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Position Control of a Differential Drive Mobile Robot in a Constrained Environment

#1R. K. Anvekar, #2 J. L. Minase

[1]rohananvekar6@gmail.com
[2]jlminase.scoe@sinhgad.edu

#1 Appearing in M.E (Mechatronics), Sinhgad College of Engineering, Pune Maharashtra, India

[2] Assistant Professor, Department of Mechanical Engineering, Sinhgad College of Engineering, Pune Maharashtra, India

ABSTRACT

As recent advances in the field of robotics and artificial intelligence, various types of robots have been developed according to need and applications. These robots are essential as well as emerging as large supportive services as growth of service robots is more in every field of science such as in hospitals, military applications. In this paper, position control algorithm is introduced for a differential drive mobile robot for use in constrained environment. The algorithm helps the mobile robot move accurately, precisely in constrained environment, robust mobility and collision free control is attained for static obstacles. The mobile robot is basically a 2-wheel differential drive robot having dimensions 430mm×292mm×322mm (L×W×H). The position control algorithm is implemented and results are in terms of position accuracy and precision constraints. The position measurement is done using Global Positioning System (GPS) and the GPS coordinates are mapped with respect to length parameters. The position accuracy of the differential drive mobile robot is 0.075 m from the goal (Final) position. This algorithm further can be implemented for use in hospital environment for medical assistance as well as surveillance mobile robot in military applications.

Keywords— **Differential Drive Robot, Motion Planning, Mobile Robot, Path Planning, Position Control.**

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I. INTRODUCTION

As recent advances in the world of robotics, various types of robots have been developed according to need and applications in which the growth of service robots is more. In order to develop a mobile robot, in a constrained environment such as hospitals for medical assistance, military application, a proper path planning and optimised control algorithm is required. Depending on the environment where the robot works, the algorithm required for the robot system can be classified into two categories: sequential and autonomous. For sequential robot system, the environment must be perfectly structured because the robot is programmed to handle the object at the exact position. If the object location is somewhat different from the programmed one, the task may fail. On the other side, an autonomous robot is programmed to find the object position and orientation, to decide the direction to approach the object, and to execute the specified task. In robotics, position control concerns with problem as how to move a robot from one point to another point.

Position control is focused on designing algorithms that generate useful motions by processing simple geometric models. Navigation of mobile robot is possible under two conditions; the robot should have knowledge of the environment which is called as global navigation and the mobile robot can feel the environment using sensors which is known as reactive navigation. When an autonomous robot moves from initial position to the final position, it should find a feasible or optimal path avoiding the obstacles in its way. To achieve this level of robustness, methods need to be developed to provide solutions to localizations, planning and control.

A robotic mobile platform i.e. the differential drive mobile robot having dimensions 430mm×292mm×322mm (L×W×H) was available in the Mechatronics laboratory. The robotic mobile platform was available for implementation of the algorithms for various applications. The mobile robot drives on DC motors having differential drive mechanism. Differential motions are small movements of mechanisms used for deriving velocity relations between different parts of the mechanism. It consists of an Atom PC, Hydra Board, Power Distribution Board, Cheetah CB Controller, Cheetah Driver, Eduarm (display) and 24V Battery.

The Mobile Robot is a general purpose research robot which runs on a 24V battery, where the power for the robot is managed by using the power distribution board which regulates and distributes power to all electronic components of the robot. The robot is controlled through a central computer Atom PC; Atom runs on Microsoft Windows 7. The robot is fundamentally broken down into three blocks where each block is connected to the Atom-PC. The major blocks of the differential drive mobile robot: Power management Unit, Display Unit, Motion Control Unit. These blocks further consist of the microcontroller base-board i.e. hydra, ultrasonic sensors, and infrared sensors, Cheetah-CB (DC Motor Controller), Cheetah (DC Motor Driver), encoders, DC motors, 24V Battery and Wi-Fi module where the mobile robot can be interfaced remotely. The aim of the paper is to control the position of differential drive mobile robot in the constraint environment. To accomplish the aim, following terms are required:

a) Position control along open loop paths
b) Position control along closed loop paths
c) To obtain high accuracy with respect to desired location and robust mobility

This paper is divided into 5 sections covering the literature review, Position Control Algorithm, Real-time experiment and results, and Conclusion with future scope. The section two reviews the literature on robot control and position estimation of the mobile robot where significant conclusions have been followed in the paper along with required amendments. The chapter three discusses the methodology i.e. the position control algorithm applied on the differential drive mobile robot where it reveals the understanding of the position control algorithms. The chapter four discusses the real time experiments performed on the differential drive mobile robot and results are summarized in this chapter. The chapter five gives the conclusion of the work carried out and the future scope of

Literature Review

Visual Servoing technique using stereo vision was proposed which in turn resulted as a powerful tool useful for positioning of a robot with respect to the environment, tracking of 3D moving object and estimation of 3D motion [1] [3]. Using stereo vision, neither shape information nor desired distance of target object is required and the image Jacobian can be updated at every second, thus it is possible to generate a correct feedback command which leads to stability even if the initial error is large. Visual Servoing with stereo vision technique leads to an exact image Jacobian for desired location as well as for the random locations. This proposed work is robust and generic and provides with an estimate of the instantaneous velocity of the object. The robot control is designed using robot kinematic equations which prove that a mobile robot can follow the desired reference path according to the prescribed velocity profile with satisfactory accuracy [2]. A visual feedback control scheme for manipulator with camera on the hand is presented [4]. The dynamic information is sent to the manipulator control and using this information, a state space representation of visual servo mechanism is formulated.

The proposed algorithm gives simple time-invariant state feedback controller which has high sample rate control system. The image understanding procedure which is noise sensitive and time consuming is omitted resulting in high sample rate controller. A practical system which, when incorporated in an autonomous mobile robot moving indoors can determine the position of the robot and detect the obstacles so that the robot can navigate appropriately [5]. Localization enables the current position of the robot and orientation makes sure that the robot follows the determined path and obstacle avoidance detects the obstacles along the path and determines the position to avoid collision. The proposed techniques can also be used for autonomous mobile robot which is specially designed for care facilities. The detection is stable under brightness variations but up to some extent. A robot control system is designed in dynamic constraints [6]. The result shows the robust tracking performance and a little faster convergence for various turning angles and different complex trajectories. The path tracking error occurs at the beginning and sometime at the end of the path due to the curvature discontinuity. The results assure that the capability of this tracking method is practically efficient for general path tracking of a wheeled differential mobile robot. Various path planning algorithms have been proposed where for fast finding of path, JPS (A*) is the best algorithm among other algorithms in various environments [7]. If the computational time is not significant and length of path is especially important then it is suitable to use Basic Theta* algorithm. The performance of Extended Kalman Filter (EKF) with Kalman Filter (KF) is been compared [8]. In simulation results, it shows that the performance of the EKF is consistently better than the KF. The fuzzy logic can be used with one of the filters for the better position estimation.

II. POSITION CONTROL ALGORITHM

The position control of differential drive mobile robot can be achieved with the use of differential drive mechanism and position control algorithm for high accuracy and mobility of the mobile robot. This section gives the detail information of the position control algorithm for mobile robot to move collision free in the constraint environment with high precision and accuracy. Before introducing Position Control Algorithm, the basics of differential drive mobile robot in terms of velocity and direction are mentioned below:

There are four possibilities for varying the velocity and direction to achieve the required goal position:

a) Both the wheels are turning in same direction at same velocity which leads which leads the robot to the straight path.
b) Both the wheels are turning in the opposite direction at the same velocity which leads the robot to turn around the place.
c) Right wheel turning counter-clockwise and left wheel turning clockwise at different velocity which leads the robot to turn right.
d) Right wheel turning clockwise and left wheel turning counter-clockwise at different velocity which leads the robot to turn left.

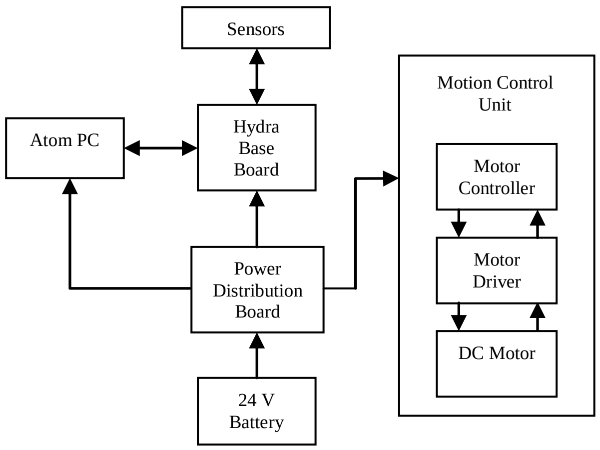

Fig. 1 System Configuration of the Mobile Robot

Depending on the environment where the robot works, the algorithm for the differential drive mobile robot system can be classified into two categories: sequential and autonomous. For sequential robot system, the environment must be perfectly structured because the robot is programmed to handle the object at the exact position. If the object location is somewhat different from the programmed one, the task may fail. Fig. 1 shows the system configuration of the differential drive mobile robot. It contains Atom PC, Hydra base board and the motion control unit which deals with the movement of the mobile robot in constrained environment. Motor controller interfaces with motor driver and receives encoder pulse which is transferred to the microcontroller base board. The Pulse Width Modulation signals for given to the motor drivers. Power distribution board is used for power regulation throughout the system with 24V batter supply.

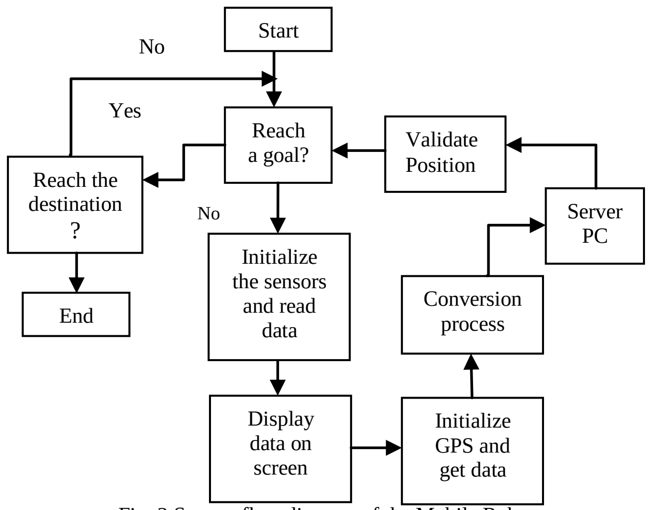

Fig. 2 System flow diagram of the Mobile Robot

Fig. 2 shows the system flow diagram of differential drive mobile robot. To detect static obstacles in the given environment, ultrasonic sensors and infrared sensors are used. The sensors are interfaced with the hydra base board and can be accessed through Atom PC. The differential drive mobile robot has eight ultrasonic sensors and six Infrared sensors located. The range of ultrasonic sensors has 20 cm to 400 cm with 60 deg and infrared sensors has 10 cm to 80 cm of range i.e. detection area. When the mobile robot moves along the desired path or trajectory, the graph of two sensors is plotted on the LCD screen as shown in Fig. 4 and Fig. 5. The graph shows the detection of the obstacles within the range of the sensors.

The Global Positioning System (GPS) is used for locating position, getting coordinates or measurement purpose. The position data obtained in Latitude and Longitude are converted into length parameters i.e. in meters. The converted data is plotted in X and Y coordinates as shown in Fig. 7. Position accuracy is measured in terms of millimetre as shown in Table I. The distance between two points can be determined and also how far the location is from another location can be determined. GSM Sim 908 module with GPS module is used for locating and measuring robot's current position with respect to the initial point.

Path tracking control on complex plane trajectories for a differential wheeled mobile robot with memorized trajectories is presented [6]. The path deviation is corrected by on-line adjustment of the desired linear and rotational velocities of the robot in the execution level called path-tracking control. Dynamic constraints were considered for robot motion and it employed the bang-bang control scheme to make the tracking motion as smooth as possible in minimum time. To overcome the non-holonomic problem associated with steering of wheeled mobile robot, the concept of the landing curve is introduced [6].

Fig. 3 shows the software flow of the differential drive mobile robot. To reflect the differential drive mobile robot behaviours acquired from differential drive motion equation and to demonstrate generalization and adaption capabilities, the mobile robot is experimented in four different types of static environments. The differential drive should be considered as information regarding the speed and acceleration in various combinations of directions can be used to achieve desired path in a constrained environment.

Initialization of the mobile robot is followed by the command signal from user interface.

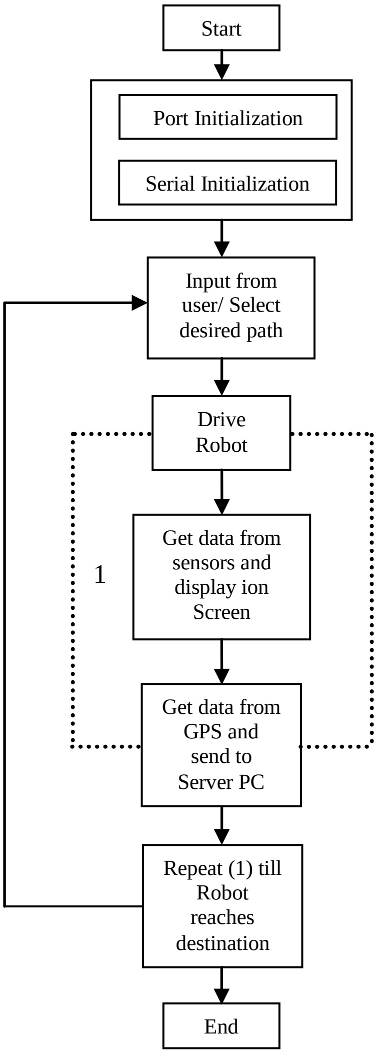

Fig. 3 Software flow diagram of Mobile Robot

There are four different paths where, users can specify the path to be run which is taken as command signal by the system. Considering certain pre-defined values, the robot moves in a desired path. The graph of ultrasonic sensor and infrared sensor is plotted and is displayed on the LCD screen as shown in Fig. 4 and Fig. 5. There are 8 Ultrasonic sensors having range of 20 *cm* - 400 *cm* and 6 Infrared sensors having range 10 *cm* - 80 *cm* located on the mobile robot as shown in Fig. 6. The graph lets the user know the status of obstacles in the constrained environment. As shown in Fig. 4, the green thick lines indicate the ultrasonics sensory data and the blue thin lines indicate the infrared sensory data. Comparing two figures, Fig. 4 and Fig. 5, obstacle detection process is indicated on the LCD screen. In Fig. 4, the obstacle is small in terms height so the ultrasonic sensors gives full length line indication which means that no object is detect by the ultrasonic sensors.

III. EXPERIMENTAL RESULTS

Real-time experiments were carried out on differential drive mobile robot to overcome the position control problems incorporated in the mobile robot. The experimental differential drive mobile robot platform is shown in Fig. 6. This robotic mobile platform was available in Mechatronics LAB at Department of Mechanical, Sinhgad College of Engineering, Pune. The position control algorithm is proposed to show the effectiveness in attaining desired position in the constrained environment. The system configuration of the mobile robot is shown in Fig. 1. In the differential drive mobile robot, the feedback signals are given by the ultrasonic sensory and infrared sensory modules are provided to the mobile robot as the environment information to detect the obstacles.

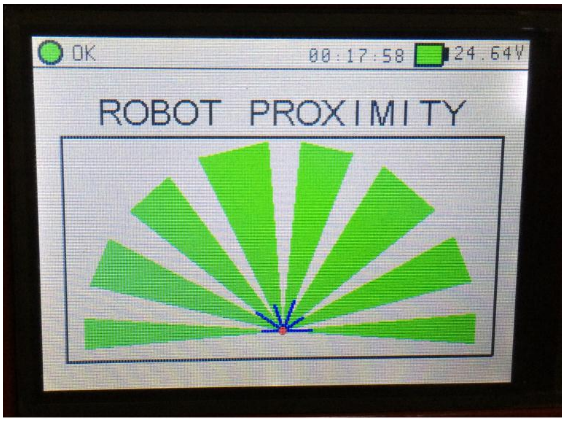

Fig. 4 Graph plot of Ultrasonic and Infrared sensors (Type 1)

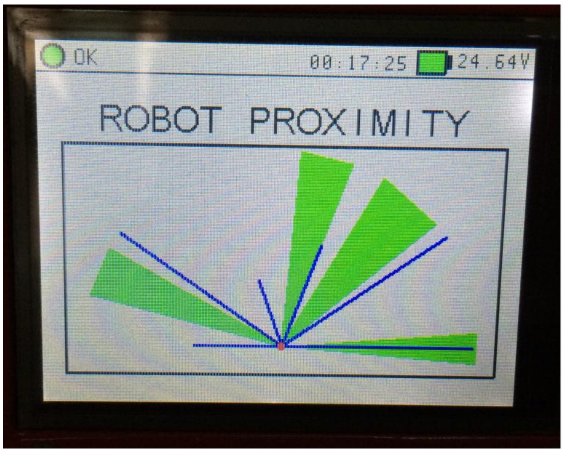

Fig. 5 Graph plot of Ultrasonic and Infrared sensors (Type 2)

The algorithm is implemented in C language whereby the environment is studied in a two dimensional coordinate system. The operating system used was WIN 7. The position control algorithm permits the robot to move from the initial position to the desired position following the estimated path. High-level programming including desired motion generation are written in C code and run with a sampling time of Ts = 100 *ms*. Server PC is used provides a user interface with real-time visualization. Wheel Velocity equations,

$$\omega\left(R+\frac{l}{2}\right)=V_r \tag{1}$$

$$\omega\left(R-\frac{l}{2}\right)=V_l \tag{2}$$

where,

l = the distance between the centers of the two wheels,

V_r = the right wheel velocity along the ground,

V_l = the left wheel velocity along the ground,

R = the distance from the Instantaneous Center of Curvature (ICC) to the midpoint between the wheels

The real-time experiments are carried out on robotic mobile platform, a general purpose robot available in Mechatronics

Lab at Department of Mechanical, Sinhgad College of Engineering, Pune as shown in Fig. 6.

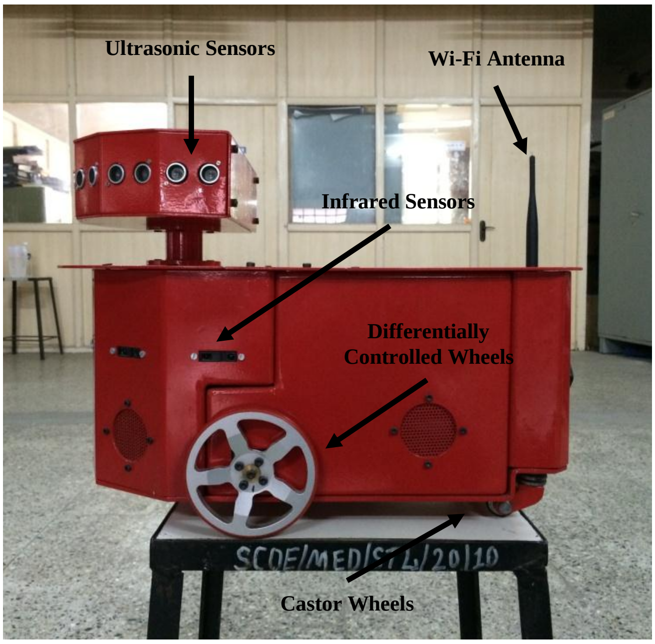

Fig. 6 The Experimental Mobile Robot Platform

PARAMETERS VALUES OF MOBILE ROBOT

A. Mobile Robot Setup

The mobile robot is a programmable general purpose robot which was available in Mechatronics Lab at Department of Mechanical, Sinhgad College of Engineering, Pune as shown in Fig. 6. The technical and software aspects are detailed below:

1) Technical Specifications: The robot has differential drive mechanism having dimensions 430mm×292mm×322mm (L×W×H), Mild Steel. Its 10.5 cm diameter wheel can deal with any indoor surface. As this differential drive mobile robot is holonomic, it can turn in its place. It forms a circle of 25 cm radius when only one wheel of any side is moved. The mobile robot is equipped with Atom PC and 256 MB of RAM.

2) Software Specifications: The mobile robot can be run from the user or client remotely using Wi-Fi server. Users are able to design their own programs under WIN32 using C/C++ compiler. Various communication protocols such as UART, SPI, CAN, Ethernet have been used for transfer of sensor data, encoder information and I/O signals to microcontroller and then to Atom PC or Server PC and also to returns control signals.

B. Position Control Results

The real-time experiments were performed for four different trajectories as shown in Fig. 7-10. There are two open loop trajectories Fig.7 and Fig. 8 and two closed loop trajectories Fig. 9, Fig. 10. In closed loop paths, the mobile robot starts at a specified initial point and returns to the final (initial) point. In open loop paths, the mobile robot starts at a specified initial point and reached the desired point away from the initial point. Two types of environment are been used for Path C and Path D where there are static obstacles placed at known distances. For all cases, the experimental data is summarised in Table II, III, IV and V.

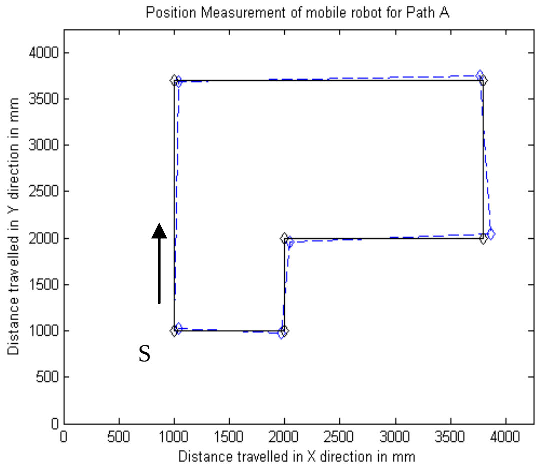

Fig. 7 Position measurement of Mobile Robot for Path A

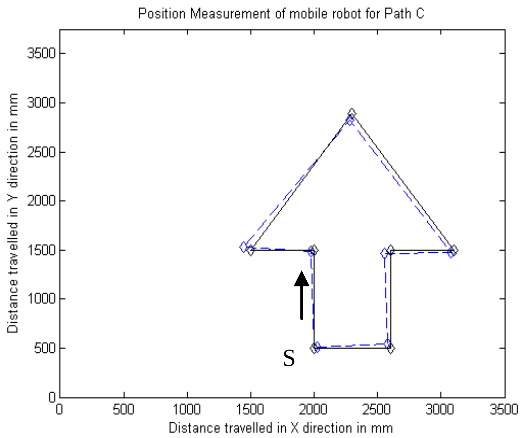

Fig. 8 Position measurement of Mobile Robot for Path B

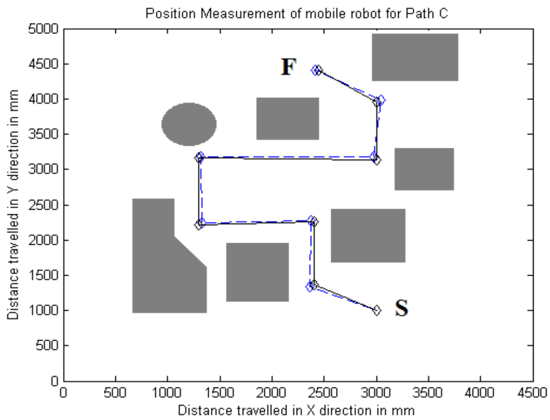

Fig. 9 Position measurement of Mobile Robot for Path C

The path was tracked as desired with some expected tolerances as shown in Fig. 7-10 keeping velocity constant for all trajectories. All the experiments performed had expected errors: the orientation, lateral and longitudinal errors that tend towards expectable numbers. The errors are described in terms of two dimensional coordinates from the desired coordinates as shown in Table II to V. The trajectories obtained in Fig. 7-10 are using position control algorithm. Fig. 7- 10 shows the real-time experiments carried on the differential drive mobile robot using position control algorithm which is robust with some system uncertainties.

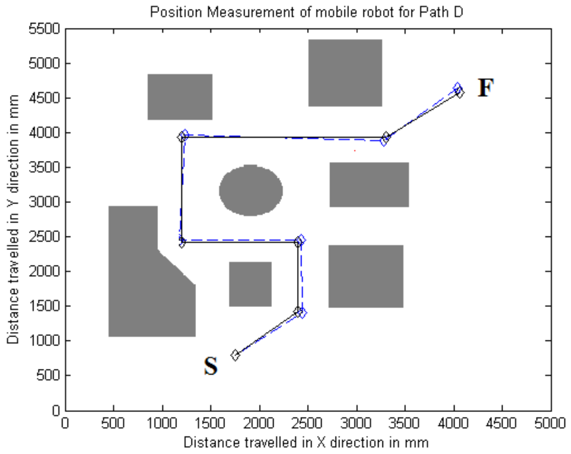

Fig. 10 Position measurement of Mobile Robot for Path D

Table I and Table II presents the experimental results of Path A and Path B, where the closed loop path is successfully executed as the mobile robot reaches the initial point with executable tolerances as shown in Fig. 7 and Fig. 8. There are lateral as well as longitudinal errors shown in Table II and Table III which are under tolerable limit considering the trajectory. Table IV and Table V presents the experimental results of path C and path D respectively where, the open loop path was successfully executed as the mobile robot reached the desired (Final) point with expectable tolerances as shown in Fig. 9 and Fig. 10. The maximum absolute values of lateral and longitudinal errors are under 0.075 *m* and the maximum absolute values of orientation errors is under 5 *deg.*

IV. CONCLUSION

This paper presents the position control algorithm for the differential drive mobile robot in a constrained environment. The proposed algorithm is for the static obstacles considering the aspects of the environment. The positional accuracy of the mobile robot i.e. the lateral and longitudinal errors are under 0.075 *m* (absolute values). The experimental results show that the trajectory path is attained with respect to desired trajectory path.

The mobility of the differential drive mobile robot is more efficient considering the experimental results. The mobility of the mobile robot is challenged with static obstacles and the obstacles are avoided successfully. For indoor surfaces, the mobility of the differential drive mobile robot is most concerned. The turning radius of the mobile robot is kept small so that it can be turned with shortest radius. For further development, the use of Omni-wheels can be put into practise for least short turn at its own place.

The experimental tests presented in this paper represent the performance of the controllers. The results summarised can be used as a guidelines for implementation of the position control algorithm for different types of mobile robots. For more advance use of this type of mobile robots, it can be preferred mostly in hospitals (Service Robots) and in defence department (Surveillance Robot).

From experimental results, it is seen that the proposed position control algorithm is indeed able to travel in hospital collision free environment or any organised work place where the arrangement of the objects in the work place are not changed frequently.

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