum cleaner which maps its environment and systematically navigates in a home[5]. Several other products have followed since then including LGs RoboKing or Neato Robotics laser-equipped vacuum robot. Currently some prominent brands cleaning robots are irobot, Neato and bobsweep. Tech-giants like Hitachi, Siemens and Cyberworks are producing robotic cleaning systems which are fairly costly[6]. While less renowned start-ups like iRobot, dyson, eufy have got success by producing cheaper cleaning robots[7].

So, an initiative is taken to develop a low cost cleaning robot which is affordable to common households. Total cost of building our cleaning bot is $655. Our prototype robot can clean dust and small size waste objects efficiently owing to its smart dust cleaning algorithm which is something new in the cleaning bot technology. When the battery is down, it can automatically go to the nearest charging hub and charge itself up. A mapping and tracking system is available in this prototype robot to increase its efficiency. It creates a map of the designated area and generates the cleaning path according to the map. Finally, the area is cleaned with the help of indoor positioning system. Also it has a system to detect and avoid real-time objects.

The paper is arranged as follows: A brief description of the prototype is given in section II, System assembling process and Software integration are described in section III and IV respectively. In section V details of the genetic algorithm are discussed, while the conclusion comes in section VI.

II. Description of System

The primary purpose of the cleaner robot is to clean the floor dirt from the different places of a building. To clean the floor, some mechanism or process is required. Here in the prototype, a vacuum cleaning process is introduced for cleaning.

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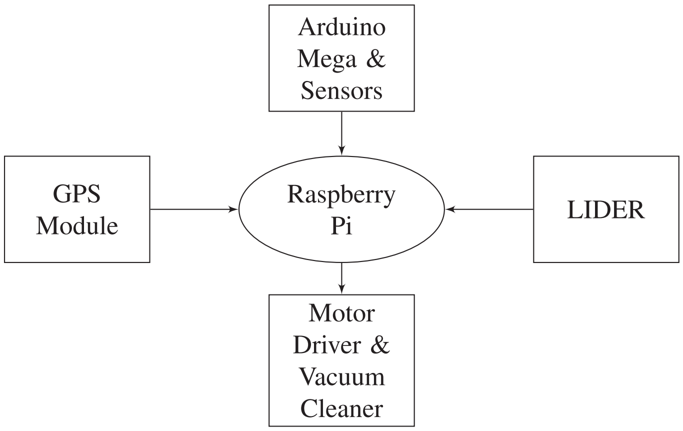

Fig. 1: Block Diagram of the System

The custom made vacuum cleaner was constructed with a DC motor. This motor is mounted inside the body of the vacuum cleaner to make it easy to suck the dirt up. The mounted DC motor rotates an omni-directional fan that creates a vacuum and intakes the dirt with air inside.

The mechanical structure is constructed by using an acrylic glass which is actually Polymethyl methacrylate also known as Plexi-glass. The plexi-glass is cut according to the requirement of the structure. The structure is made by making a shaped like a circle. There are three decks one over another so that the components can be mounted on each of the decks. In the lower part of the body, the suction cap is mounted below.

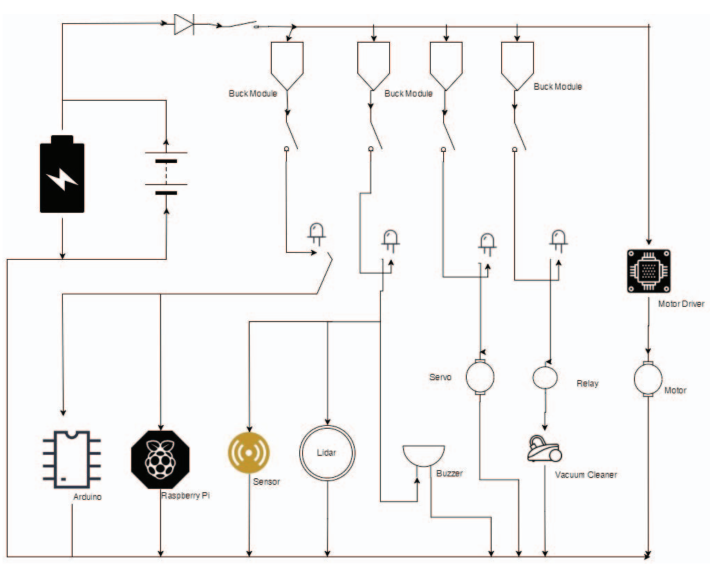

Fig. 2: Schematic Diagram of Electrical Unit.

The cleaning system includes another two DC geared motors, two rotating brush, sprockets for moving chain from geared motor to rotating brush and aluminum sheet for supporting vacuum cleaner. This DC geared motor has been fitted on the acrylic sheet with metallic element holder and sprockets put in with it which have been fitted into the shaft of the motor. All components are installed on the lower part of the acrylic sheet. Operation of the rotating brush is to move the dirt to the center position of the bot. A suction pipe from the vacuum cleaner is placed at the center so that it can easily suck up the dirt. The vacuum cleaner is mounted in the middle of the main body. The sensors are mounted in front of the main body so that any kind of obstacle can easily detect. The robot looks like a cylinder having 7 inches in radius and 1.5 feet in height.

There are two packs of ten cells of 3.7V and 3600 mAh Li-ion batteries where 10 cells are connected in series making 37V and two packs are connected in parallel to increase the current rating. By connecting these two pack batteries in parallel, we got 7200mAh=7.2Ah. The input power rating is (7.2Ah*37V = 266.4Wh). The power consumption of vacuum cleaner is 30W. We used four DC gear motors. The power consumption of these motors is 72W. So, the total power consumption of the cleaning Robot is 102W. The input power rating is (7.2Ah*37V) 266.4Wh. When the battery is fully charged, this robot can clean continuously for 3.7hours on battery.

There is an autonomous process for auto recharge of the battery namely 'auto docking and charging process' which is necessary to make the robot auto rechargeable. It can be line back for the charger if it runs low on battery power, even if its in a distant room. And most importantly, while cleaning floor if the battery runs out, it stores the current location in the memory, goes to the docking position and recharge and then remembers the last location and start from where it left off. This solves a significant limitation of the traditional cleaning robot refers that the traditional robot can go back to the charger, but it doesnt know how to resume from where it stopped for charging as it doesnt have a map. The lithium-ion battery pack of the robot lasts at least for two hours, which is sufficient, but full autonomous operation including recharging means that the battery life doesnt matter.

III. System Assembling Process

The cleaner robot is a combination of different electrical and mechanical components such as- Raspberry Pi (model 3B), Arduino Mega, servo motor, GPS module, LIDAR, motor driver, relay module, vacuum cleaner, proximity sensors, wires, buck module, diodes, mechanical structure etc. At first, these components are assembled in the mechanical structure than the electrical connections were set up.

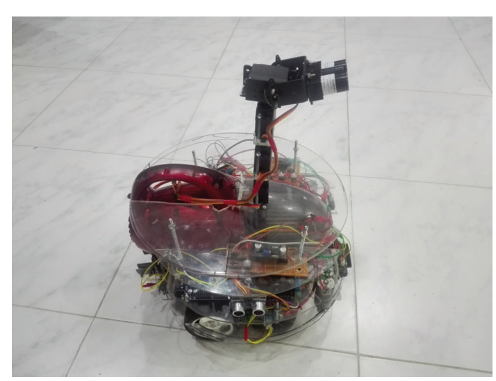

Fig. 3: An image of fully functional cleaning robot

In the first stage, Power is given to the buck modules from battery through diode and a kill switch. At the starting LiPo

(Lithium polymer-ion) battery is used for testing purpose, then when the robot is ready, rechargeable Li-ion pencil batteries are used for power supply. Diodes are used to avoid reverse connection problems. Three buck modules were used. One is for empower the vacuum which has 30V output and another two has 5V and 24V output respectively for sensors, switching relays and motors. We use 30V terminal voltage to the vacuum because lower than 30V can not create enough suction to clean the small particles of dust. From the 5V output all the sensors, Arduino and Raspberry Pi get the power. As mentioned above various types of sensors are used in the cleaning Robot, so there are buck modules to provide huge amount of currents. For this reason high power buck modules are used to serve this purpose. Four proximity sensors are used for detecting near obstacles, although LIDAR is used to have good mapping but for instant appearance of any obstacles we use proximity sensors. Proximity sensors are connected to the Arduino input pins. As mentioned above LIDAR is used for mapping the surroundings[8], it is also connected to the Arduino input pin. Four servo motors are used in the bot. One is for charging dock and another three are for moving the LIDAR in 360 degree space and all these servo motors are connected to the output of the Arduino. Arduino takes the inputs from the Proximity sensors and LIDAR, it also sends command to the servo motors for moving LIDARs according to the Raspberry Pi's command at the same time when taking data from LIDAR. An output of the Arduino is also connected to the relay module to turn on and off the vacuum cleaner. Motor driver's input is connected to the Arduino output pins to control the speed and direction of the motors. Arduino is connected to the Raspberry Pi for communication between sensors and Raspberry Pi. A GPS module is also connected to the Raspberry Pi so that the robot can be aware of its location. All the connection of the system were made by connecting wires.

IV. System Integration (Programming)

To acquire data from the devices and sensors e.g. GPS, LIDAR, IR proximity sensors and Ultrasonic Sensors and process them with necessary instructions, a software is designed. The

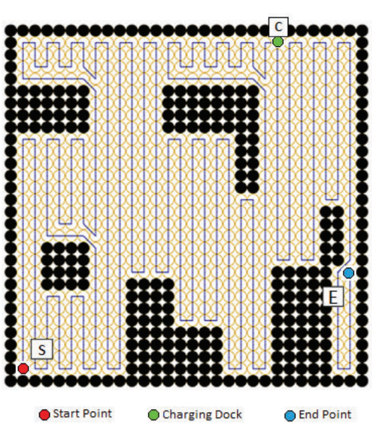

Fig. 4: Robot's Cleaning Path (Generated).

sensors are used to perform different tasks. They all require different type of instructions.

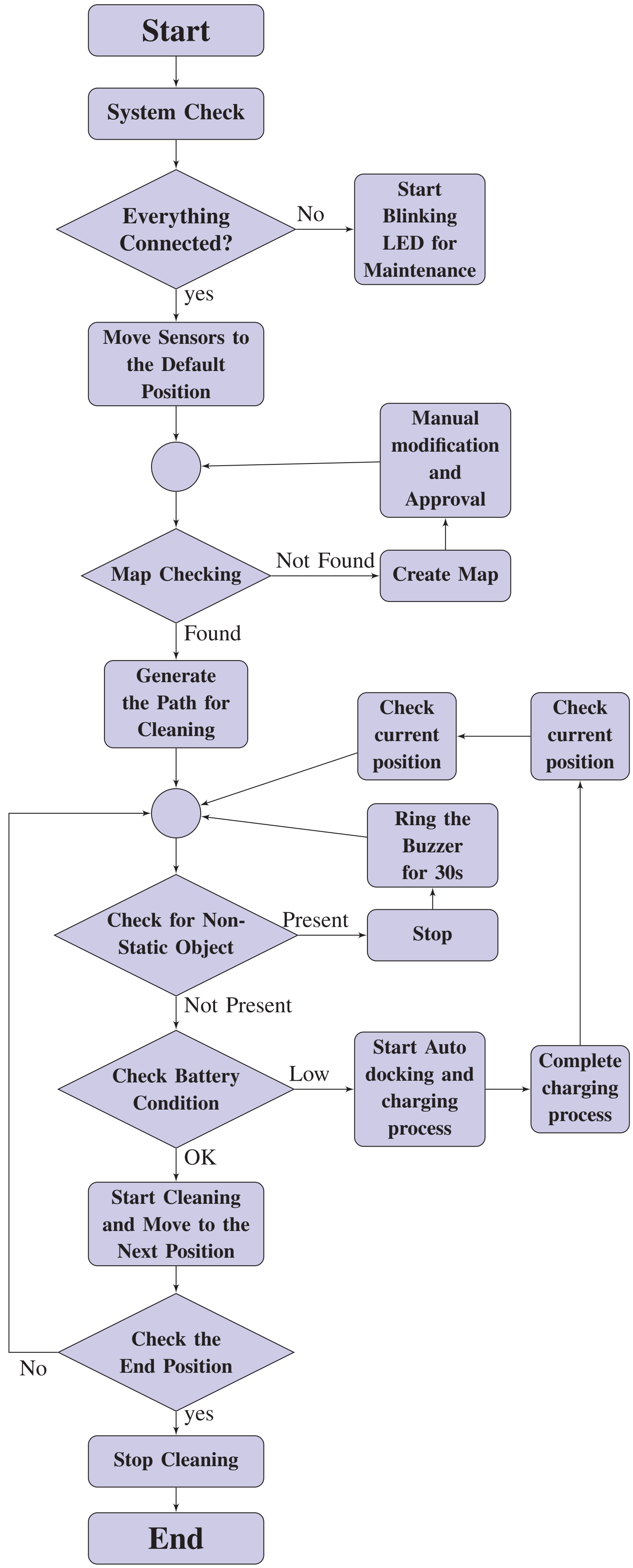

Fig. 5: Flowchart of th System's working process (Simplified)

The software was implemented on Arduino mega and Raspberry

Pi to make the robot autonomous and fully operational.

Raspberry Pi works as central processing unit. Arduino mega is used as a sub-system to read the analog data from IR proximity sensor and Ultrasonic Sensor and send it to the main processing unit. Then the Raspberry Pi processes the data and performs necessary tasks.

Mapping is an important task for the cleaning robot. It is very fundamental to the cleaner robot that it possesses the entire map of the area that it has to clean, a more specific map of rooms and the possible location of obstacles that it has to avoid and its current location. We used a GPS module and LIDAR unit to get the map of the building floor and guide the robot accordingly. Specifically, the LIDAR unit is used for room mapping and GPS module to guide the robot to the right direction. LIDAR measures the distance of the object from the robot with very good accuracy. By spinning the LIDAR unit, systems can get the detailed distances required for mapping. When mapping was completed, the location of the docking and charging position was known by the robot and store it in the memory.
This map can be edited manually by operator if there is anything wrong. Then the Raspberry Pi generates the cleaning path according to the map using genetic algorithms.
After completing the mapping and path generation process the cleaner robot start its main mission of sweeping every accessible area in the entire environment avoiding obstacles. During cleaning process the cleaning robot must face obstacles like walls, tables, chairs, doors and moving people. Infrared proximity sensors and ultrasonic sensors are used for obstacle detection. A proximity sensor can detect the presence of nearby objects without any physical contact. But the range of object detection is small, thats why we used another sensor for distant object detection called ultrasonic sensor. The ultrasonic sensor is mainly used for measuring the distance to the object. But if the distance is small, it shows garbage value which can be misleading. So infrared proximity sensor also used for low distance measuring purposes. After that, everything is combined with an algorithm to form a complete mapping. In a word, whole coordination process consists of GPS, LIDAR, IR proximity sensor and Ultrasonic Sensor.
When battery parameters indicate that charging is necessary, the cleaning robot can call the memory for the location to start executing the docking and charging sequence automatically to take the robot to the charging position. There is a complete map of 3rd floor of IICT building of our university where the robot is placed. Using the map, the robot start cleaning. First, the robot gets its own position by using GPS and other proximity sensors. Then the bot started to clean by following a side wall in a circular pattern. After finishing one complete circle in a certain zone, the bot added that area ti the clean list and again start cleaning by increasing the distance from the wall. Repeating this process continuously when the bot reached the center of the zone, the zone is marked as a clean zone and the bot move to the next uncleaned zone and repeat the whole process. During the scan, if any obstacle is found in its path, it will follow the edges of that obstacle until it riches to its desired path again.

V. Algorithm Details

The algorithm is based on Genetic Algorithms (GA) which is done is several steps to find the correct path[9]. Each gene represents the robot position and some of the chromosomes represent also the mini-path. In addition, this algorithm helps the robot to pass through every part of the room by avoiding obstacles using different sensors. The algorithm can be divided into several parts.

1) Modeling of the room: In this step, a map of the room is created using different sensors and camera data. The positions of the obstacles are also determined and stored in the robots memory, which used later for planning the path. The model of the room always updates during the run time based on different sensor and camera data.

2) Path planning: The path which is covered by the robot from a start position to the position with passing over all the accessible positions and avoiding obstacles that are named as the global path. The global path is divided into several mini paths. The mini path is always shorter than the range of sensors.

The Genetic Algorithms helps the vacuum cleaner robot to find associate degree economical path and clean all accessible areas from a begin position to an exit position. It consists of several steps which are shown in the flowchart below.

3) Fitness function and selection: A fitness function is necessary to know the detailed description and solution of the problem. It is directly related to the constraints of navigation coverage. To evaluate the fitness of individual mini-paths three parameters are taken into consideration: the total distance of the mini-path, the number of consecutive unclean cells and the total distance of every position cell relative to the present robot position. An appropriate fitness function of mini-path is constructed as, where is the constant number and are the distance of mini-path, the number of free cells and the distance of the free cell relative to the present golem position severally.

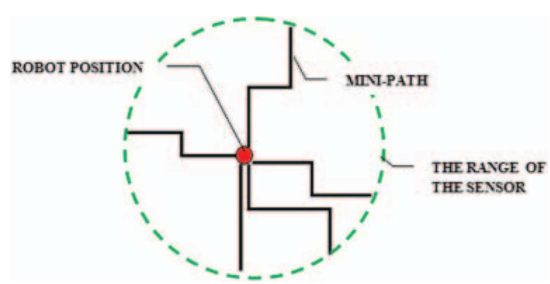

Fig. 6: Mini Path Planning Picture

The mini-path contains some points which are occupied by the robot during its movement. These positions become cleaned but the others remain unclean until they are taken into consideration by the next mini-paths planning.

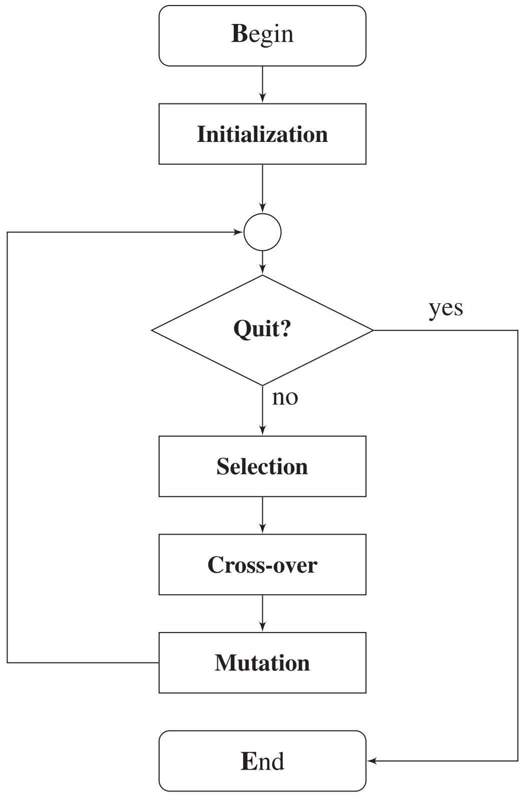

Fig. 7: Genetic Algorithm Diagram to Find Efficient Path[10]

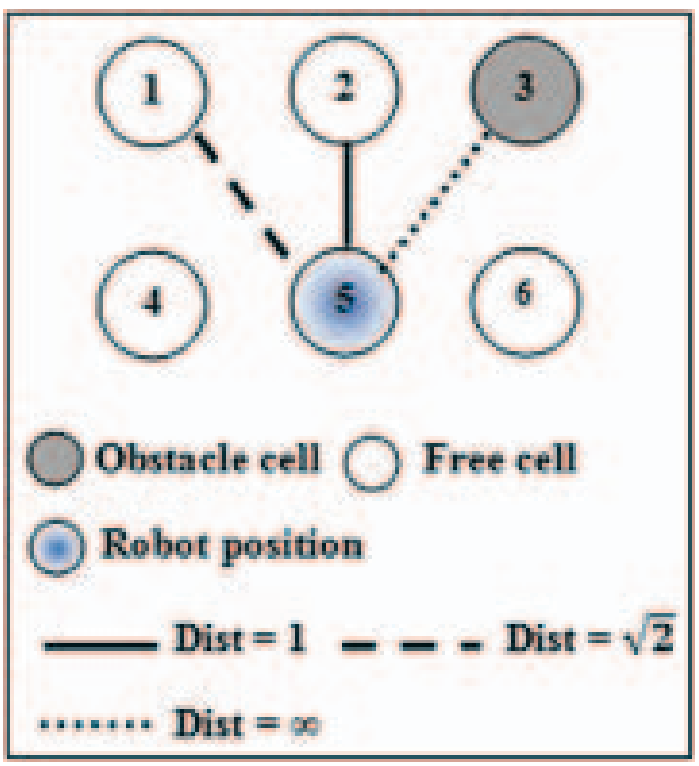

Fig. 8: Total Distance of Mini-path Representation by Euclidean Distance

The total distance of mini-path: It is calculated by the sum of each distance between two cells position in which this distance represents the Euclidean distance as shown in the following figure.
The number of unclean cells: It is the number of consecutive unclean cells that belong to the mini-path from the current robot position. The total distance of each position cell relative to the current robot position: It represents the distance between the current robot position and the unclean cell position which belongs to the mini-path. The ideal fitness is the solution that contains no redundant visited and obstacles cells. Stochastic tournament selection with elitism is applied based on fitness values.

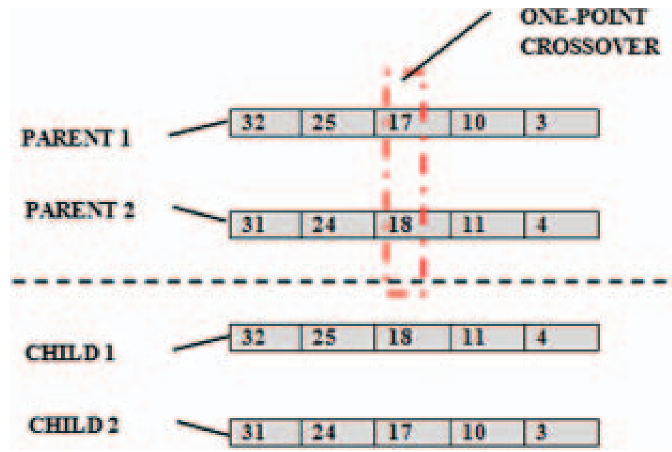

Fig. 9: Crossover Technique Picture

4) Crossover: After two mini-paths were selected by the selection operator, they will be considered as parents. The crossover operator allows the generation of children to inherit the genetic code of the mixture between the father and the mother. We opted for a one-point crossover techniques and the two children are then added to the population. An example of a crossover operator is illustrated in Fig. 9 in which we notice that from the point crossover (the third gene), the genes value of chromosome1 is replaced by the genes value of chromosome2 and the same case for the chromosome2. Therefore, we obtained a new two mini-paths.

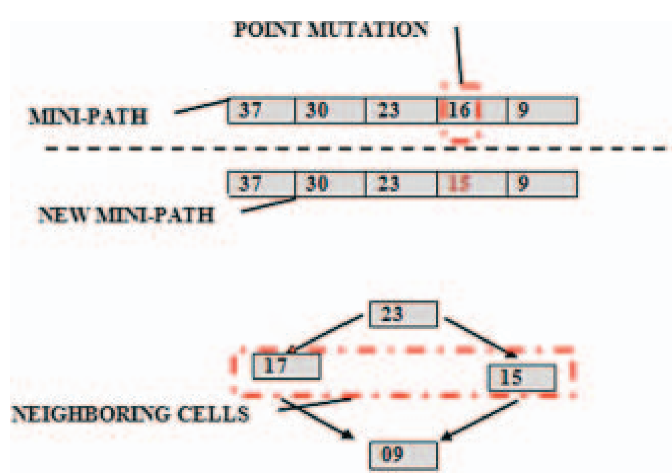

Fig. 10: Mutation to Incorporate the Exploration Impact

5) Mutation: It is used to incorporate the exploration impact. The genes value is modified by one of the neighborings precedent gene. The selected point of the chromosome is random as shown in figure 10.

VI. Conclusions

The primary purpose of the Cleaner Robot is to clean the floors efficiently. As earmarked, it can clean the dirt with efficacy. The robot can detect obstacles and can avoid those to clean the area . The robot not being a large-sized one can be mistakenly hit by unwary pedestrians. We aim to introduce an automated fix to this problem in the later versions. The mapping process involving a GPS module is quite complex. While working in an indoor environment , its slightly hard to track the robot using GPS. GPS signals are carried through waves at a frequency that does not move easily through solid objects. The signals from satellites are attenuated and scattered by roofs, walls etc. Using more sensitive GPS chips can get a fix. As a low power DC motor was used in the vacuum cleaner, the suction process is not optimized for a huge bunch of dust and dirt. So, these drawbacks should be resolved. We will use a garbage scanner that will detect garbage and only then will start the vacuum cleaner. This way, we can reduce the power consumption of the robot. The robot can clean a plane floor. Our future endeavor would be to modify it so that it can clean the stairs too.

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