A Unique Path Tracking Method of a Rectangular Robot

D K Biswas, S Bhaumik, J Saha

Abstract

Path planning of holonomic robot is a difficult task particularly when the robot has a finite size with holonomic characteristics. Basically the kinematic configuration in each stepwise movement is difficult to predict before the findings of gait constraints. So far the path planners are available those are worked on the movement of geometric CG vector but in our analysis CG becomes the secondary parameter rather the centre points of front and rear plays an important role in path planning. Moreover the analysis results show that the path obtained in this methodology is more stable than the earlier analysis. In each instant the pose variants are calculated and the related required data are handed over to find out the decisive variable in respect of its pose. The algorithm developed is based on geometric intervention of various curves and geometric figures. The chronology of this development is maintained and elaborated sequentially.

Keywords: Robot, trajectory, CG, path planning, potential field, heading angle

1 Introduction

Navigation of autonomous and intelligent robotic vehicle in known workspace require a well accepted, fast, optimal and on-line path planning algorithm that can perform efficiently and effectively [1,2]. The planning is function or task specific and track or path specific. The task is predefined or autonomous as per the requirement and stationary but the path is environment specific and target oriented. It is to plan a task whereas planning of path necessitates goal targeted collision free space with acceptable cost in terms of time, energy and distance. An autonomous robot, working in any environment, plans a feasible trajectory avoiding obstacles on its way. This results the foremost mission for path planning of autonomous mobile robot towards exploring a realistic collision free path.

Path generation is the basic criteria for a mobile robot to be autonomous [3,4,5,6]. Problems of finding desired path or trajectory may be very simple but it is not so easy to find out a result of desired outlay. The complexity of path planning may accumulate with the increase of number of constraints such as path-planning, obstacle avoidance, kinematics, dynamics and uncertainty. These considerations make the path planning problem an active research area.

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The configuration space, C_{space}, [4,5,6,7,8] of a planner robot moving on a plane has the same dimension as the work space. If the space is free from obstacles it is C_{free} and occupied by obstacles it is C_{obs} or forbidden space. The work space of the mobile robot is throughout the free space, C_{free} and extended till boundaries of the C_{obs} or forbidden zone.

An intelligent mobile robot [1,2,7] is capable of functioning in a structured or unstructured; lightly or densely cluttered environment. The robot intelligently finds out a feasible collision free path during movement in the workspace. The path planning algorithms [4,5,6,7,8] guide the robot along the generated trajectory in the C_{free} zone satisfying implied holonomic or non-holonomic vehicle constraints. This guiding methodology drive the vehicle to satisfy the reachability criteria from initial pose to the final pose maintaining configuration space barrier. To maintain the poses a non-holonomic vehicle may require long path but holonomic vehicle, for its intrinsic kinematic constrains, can behave instantly. So the spot rotation, whatever we are habituated to listen for non-holonomic vehicle is almost imaginary.

A collision free path planning strategy is essentially required to realize the autonomous motion of a mobile robot through work space populated with obstacles. Various techniques such as visibility graph, Voronoi diagram, cell decomposition, behavior based model, genetic algorithm [6,7,8,9] etc are very much fruitful to search for the free space in the environment. All the methods are ‘off-line’ and check whether the goal is reachable or not prior to start moving.

The robot should have the ability to perform as per the requirement and can take decisions independently to avoid collision with any unwanted perturbation which has appeared on its path. In each step of online planning, the robot considers the environment as static and forgets all the conditions at the next moment. It starts again to examine the surroundings as well as the goal to react in the next moment and considers the environment again to cope up from any undesirable situation [10,11,12].

2 Existing Path Tracking Method

Presently in path planning and navigation the geometric centre (CG) of the mobile robot follows the trajectory [1-12]. For off line planning, where the environment is

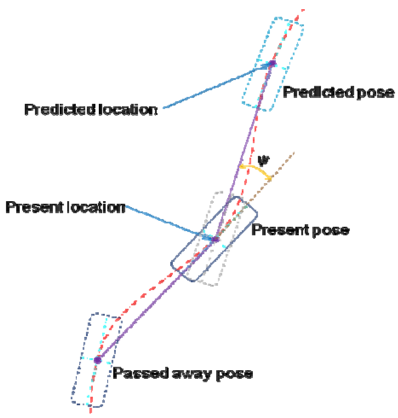

Figure 1: Present method of path tracking by a rigid body robot, path points traced by the CG of the robot

known prior to the robot, construction of path curve is easy but in unknown environment generation of path curve from start to GOAL point is not possible at any intermediate running condition. In this unknown environment the robot is awaiting for the information of existence of the next predicted point to traverse. A series of path points generated during the course of action and presently the C.G. of the robot should pass through the generated path, fig-1. The tracking method is also interesting. Each existing predicted points is targeted as soon as the robot reaches its current location. For a wheeled or legged robot this technique of path following is considered and all the related calculations are focused with CG guiding technique.

3 Robot Follows Straight Line

In path planning problem, the computer generates path points in 2D or 3D workspace from the path planning algorithm. In broad sense these path points are continuous in

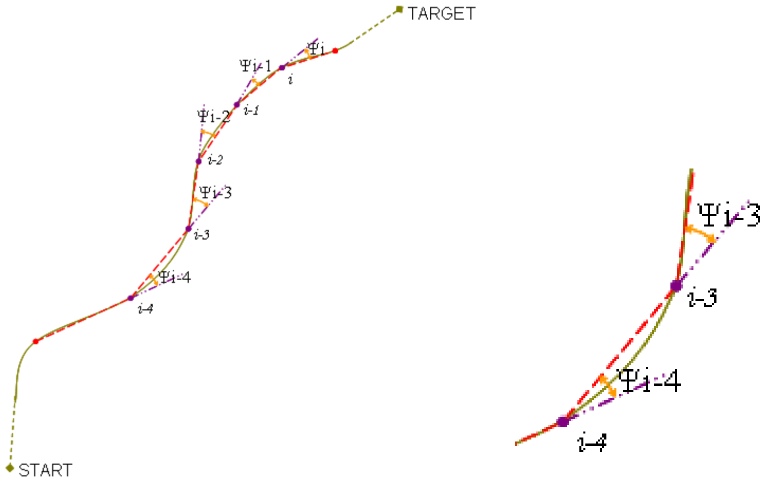

Figure 2: The actual trajectory of any mobile robot and its heading angles at each step during traversal along any generated path

nature and following certain path planning algorithm generates continuous curvature positions. All the generated path points/positions are minutely discrete in nature. This means all the path planning algorithms generate discrete path points which follows certain planning rules following the planning algorithm as shown in Figure below. To reach to the goal/target pose starting from the initial pose the autonomous robotic vehicle follows these discretely generated points. There is sudden change in position of the robot from one pose $(i-1)^{th}$ to the next i^{th} pose. This sudden change creates stair casing effect on the robotic path which can be connected by straight lines. In path planning problem the robot has to predict the next incremental position in terms of (x,y,z) cartecian coordinates, which means that there is no information present between two successive positions e.g. $(i-1)^{th}$ and i^{th} positions. The robot virtually jumps from $(i-1)^{th}$ position to i^{th} position. If the present location is at $(i-1)^{th}$ point then the predicted position calculated by various path planning algorithm as i^{th} the feasible existence of which is also checked for obstacle avoidance. The robot targetted the valid predicted position following LOS (Line of Sight), which results a straight line.

4 Path Planning Algorithm

Path planning of robot using off-line or on-line technique require well established, fast, efficient and low cost algorithm. To get a smooth and stabilized movement of a robot the path planning algorithm so chosen must be fast and real time. There are many on line path planning methods present in the literature in the area of soft computation and classical technique. Soft computational methodologies are not much faster and real time, they may lead optimized path but classical techniques are faster and the path generated may not be optimal but near optimal path may be resulted. Out of the entire path planning techniques, irrespective of some inherent problems, the Potential Field Method (PFM) is one of the best path planning algorithm [9,12,13,14], which produce fast, agile and near optimal path in both ways, ON-LINE and OFF-LINE planning. In this methodology the robot is considered as positively charged particle that attracted due to the presence of negatively charged Goal and repulsed by positively charged mobile agents or obstacles. In combined effect the robot follows the resultant force vector. The nearest obstacles are considered as real and the others are treated as virtual obstacle and an extra weight factor is added to selected obstacle. This forcibly found the predicted position and the existence of the predicted position is quantified by checking feasibility using the PFM.

4.1 Potential function

The fastest and cheapest online path planning algorithms used in the last decades may be the Potential Field Function. This method is particularly attractive because of its elegant mathematical analysis, simple to understand, simple to implement and computationally fast [2,7,9,12,13,14]. The potential function methods direct a robot as if it were a particle moving in a gradient vector field. Gradients can be intuitively viewed as forces acting on a positively charged particle which is attracted to the negatively charged goal. Obstacles also have a positive charge which forms a zone of repulsive force vector directing the robot away from obstacles. The combination of repulsive and attractive forces hopefully directs the robot from the start location to the goal location while avoiding obstacles.

Knowing the potential function (on which the performance of the approach will depend), the force can be determined as follows:

$$\mathrm{F(q)} = -\vec{\nabla} U(q) \tag{1}$$

Where q indicates the position of a robot, U(q) is the artificial potential value at the position q, F(q) indicates the force experienced by the robot at the position q, and

$$\vec{\nabla} U(q) = \begin{bmatrix} \dfrac{\partial U}{\partial q_1} \\ \vdots \\ \dfrac{\partial U}{\partial q_n} \end{bmatrix} \tag{2}$$

The combined force experienced by the robot at a position X is calculated by considering the attractive and repulsive forces as given below.

$$F_{res}(q) = F_{att}(q) + F_{rep}(q) \tag{3}$$

The robot moves in the direction of resultant force with a speed proportional to the magnitude of the resultant force noting that the maximum velocity is predefined by the actuation system and the computational interval.

5 Proposed Methodology

The proposed method required a holonomic robotic system. Non-holonomic system cannot perform as per the instruction of the algorithm. So only the holonomic robotic system such as quadruped robot can follow this development. We have chosen a quadruped robot for implementation of the algorithm with 3DOF leg having compliance. The centre line (CL) of the robot is chosen for our analysis. The path followed by the robot is shown and plotted graphically in MATLAB environment. A comprehensive comparison is drawn between angular deviation of CG following holonomic or non-holonomic robot and the holonomic robot which follows proposed method.

During traversal along an online path presently the robot is considered as a point robot basically the CG of the robot is chosen. It starts from the initial position and tracked all the generated points and finally reached the target location. But to implement our technique two CG points of a robot is considered, the Front CG and the Rear CG. This is more practical as the robot has certain length. The holonomic robot has propelling and steering capability in all the actuation set (like robot leg) at any instant.

5.1 Background

In this analysis the mobile robot is considered as combination of three sub modules, combined in a single rigid body; the frontal portion, the body and the rear part. The geometric centre of the frontal portion, the frontal CG (Geometric Centre of front drive system) and the geometric centre of the rear drive system, the rear CG are considered for the path planning problem instead of the CG (Geometric Centre) of the whole body or the origin of the body reference frame. The beauty of selecting these CG's is that they produce a linear pose of the robot in every step by which the robot is moving forward. But present scenario is such that the pose is dependent on the heading angle and the positional information of CG of the robot. This produces instantaneous centre of rotation that results spot rotation causing huge spike in dynamics. The method of movement behaves like a vector but actually the motion produced by scalar.

In this methodology first of all the environmental data are collected for its target finding notion. The data's are segregated accordingly as per the configuration space and decisions are taken to find the free space for shortest route. Once the shortest route is selected the algorithm finds out the position of frontal CG as step position and following geometry based curve intersection method finds the rear CG. Once the process starts, it ends at the target position.

5.2 Finding rear CG

To find the positional information of each CG we have adopted a very lucid and easy method. With reference to the figure below considering the robot length be 'L' and the step distance between two consecutive points 'n^{th}' and '$n\text{-}1^{th}$' path points be 'ds' and the kinematic configuration of the robot at any instant is shown in fig-3. It is to be noted that the relation between the robot length and the maximum step size to be selected as 'L>ds'. In any instantaneous step the head follows each of the step position. But where will be the position of the tail? To find that location we

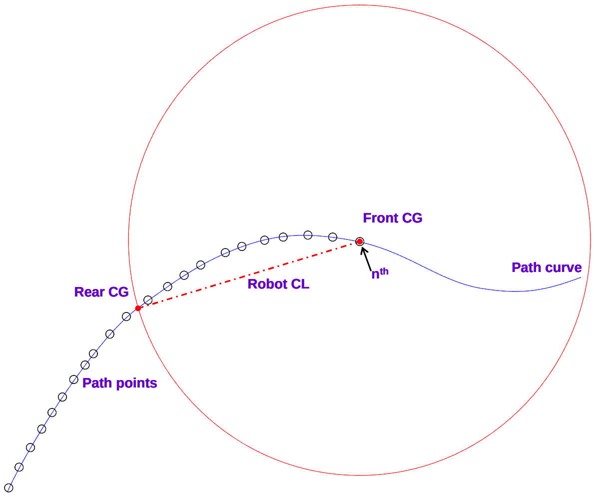

Figure 3: Instantaneous robot circle and the path points

have considered intersection points of circle of radius 'L' and the line connected by two closest points of the boundary of the circle. In this methodology we use the Boolean algebra. The intersection between the set of path points and the circle is considered as internal points of the circle and all other path points are external. Out of all the internal points one point is closest to the periphery of the circle and out of all the external points one is closest to the outside of the circle. These two points are the mostly useful set for finding out the rear CG within certain tolerance. The valid boundary path points found out as per the Boolean algebra and through other logics (as stated earlier) be the two consecutive points of the generated path, and they are $(n\text{-}m)^{th}$ and $(n\text{-}m\text{-}1)^{th}$. This pair of the path points generates the valid solution for the position of the rear CG. The line joining this pair of points intersects the circle provides two solutions but only one solution is closest to the $(n\text{-}m)^{th}$ path points and that is the valid solution fig-4. The poses of the robot depends on the positional information of front and rear CG

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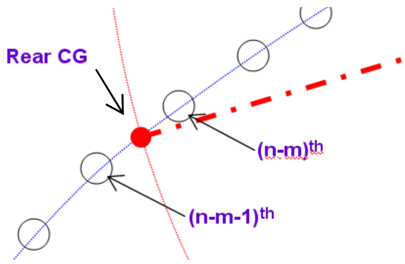


Figure 4: Enlarged view of instantaneous rear CG and the path points

6 Simulation Result

We have considered a 2D workspace of 35x45 m^2 with lightly cluttered static obstacles in which a robot of length 1m is under consideration. The robot has stations

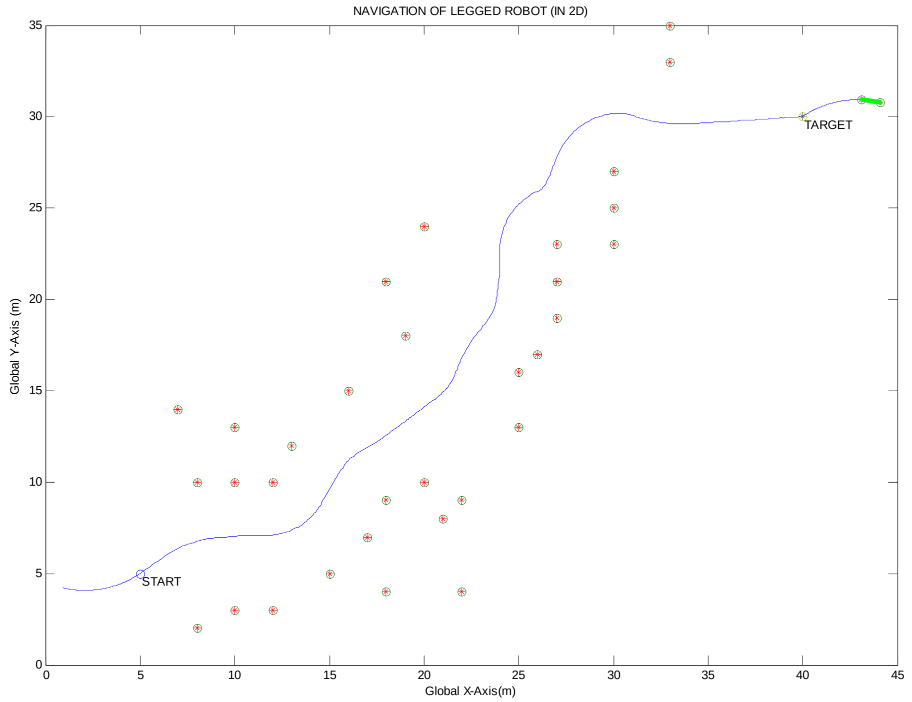


Figure 5: The path followed by a holonomic robot of finite length avoiding obstacles on its path.

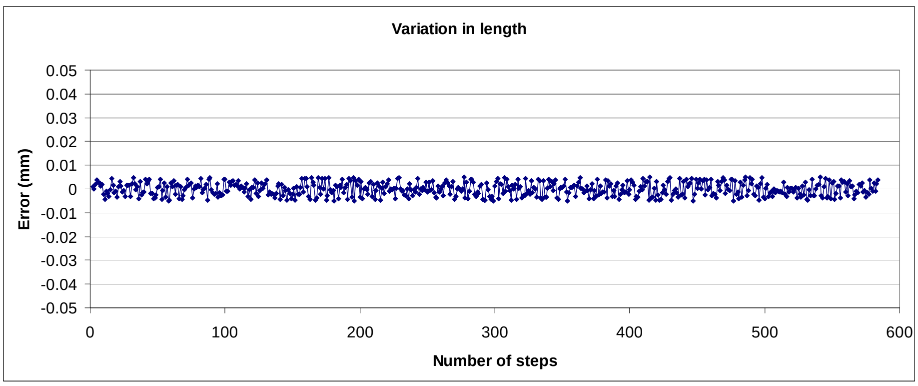


Figure 6: Error in length of the robot in each intermediate steps

at starting and goal position which are predefined, but optional. Path generated using classical potential field to verify the feasibility of the proposed algorithm. The path traced by the robot through this methodology is shown in fig-5 and found that the robot reaches to its destination without colliding with any obstacle. During the path traversal the exact solution of finding the Rear CG is not possible. So the optimum values of nearness of the exact solution are evaluated and the values are found within acceptable tolerance value. During this course of action the length of the robot virtually changing within the tolerance and the variation of length is shown in fig-6. The maximum deviation in length for 1 meter length of robot is calculated and is within 0.01mm as shown in fig-6. This finding states that the robot may move without any trouble with the help of any holonomic system for e.g. legged robot. The compliance of the mechanical system and the system tolerance may take care of to compensate this minor error.

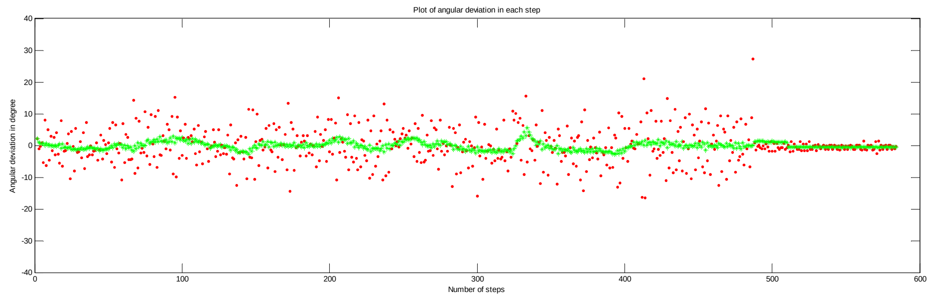
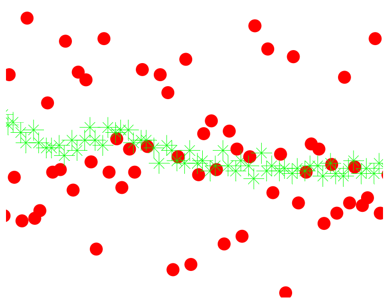


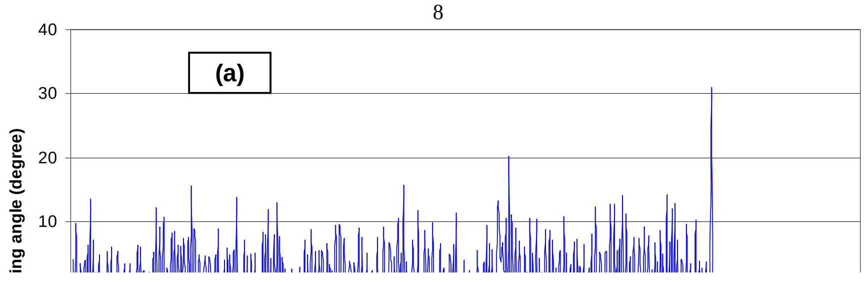
Figure 7: Variation of heading angle in each step movement of the robot. * Points imply that the variations of heading angles are less than the earlier method.



The dot points (red) are the rotational angles (heading angle) found by earlier method and the * points (green) are the rotational angles of the robot generated by the proposed method in each step, fig-7. To understand the fluctuation of angular movement an enlarge view is given, fig-8. This implies that the robot feels less vibration, it uses less energy and life of the system may increase.

7 Discussion

The robot is considered as a straight line segment connecting the front and rear CG of length one meter only. It is working in a 2 dimensional environment with the presence of many obstacles. Virtual navigational sensors are attached at the front side of the robot and at the both sides along the central axis there are proximity sensors and the means of locomotion are considered to be attached at suitable positions of front and rear CG. Each CG has to pass through the path so generated by



the proposed planning algorithm. It is to be considered that the robot has certain flexibility to impart springing action to accommodate the compliance characteristics and this is achieved by the compliance present in the leg. This allows that the robot is expanding or contracting to a certain amount without affecting the basic shape of the rigid portion of the robot.

Online path planning of this robot in an unstructured unknown environment is a difficult task. The computation related to the robot is much higher compare to point robot and if the path planning algorithm is little complicated then the total computation time required will be more which may lead collision instead of avoidance. The obstacle may come closer before the end of single step computation of taking decision.

In our present task the robot's frontal CG follows the path planning decisions but the rear CG is computed on the basis of circle and straight line intersection. But the exact solution is not found out so theory of approximation is applied along with the Boolean algorithm. This results an approximate solution that is closest to the exact solution.

It is to be noted that the robot is a quasi-rigid link of finite length with compliant leg. Obstacle avoidance is easy in lightly cluttered environment. The robot has an initial and final station those maintain continuity and for our robot these station are the segment of a circular path.

The robot rotates instantaneously in an amount of absolute heading angle to align itself towards the next predicted position. From analysis it is shown that the fluctuation of change of heading angle is more in present method comparing to the proposed method as shown in figure-9. The present method leads huge angular velocity and acceleration in proportion to the huge change of heading angle in comparison to the angular velocity and acceleration of the proposed method that resulted in proportion to the change of heading angle. It is also to be noted that due to less variation of angular rotation the robot leads a smooth and less vibratory path. The algorithm so developed is uniquely applicable to holonomic robot such as legged robot. To utilize this for nonholonomic robot the algorithm has to be changed accordingly, where only the midpoint of the two CG may need to be found out with other parameters.

8 Scope for Future Work

The proposed planning method is simple and the computational complexity is less so, this can be used in wheeled or legged holonomic robots for implementations.

Only the body segment is considered in the present work the locomotors will be considered in future work.

Dynamic properties of the robot are not considered in the present work, which will be considered in future study.

Only 2-D workspace is considered in the present work but in future, an attempt will be made to consider a 3-D workspace.

9 Conclusions

Path planning problems of holonomic robots working in a 2D workspace have been solved using a unique path planning method. The performance of the path planning approach depends on the nature of the functions used. As the potential field approach is found to be computationally not so complex, it is used for on-line implementations that results a smooth path.

The frontal CG is the director and it helps to find the rear CG of the robot in consideration. The two CG provides the necessary pose information at any instant. This pose information is generated through the path planning algorithm. The robot must pass through the curve generated/constructed by path data points. For off line planning, where the environment is known prior to the robot, construction of curve is easy but in unknown environment generation of curved path from start to GOAL point is not possible before reaching to the goal. In this unknown environment the robot is awaiting for the information of existence of the next predicted point to traverse. So a series of path points generated during the course of action. In present method both the C.G. of the robot have to pass through the generated path. The tracking method is also interesting. Each of the generated predicted points, which existing, is targeted as soon as the robot reaches its current location. For a single segmented wheeled or legged robot this technique of path following is considered and all the related calculations are also faced with both CG guiding technique.

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