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Design & implementation of a simple sweeping algorithm and control of a floor traversing robot

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***Abstract*—Robotics Technology is the latest miraculous application of engineering science that has ushered a revolution in various fields of modern day world namely industry, medical field, space and household domain and it aims at the betterment of life. This paper attempts to address one such household chores with the intention of reducing our labor and time. The paper has mainly two parts. First part is an algorithm of obstacle detection, obstacle avoidance and an efficient floor traversing mechanism. This algorithm can have many applications like ground scanning, collecting items from floor, surface painting, floor cleaning. Second part illustrates one such application- dusting the surface**

***Keywords*—ultrasonic sensors, obstacle avoidance, domestic robot**

I. Introduction

Robots are the largest growing technical devices in the world. They perform many functions ranging from space exploration to entertainment, manufacturing to medical and healthcare. Robotics integrate many different component disciplines and technologies. To reduce man power and cost for daily activities, robots are extensively used. They are programmed to make quick decisions and complete the tasks perfectly with minimum variance. In household domain also there are lot of scopes for robotic technology. This thesis attempts to address one such household chores- that of floor sweeping. There are many robots in the market like Mint Automatic hard floor cleaner, SR8855, Roomba-560, Roomba-570, Icelob intelligent cleaning robot etc. which are used for the floor cleaning purposes[1][2][3]. They have some advantages and disadvantages. The workspace can be known or unknown to the cleaning robot. The elementary and cost effective nature of the proposed algorithm is what makes it different from the ones available in market.

This application however is the extension of floor coverage algorithm which consists of three main parts obstacle detection, obstacle avoidance and path planning. There are various spheres where this algorithm is applicable such as ground scanning, surface painting floor cleaning each of which requires the additional challenging feature, of covering the complete workspace and the robot must go very near the obstacle without colliding it at the same time it must go to hard to reach places. Workspaces are generally full of obstacles like in homes table, chairs, bed, toys, moving obstacles like person etc.. Section II describes some obstacle detection techniques, section III elaborates the algorithm that we have used and section IV illustrates how the robot performs the sweeping.

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II. Background

In most techniques efficient detection of obstacle comes at the cost of increased number of sensors. As many as 24 Sonar Sensors have been used in [4].They are all fired simultaneously. Then the range data due to multiple echoes from multiple targets by each receiver are obtained. Those range data includes true range data from the different targets and error range data due to crosstalk. The relation between range difference between neighboring receivers and the location angle of the receiver is

$$\vartriangle(\theta i)=ri(\theta i)-d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

Where d is the actual minimum distance between the target and robot, △ (θi) the range difference, riθi) is location angle of the receiver [4]. The minima corresponds to true range data to the target and other range data by other receivers lying on the curve are the error range data formed by crosstalk. To eliminate error data due to cross talks in the simultaneous firing, a filtering method based on pattern matching using neural network is used. In [5], five ultrasonic sensors making 30 degree with each other four IR sensors are placed in between the ultrasonic sensors(Fig 2.2.2).They form five groups middlemost ultrasonic sensors detect obstacle in the front direction and the groups in the other directions To realize decision control, a fuzzy control logic is used. In [6], one IR sensors, one ultrasonic one and one laser scanner are used. Area is divided into ten fan-shaped regions within 180 degree in front of the robot. Correlation coefficient method is used to classify the ten regions, and establish the fuzzy relationship R for 10 regions. Accurate data is obtained by correlating the obtained data in the following way:

$$r = [\textstyle\sum_{k=1}^{3}(xik-xi)(yjk-yj)]\div[\left(\sqrt{\textstyle\sum_{i=1}^{3}(xik-xi)^2}\right)(\sqrt{\textstyle\sum_{j=1}^{3}(yjk-yj)^2})]$$

. …………………………………………………………….(2)

where, x_i and y_j are the mean values of the respective outputs and r is the correlating factor [6].

In [7], is described the "Boustrophedon cellular decomposition" algorithm. This is an Exact cellular decomposition in which, each free space working environment is sub-divided into regions called cell. This method is designed to minimize the excess lengthwise motions. This algorithm is just like an Ox-plough the field. It first plough in one direction and then takes a turn and plough parallel, adjacent to the already ploughed field.

III. The path planning algorithm

A. *Components (hardware and software) used*

1) Sensors

Ultrasonic sensors are used for obstacle detection. Ultrasonic sensors generate the high frequency sound waves. They are able to both send and receive the sound waves. These sensors calculate the time interval between sending the signal and receiving of the echo by the sensor, to determine the distance to an object.

Principle of working:

Ultrasonic sensors emit short, high-frequency sound pulses at regular intervals. These propagate in the air at the velocity of sound. If they strike an object, then they are reflected back as echo signals to the sensor, which itself computes the distance to the target based on the time-span between emitting the signal and receiving the echo(Figure 3.3).

CALCULATING DISTANCE BETWEEN OBJECT AND ROBOT

The following equation explains the distance measurement between obstacle and the robot.

$$d = (t \times c)/2c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

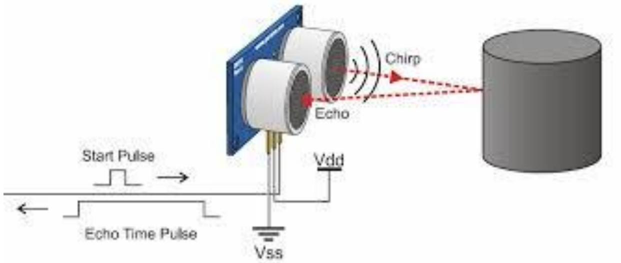

Fig. 1. Working of ultrasonic sensor [8]

Where c is the speed of sound in air (344 m/s), t is the time taken by sound wave to bounce back, d is the distance between object and robot [9].

2) Processor and compiler

The mbed microcontroller (ARM Cortex-M) is used and the corresponding compiler used was the mbed online compiler SDK.

3) Other hardware/ software used

SolidWorks, dc motor, servomotor, power supply, driver circuit, screw, nuts, bolts clamps, platform (chassis), resistors, capacitors, voltage divider etc are used.

B. *Robot model*

The robot has three ultrasonic sensors. The shape of the robot platform and the placement of the sensors are shown in Fig 2. The four sensors are marked in the Fig 2 as S1,S2, S3. The front portion of the platform is elongated for better sensor positioning. There are two dc motors beneath the platform which are connected to two wheels

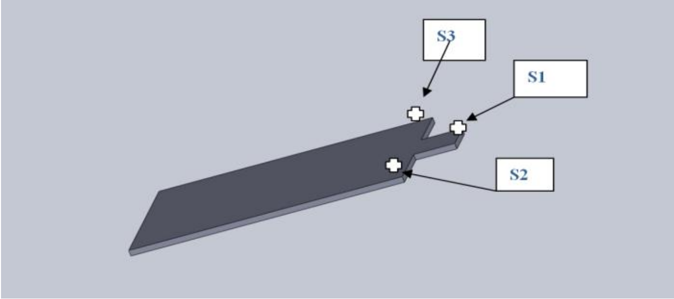

Fig. 2. Robot platform showing sensor placement

C. *Traversing Procedure*

There are three ultrasonic sensors (S1, S2, S3) on the front of the platform. One sensor(S4) is at the bottom of platform. The middle sensor (S1) is always active. But the remaining two sensors(S2, S2) become active only after avoidance of first obstacle. When the avoidance angle become 900 right the sensor at the back become active.

The idea is that robot moves in Boustrophedon path that is it moves in one direction and takes a right turn and moves in opposite direction in adjacent to the previous path as shown in figure 3.

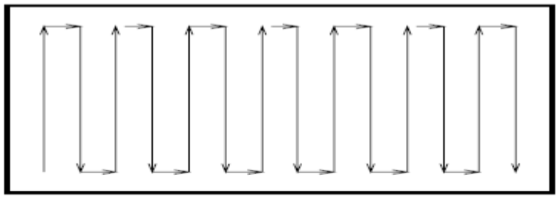

Fig. 3. Boustrophedon path[7]

Advantage of boustrophedon path are:

- It requires less number of back and forth motion
- This algorithm minimizes the excess lengthwise motion .

D. Assumptions

1) Room is rectangular
2) Initial point of robot is leftmost corner of the room
3) Robot faces the front wall and turned on
4) There is no obstacle just in front of the robot at the start

E. Main feature

1) It can go to hard to reach places
2) Remains very close to the obstacle going almost round it but does not collide with it.

F. Avoidance principle

By providing different velocities to the two wheel the robot can make angle 22.5^0 or 45^0 or 67.5^0 or 90^0 or 112.5^0 or 135^0 or 157.5^0 or 180^0. When there is no obstacle robot moves in boustrophedon path and only the front sensor works .Now if there is an obstacle it goes near the obstacle, moves back to change the direction, turns left by an angle 22.5^0 or 45^0 or 67.5^{0}depending on the size of the obstacle and now the front and the left sensor is turned on. For slab/L/U shaped obstacle it turns back to the initial direction and turns on the back sensor to check whether it has reached the front wall or not, if not, turns right by an angle 22.5^0 or 45^0 or 67.5^0 or 90^0 or 112.5^0 or 135^0 or 157.5^0 or 180^0 depending on the size/shape of the obstacle after activating the right sensor, otherwise turns and moves in opposite direction in adjacent to the previous path. The code was written in C++ using mbed online compiler SDK. For this reason the net connection was compulsory and compilation was done through an online account with the compiler. On connecting the board to PC through USB automatically the removable drive opened up where we found .HTM file, clicking which we were directed to mbed website and we were needed to login into our account. We edited the default blinking LED program that was provided with each new program that we created. When the compilation was done a .bin file was created after successful build, which was downloaded to the board. The board then was restarted and the program got dumped in the board. Steps followed by obstacle avoiding robot

1) Once the robot is started it moves with minimum velocity
2) It starts the front sensor(S1)
3) If there is no obstacle it moves straight till it comes at a distance of 3mm of the wall then it takes right turn and again right turn to move in a boustrophedon pattern
4) If there is an obstacle and size of obstacle is small then the robot takes left turn of 22.5^0 or 45^0 or 67.5^0 depending on the size of the obstacle
5) The right sensor (S2) is turned on and the front one (S1) also works simultaneously.
6) If the right sensor does not detect obstacle then it turns right by the same angle as in 4) and turns off the right sensor
7) In the mean time if S1 detects any obstacle it follows steps 4)
8) If there is a obstacle and size of obstacle is very large or the front wall is reached then it takes right turn and again right turn to move in a boustrophedon pattern
9) If size of obstacle is medium, the left sensor(S3) is turned on and it turns right by an angle 112.5^0 or 135^0 or 157.5^0 or 180^0 depending on the size/shape of the obstacle
10) If S3 does not detect any obstacle robot turns left by the same angle as it has done in 9) and turns of the left sensor
11) Simultaneously S1 works such that if it detects obstacle then it follows step 4) to 10)

According to the algorithm the path followed by the robot is shown in Fig 4 where the rectangular strip (border) is the boundary wall of a room. The circle, triangle and rectangular slabs are the obstacles of a room. The black straight lines represent the path of the robot as it comes across the obstacle.

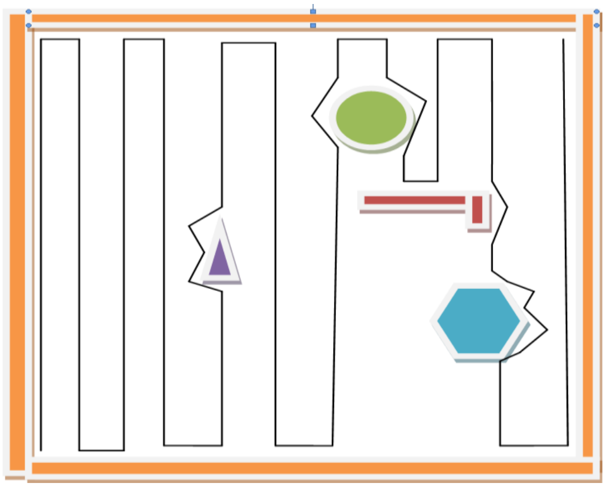

Fig. 4. Path followed by the robot according to the algorithm

IV. Surface sweeping

One application of the described floor traversal is presented here. This thesis attempts to relieve human beings of the day to day mundane activity of floor sweeping thereby reducing time and energy. There are many robots in the market like Mint Automatic hard floor cleaner, SR8855, Roomba-560, Roomba-570, Ice lob intelligent cleaning robot etc. which are used for the floor cleaning purposes. Here a very simple technique is used.

A. *Components used*

Components used for this purpose are DC motor, Servo motor, a dust collecting container, brush and all necessary connecting parts.

The dust collecting container is shown in Fig 5. It has been created in SolidWorks. The extended slant portion shown in the figure can be folded. The servomotor is connected to it. The arrangement is such that the servomotor enables the folding as per the programming. The collector is attached to the base of the chassis between the wheel and the slant portion almost touches the ground.

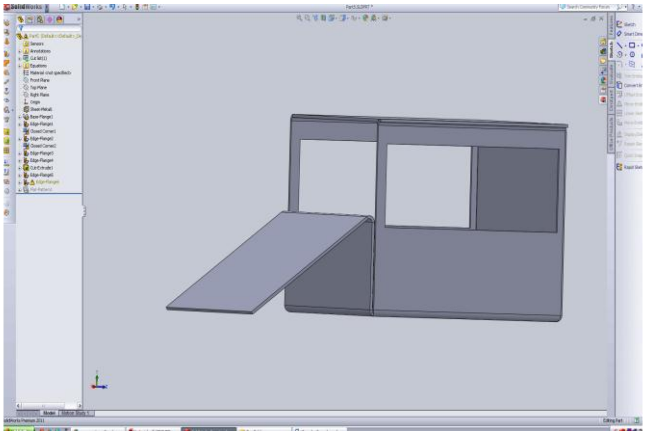

Fig. 5. Dust collecting container

A brush is attached to the shaft of dc motor on the back of the chassis.

B. *Working principle*

The dc motor is placed at the bottom of the base in the extended portion at the back of the platform of the robot (Fig 6) with the shaft inside.

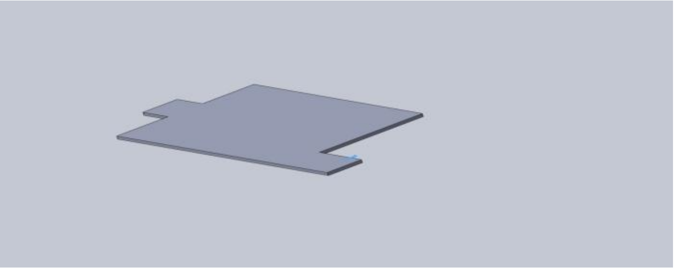

Fig. 6. Modified robot platform

The back of the brush is attached to the shaft and the tip of the brush touch the ground slightly. The arrangement of the motor is such that when the motor rotates the tip of the brush touch the slant surface and glide along the surface for a small duration. The dc motor is made to rotate in a clockwise direction it removes the dust from the surface and drags them into the box thereby collecting the dust in the collector. This is elaborated in Fig 7, which clearly shows the position of tip of the brush, slant surface with respect to the ground at the start of collecting dust.

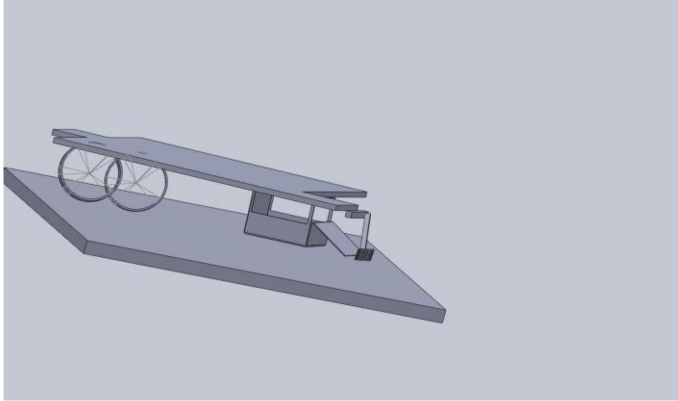

Fig. 7.Sweepng Robot on the surface

C. *Further improvement*

An improvement in the dust collecting technique is made by making the slant portion foldable and controlling the folding by a servomotor. The servomotor is to make to and fro motion and the slant portion also makes the to and fro motion when the servo horn is joined to the slant portion. By carefully making the time period of dc motor and servo motor same or multiples of each other, the start of folding of the slant potion and the touching of the tip of the brush can be made at the same instant. This is shown in Fig 8 and Fig 9. This leads to a better dusting with minimal complexity.

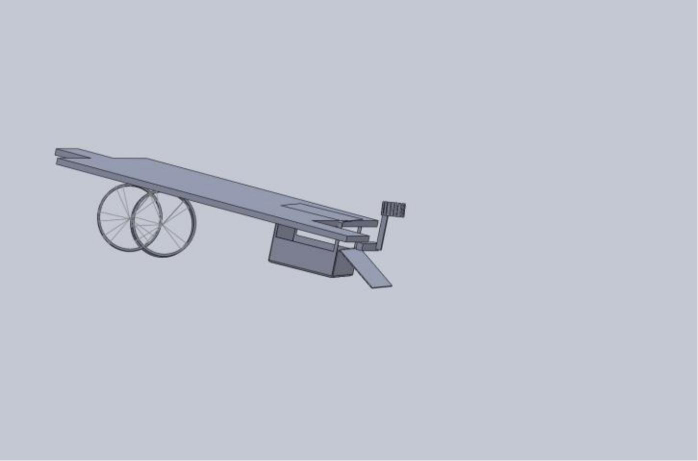

Fig. 8. Brush and slant surface at maximum distance from each other

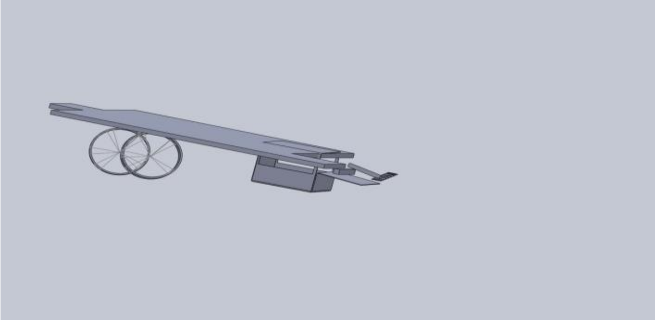

Fig. 9. Brush and slant surface at maximum distance from each other

V. Conclusion and future work

The avoidance and coverage algorithm has some shortcomings. The main drawback is that large slabs are treated as walls. This results in bypassing certain areas. Best results are obtained in rooms not having large slabs and huge portion of floor area is evaded if there are many large slabs. Other than that the algorithm is most suitable for rectangular rooms. These limitations needs to be addressed by using Probabilistic localization. The methodology is simple, easy and less expensive to implement without requiring any memory elements. The sweeping action is also simple but has adverse effects if surface has wet dust. This is just a prototype. For practical applications in proper application high torque motors, large collector box and better brush are required. The other limitations

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