DOCKING A MOBILE ROBOT FOR CHARGING USING LABVIEW

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ABSTRACT

Autonomous robots are trying to become self sufficient day by day and this paper presents an attempt towards making a robot self-sufficientat least in its power requirements. Necessary electrical design of a system is done for the robot to locate a charging/docking station, go towards it and recharge its battery when necessary without manual intervention. The results of the experiments performed on the system are also presented.

Keywords: Automatic Docking, LabVIEW, Mobile Robot.

I INTRODUCTION

A docking station for the National Instruments DaNI robot was designed using the requisite hardware and software systems. The mechanical design of the hardware used in this paper is from a previous work undergone, which is presented in [1]. Its task was to enable the robot to charge automatically when the robot's battery is below a certain threshold. The hardware consists of the docking mechanism and the sensors were integrated with circuits; several such circuits were mounted directly onto the robot. Circuits for auxiliary supply, automatic switching of power supply and to measure voltage were designed. The software controls the robot by continuously monitoring the battery levels and executing a docking algorithm, which makes decisions with the help of IR LED- Photodiode pairs and optical encoders as sensors. The voltage sensors were used to detect if the robot is docked.The robot has a built-in FPGA and RT processor along with quadrature optical encoders and two 152 rpm dc motors. The four wheeled robot uses the differential drive mechanism for movement. National Instruments LabVIEW is used for graphical coding, National Instruments Multisim 11.0 is used for electrical circuit design.

II PREVIOUS WORKS

In [2] a camera is used to locate the docking station and a laser beacon is used to calculate the angle of rotation of the robot. Once the robot is docked, an IR LED mounted on the station sends a signal to the robot controller. Battery voltage level is also monitored continuously to check for docking.

In another system a camera is again used extensively for locating the docking station aswell as for aligning of the robot correctly. The camera determines the angle and distance from the target by calculating the dimensions of a known shape placed above the station and later formulates a virtual spring model[2]. Kim *et al.* [4] tried to solve the same problem using simple infrared sensors on a circular shaped robot. The docking station is connected with six IR LEDs placed at different angles and IR sensors are kept around the robot. Depending on which IR sensor receives data and from which IR LED, the position and angle of approach is calculated. A unique coding system is used to differentiate between the signals from the IR LEDs.

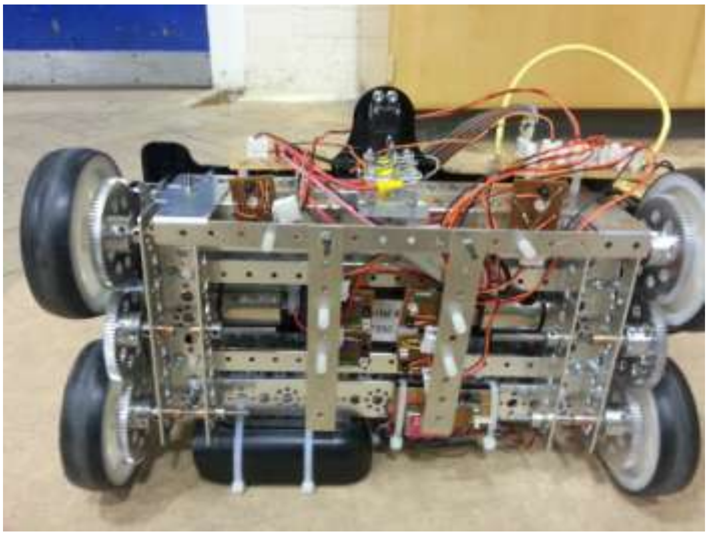
Wu *et al.* [7] goes a step further by designing a docking station for exchanging a discharged battery with a charged one. A variety of sensors are used in the process; a magnetic tape used for guidance, optical sensor used for detecting the state, and other sensors for rotation of carrier as well as for grabbing arms in the docking station. The carrier rotates to align it with the orientation of the robot while a grabber is used to hold the robot steady while the battery exchange happens through a push-pull device. Separate electrodes are also provided to power the robot at the time of exchange.

Most of the solutions use a combination of sensors for docking. Camera, laser beacon and IR sensor in Silverman *et al.* [2], camera and infrared sensors in Luo *et al.* [3] and magnetic sensor, optical sensor and camera in Wu *et al.* [7]. Kim *et al.* [4] and Wu *et al.* [7] have complex docking mechanisms which makes them easily susceptible to mechanical faults. The docking mechanisms in [2], [4], [5], [6] and [7] contains some kind of power consuming controller at the docking end which has to be left turned on continuously.

III THE SYSTEM

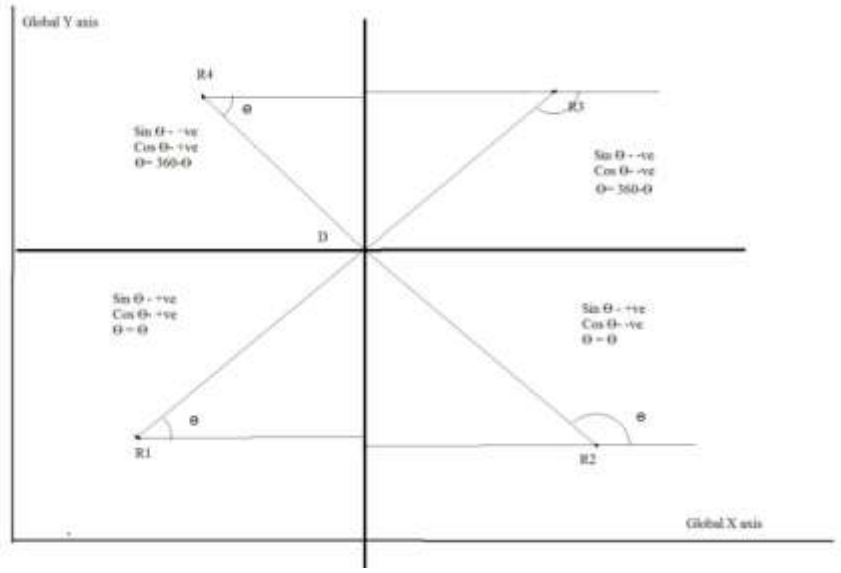
In the previous work [1], a mechanical design of the docking station is already presented. In the next step, to enable docking, the already present optical encoder is used to locate the robot in a space and using those data, the robot is driven towards a predefined location. Two IR sensors are placed next to the front wheels for this. From there, using another 4 infrared sensors the robot tracks a line which leads the robot towards the docking station (figure 1).

Circuits were designed for switching over between batteryto external source. The external source circuit takes an input of 220V AC from the wall socket and converts it into a 12V DC (using a rectifier). The design is done such that the present battery charger adapter is not modified at all. A voltage sensor is also added to the circuit to enable the robot know whether the battery is fully charged or exhausted.



IV METHODOLOGY

IR LED-photodiode sensors were used to align the robot correctly with respect to the docking station. A non-reflective line was drawn from the docking station which was 1.4 m in length(calculated after accommodating maximum possible errors). Using the optical encoders on the robot, the robot would know its position in the 2D space at any time. The robot would also know the coordinates of a predefined point in the line. When the battery level was low, the robot would move towards the point on the line. The point was given such that even after the possible odometric errors, the robot should be able to able to steer itself to some part of the line. Once the line was reached, the robot would move along the line towards the docking station. The robot would follow the line until, the battery started charging. Once the battery charging was finished, the robot would correct for the odometric errors by updating its position to the coordinates of the docking station. This would help the robot to come back easily to the docking station at a later point of time.



Another problem which had to be taken care of was, when the robot reaches the line, how would it know in which direction it should move so that it can reach the station. The robot knows in which direction it should move, to reach the point on the line. Based on the coordinates of the point of the line and the coordinates from which the robot started to look for the line, the robot could tell which direction it should rotate in order to reach the station.

*Figure*2 shows the possible positions on the robot with the docking station at the centre of the figure. The initial x coordinate, y coordinate and the angle with respect to x axis is given as inputs to the VI. The robot is at (0,0) and oriented towards the positive x axis. The point which is supposed to be reached by the robot is given as (500,500). Based on the two coordinates, the shortest distance between them is calculated using the formula

$d = \sqrt{(l_x - r_x)^2 + (l_y - r_y)^2}$ where d is the distance, (l_x, l_y) is the point on the line and (r_x, r_y) is the robot coordinates. Then the slope of the line is calculated as $\cos^{-1}\left(\frac{y}{x}\right)$ along with the value of $\cos\theta$ and $\sin\theta$.

In *figure* 2 the possible positions of the robot with respect to the point on the line is shown. For every quadrant, the updated value of Θ is shown. If $\cos\theta$ and $\sin\theta$ are both greater than 0 or if $\sin\theta$ is negative and $\cos\theta$ is positive, the calculated value of Θ is not altered. In the next two quadrants, the obtained value of Θ is not the actual rotation angle as LabVIEW generates only angles between 0º and 180º. Therefore the angle is subtracted from 360º which is later used. To know whether the robot is in any of the two quadrants, the sign of $\sin\theta$ and $\cos\theta$ are checked. If both are negative or if $\sin\theta$ is negative and $\cos\theta$ is positive the angle is subtracted form 360º.

The next step is to calculate the angle the robot should rotate based on its current orientation. If Θ obtained from above is less than *A*(orientation angle), Θ is subtracted from *A* and the robot rotates the new angle (*a*) in the anti-clockwise direction. Else the robot is rotated in the clockwise direction for the difference.

A*ms* counter is used in the program which start counting when the robot starts rotating and it is multiplied by a rotational velocity of the robot to obtain the angle rotated. To convert the wheel velocity to robot rotational velocity a multiplication factor of 7.8 is used. This factor is found by trial and error method as it was impossible to calculate the extremely unpredictable slip occurring on the wheels when the wheels skid to rotate. The robot stops rotating when the measured angle equals to the calculated angle. At this point the robot will be oriented towards the point on the line.

Once the robot is looking towards the line, the robot should move forward till it reaches the line. Again based on the Θ and $\tan\theta$, a decision is made on which sensor to look for is made as follows. If the angle is less than 90º and $\tan\theta$ is positive or if angle is greater than 90º and $\tan\theta$ is negative, look for output of front left sensor (L). If the angle is less than 90 and $\tan\theta$ is negative or if angle is greater than 90 and $\tan\theta$ is positive, look for output of front right sensor (R).

Once that decision is made, the robot stops when the sensor shows a high reading. Now the robot has to go forward till the corresponding next sensor crosses the line. To do this, a count variable is initiated and the value of 0 represents the left sensor and the value 1 represents right sensor. Once the decision on which front sensor is to be looked for is made, the value of the count variable is assigned 0 or 1.
If the variable returns 0, the code initiates to look for L_1 sensor and the following operation is done. Another counter is initiated to let the program know how many times the sensor detect after every iteration of the while loop. The count value greater than zero means that the sensor has shown high readings at least once. This means that the sensor is already on the line. But the robot has to stop only after it crosses the line and so, at the instant where the variable shows a value over 0 and the sensor gives a low reading, the robot stops. Similarly if the returned value of the count variable is 1, the robot looks for the R_1 sensor and follows the same procedure as for

the other sensor. The robot is asked to move further forward for another 500ms to let the robot be in a better position to bring all sensors above the line after it rotates.

The direction the robot should rotate in order to align along the line and also towards the docking station is decided as follows. It should either rotate left or right from alignment. It is found by considering the coordinates of the point on the line and the initial coordinates of the robot. If l_x(point x coordinate) is greater than R_x(robot x coordinate) and if l_y(point y coordinate) is greater than R_y(robot y coordinate) or if l_x(point x coordinate) is less than R_x(robot x coordinate) and if l_y(point y coordinate) is greater than R_y(robot y coordinate) rotate clockwise. In the other condition rotate counter clockwise till all the sensors are on the line or if at least one sensor pair (L_1 and L_2 or R_1 and R_2) is on line. When all the sensors are on the line the robot stops.

At this point the robot should have reached on the line and be looking towards the docking station. Now the robot has to track the line till docking station is reached. For this the robot monitors the output of its sensors in pairs. At once, it looks for sensors L_1 and R_2, if either of the sensors gives a low reading, it means the robot is not exactly above the line. Therefore the robot rotates clockwise till both are on line. It again goes forward until either of the next pair of sensors i.e. R_1 and L_2 is outside the line. To correct that error, the robot rotates in the counter clockwise direction until both are on the line. Since the robot skids unpredictably while rotating, a new code segment is also added which considers that scenario as well. When the robot rotates, there is a possibility that the sensor pairs on each side can end up outside the line. When this happens, depending on which pair, the following logic is executed. If L_1 or L_2 is out of line, the left wheels is run at a speed higher than the right wheels until the sensor L_1 is back on the line. After this, the robot moves forward till sensor R_1 is just outside the line. Then the robot rotates in the anti-clockwise direction till all the sensors are on the line. A similar operation is followed if the other sensor pair also displaces due to skidding. This process continues until the voltage sensor detects charging. In that condition, the robot has touched the docking station contacts. But as the robot is not yet docked completely, the robot is asked to go further forward for 1 sec and then stop. Now the robot is completely docked and its battery is charging. Then the robot is asked to wait till the battery finishes charging. Once charging is completed, the robot will go back to follow its objective until the battery charge is almost empty again.

V EXPERIMENTS AND RESULTS

The robot was kept in all the 4 quadrants (*figure*2) assuming the point on the line was at the centre and with 3 different orientations(0º, 135º, 225º). The calculated angle of rotation, corrected angle of rotation and actual angle of rotation were tabulated (table 1) for every robot position.

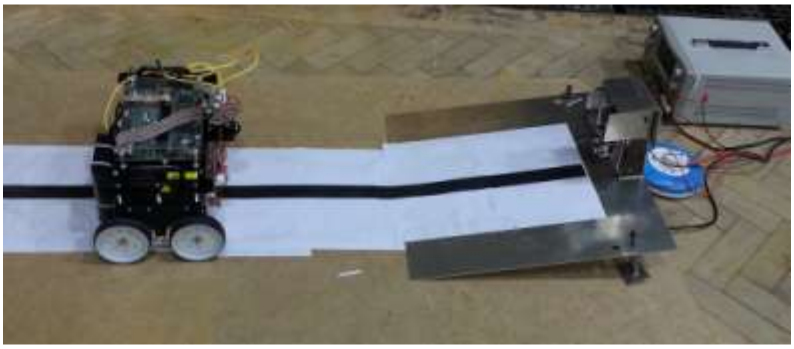
The results show that the logic used was correct.

R_x(cm)	R_y(cm)	A(°)	Calculated angle (°)	Corrected angle(°)	Actual angle(°)	Direction of rotation	Expected angle	Result
0	0	0	45	45	45	CCW	45	OK
0	0	135	45	45	90	CW	90	OK
0	0	225	45	45	180	CW	180	OK
200	0	0	135	135	135	CCW	135	OK
200	0	135	135	135	0	-	0	OK
200	0	225	135	135	90	CW	90	OK
200	200	0	135	225	225	CCW	225	OK
200	200	135	135	225	90	CCW	90	OK
200	200	225	135	225	0	-	0	OK
0	200	0	45	315	315	CCW	315	OK
0	200	135	45	315	180	CCW	180	OK
0	200	225	45	315	90	CCW	90	OK

Since the experiment of rotation in various quadrats were already performed, this experiment concentrated mainly on the rotation towards the line, line tracking, stopping after docking, entry angle and position and disconnecting after recharging was completed. In every case the robot's voltage level was measured and the robot was connected to the docking station manually to find the voltage after docking. These voltages were used to set the voltage level in the program (to know whether docked or not and to set the disconnection voltage level).

1. The robot was placed at coordinates (0,0) and orientation as 0° and the program was run. It was verified whether the robot turns towards the right after reaching the line and finished docking.
2. Then the robot was placed at (150,0) and orientation as 0° and checked if the robot rotated towards the right and successfully docked.
3. The rotation towards left was checked by keeping the robot in the other two quadrants.

The experiment is undergone successfully with the robot rotated towards the line in the right direction and later



tracked the line satisfactorily and stopped after docking. The entry angle and position did not go over ±5° and ±2mm. The robot also came back after the given voltage level is reached. The image of the robot going towards the docking station is given in *figure 3*.

VI CONCLUSION

The robot was able to locate the docking station and charge automatically when required. All of this was made possible using simple IR LED-Photodiode sensors, voltage level sensor and optical encoders as sensors. The docking station turned on only when the robot entered the station and this helped in power saving. There are no electrical actuators used on neither the robot nor the docking station. Only passive devices such as springs and bearing were used to enable various degrees of freedom. The robot was able to dock at high accuracy and precision in all the trials taken.

In the future, an extra support (possibly another rod end bearing or something similar) should be added to the docking mechanism to not let it hit back on to the surface when the robot disengages. Sensors more reliable than IR LED- Photodiode sensors can be used to decrease the setting up time of the whole system.

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