Navigation of Mobile Robot in the Presence of Static Obstacles of Various Shapes

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Abstract- The main objective of path planning is to acquire a collision free path for a mobile robot operating in various environments. Diverse approaches and techniques have been implemented to solve a path planning problem by considering certain factors like obstacle shape, its orientation, type of environment etc. Based on the surrounding environment the robot navigates globally or locally. This paper focuses on the navigation of mobile robot operating in a static environment consisting of elliptical and polygonal obstacles. A mathematical formulation has been developed to obtain these paths and also to find the shortest path among them using Centre of Gravity Approach (CGA) and Coordinate Reference Frame (CRF) technique. The simulation results prove the proposed approach to be effective as the robot navigates to the defined target point without colliding with the obstacles in the environment.

Index terms- path planning, collision avoidance, mobile robot, static obstacles, off-line environment

I. INTRODUCTION

Robotics is a fascinating field with a wide range of development and utility, both technically and commercially. In particular, the field of autonomous mobile robots gained serious attention due to the enormous potential in various sectors ranging from simple household to complex industrial, military applications. For instance the role of these autonomous mobile robots had been greatly exploited in areas which include transportation of cargo, unmanned bomb disposal, planet and underwater exploration [1] supermarkets or airports [2] and service for elderly persons. One of the key aspects for fine tuning the navigation of these mobile robots is motion planning which aims to find a suitable collision-free path from an initial configuration to final (target) configuration for a mobile robot moving in an obstacle prone environment. Many techniques and methods had been previously demonstrated and adopted to solve a path-planning problem [3] where each method has its own prominence in attaining the optimal path over others, they possess certain amount of limitations. Distance is termed to be a common criterion for these problems [4]. This paper explains a methodology for a static path planning problem in attaining the shortest path among elliptical obstacle to minimizing the distance of travel thereby reducing the time and cost of travel.

In the past, various obstacle avoidance algorithms had been developed and are briefly classified into two major areas: global path planning and local path planning [5]. In global path planning (off-line) the robot is familiar with the surrounding environment consisting of obstacles in advance, and navigates in an off-line mode to reach its destination by avoiding the obstacles. On the other hand, in local path planning (on line) the robot is unaware of the surrounding environment in advance; hence the motion planning of a robot is done dynamically from the information given by the sensor For an on-line path planning it is essential for a robot to begun its initial path through off-line mode and then later it switches to on-line depending on the changes occurring in the obstacle scenario. Therefore it is essential to navigate a robot globally where in the later case it can be extended to a local path planning problem using sensors.

Many path planning methods [6-12] are proposed in the past. The Configuration Space Approach (CSA) is a fundamental approach where a robot is represented as point robot, thus reducing it to a 2-D problem. Roadmap is another approach which is a graph based modeling. Voronoi diagram and Visibility graph are well known road map techniques. In Visibility graph approach the shortest path is recognized by joining the two vertices of a polygon that can see each other in a graph drawn. Path attained through Voronoi diagram is constructed by using a set of data points which are equidistant from 2 or more obstacles and generally the path is not the shortest. Grid method is another classic approach under cell decomposition method where an environmental map is generated with the help of grids. There are few difficulties in this technique like knowing the size of grid, more memory space etc. In Potential Field Approach the robot navigates in the direction of the resultant force. This approach is simple but a robot might be trapped when the opposite forces of equal magnitude get cancelled. These approaches have computational difficulty in higher dimensions or non-polygonal world. Then we have Particle Swarm Optimization and Genetic Algorithm technique which are widely used algorithms for their strong optimization capabilities. The problem of path planning can be solved effectively and efficiently both in static and dynamic environment for various tasks. As they are evolutionary approaches, thus reducing the computational time when combined with classical approaches. The other optimization algorithms are Ant Colony Optimization and Simulated Annealing. Ant colony optimization is used for finding the shortest optimum path to reach the target inspired by the ferret behavior of ants. In the search space Simulated Annealing approach vertices of static and dynamic obstacles are used for finding the optimal path. Most of the approaches have been applied for polygonal obstacles and have attained competent results with a few limitations and also few approaches have been developed for solving elliptical obstacles [13-14].

The main objective of this paper is to control the navigation of a point robot present in an environment consisting of stationary obstacles and has a prior knowledge of the environment as it is a global path planning problem, to attain the shortest path. A mathematical approach has been developed and programmed using matlab which will work for any number of elliptical obstacles with various shapes and orientations. In this paper two elliptical obstacles are taken with various orientations to solve the problem of collision avoidance.The proposed method is integrated with centre of gravity approach and coordinate reference frame technique for solving the path planning problem for both polygonal and elliptical obstacles.

II. Mathematical Approach

The main purpose of path planning is to find a shortest distance path among all feasible paths attained. In this paper navigation of mobile robot in static environment is studied. In the process of solving the problem it is defined as follows. (1) The robot is a point in the configuration space. (2) The robot navigates globally so it has a prior knowledge of the environment and the obstacles present in it. (3) Considered obstacle shape is two ellipses with different orientations.

Depending on the organization of the environment i.e. source, destination and the obstacles (two ellipses) there may be four maximum possible solutions. The solutions are attained through mathematical expressions.
General form of an ellipse with centre (h, k) is:

$$\frac{(\mathbf{x}-\mathbf{h})^2}{\mathbf{a}^2}+\frac{(\mathbf{y}-\mathbf{k})^2}{\mathbf{b}^2}=\mathbf{1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{1})$$

Where a, b are semi major and semi minor axes respectively.
As two ellipses are considered there centers are (h_1, k_1) and (h_2, k_2) with major and minor axes as (a_1,b_1) and (a_2,b_2) respectively for the first and second ellipse. The orientation of the ellipse form is achieved by the product of rotational matrix with the ellipse equation. The equation of a straight line is in the form of

$$\mathbf{y}=\mathbf{mx}+\mathbf{c} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(\mathbf{2})$$

Where m is the slope and c is a y intercept
A polynomial expression was developed for finding the slope ‘m’ of common tangent between the two ellipses [15] using the above equations which are given as:

$$\mathbf{Am^4+Bm^3+Cm^2+Dm+E=0}$$

Where, A, B, C, D, E are constants
From the above expression, the value of m is determined. Since it is a forth degree expression the slope m has four values which are the slopes of the four possible paths between the two ellipses. This expression could be justified using simulation software.

III. Matlab Programming

To demonstrate the effectiveness of the approach, it is implemented and executed using matlab software. In this software we designed an environment through programming and performed several computations by altering the source and destination points and also reorienting the ellipses. Here two elliptical obstacles are considered, so a maximum of four feasible solutions are attained through execution. The shortest length among them is the required optimum path to navigate a mobile robot. Depending on the number of obstacles the possible numbers of solutions will also increase.

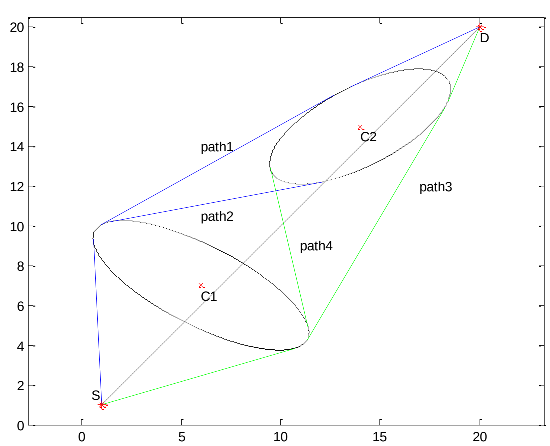

Fig 1: Feasible paths obtained through programming. Here S, D are the source and destination points. SD is a constrained path which is obstructed by the ellipses. C1 and C2 is the centre of the ellipses.

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The paths obtained through programming are shown in figure 1. As discussed earlier, in this problem four possible paths are attained with varying lengths, the length of path1 is 30.8338, path2 is 32.9343, path3 is 28.9083 and path4 is 33.2873. The shortest among them is path4 with a minimum length is the required distance to navigate a robot. This reduces the time of travel and also the travelling cost.

Simulation Results

The shortest path could be identified forthwith using centre of gravity approach (CGA) to reduce the time of evaluation.The results obtained through programming using CGA technique [16] for two obstacles is shown in figure 2

A. Two Obstacles:

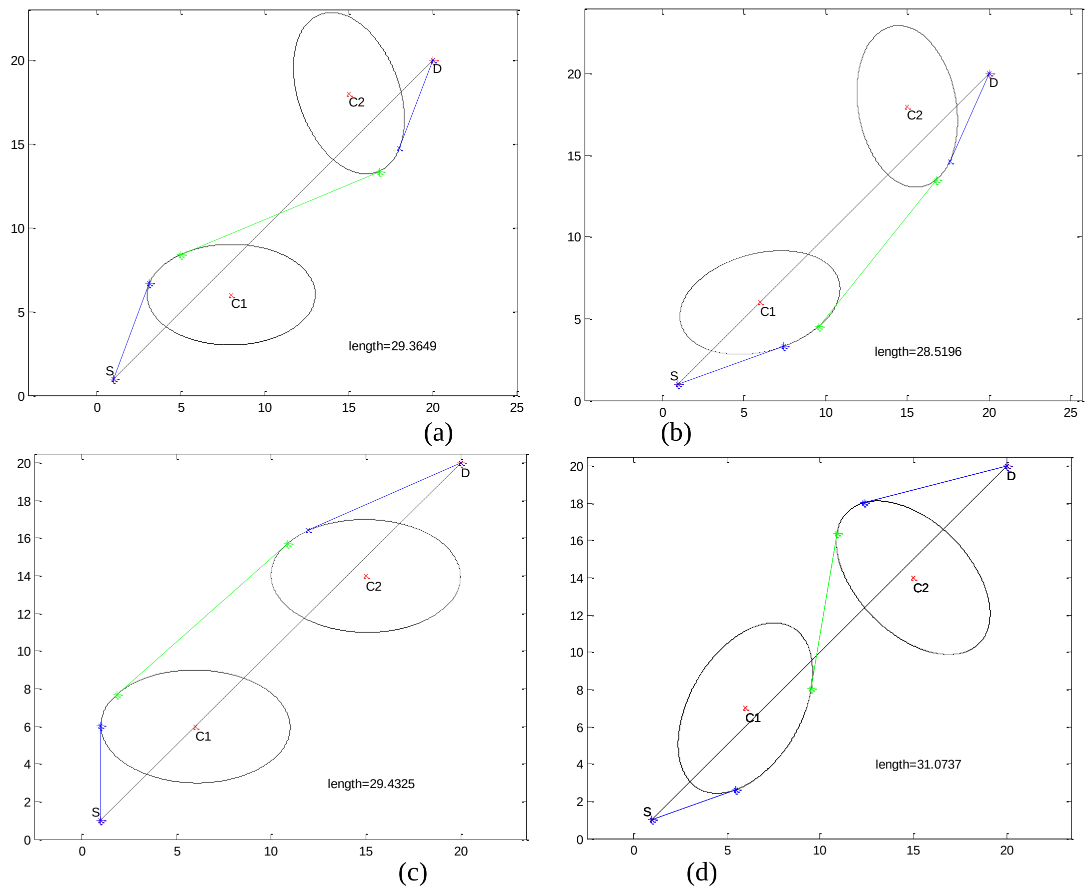

Fig 2: a, b, c, d shows the simulation results for various orientation of the obstacle. Here S,D are the source and destination points. SD is a constrained path which is obstructed by the ellipses. C1 and C2 is the centre of the ellipses.

The data has been shown in table 1.

Table 1: Problem data and optimum solution for two elliptical obstacles

S.No.	Ellipse 1		Ellipse 2		Optimum Path through CGA
Case	Centre		Centre		
	h_1	k_1	h_2	k_2	
1	6	6	15	18	29.3649
2	6	6	15	18	28.5196
3	6	6	15	14	29.4325
4	6	7	15	17	31.0737

Here, the Source is at [Sx Sy] = [1 1]
Destination at [Dx Dy] = [20 20]
Shortest Constrained Distance is the line joining source and destination = 26.8700

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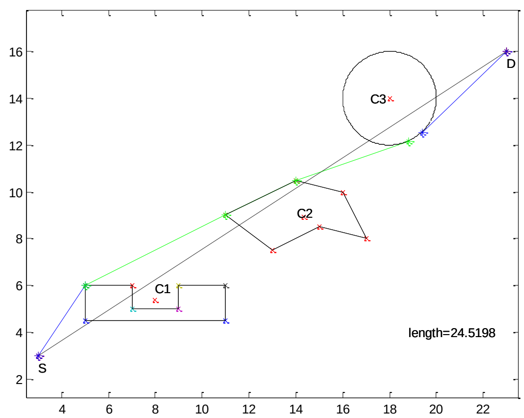
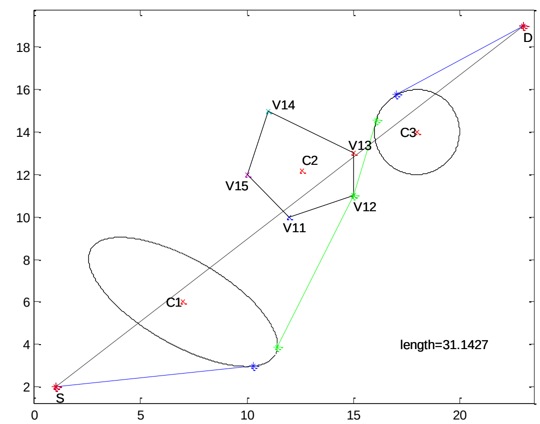
Combinations of feasible paths are attained from the start point to the target point. Among these paths the shortest unconstrained path is required in order to minimize the distance of travel. During the process of attaining these paths it is also necessary to optimize the time of programming in order to acquire the desired results. This is done by incorporating a CG technique to the developed equation in the programming. This technique helps in reducing the evaluation time and also directly generates the shortest path for the navigation of a robot to reach its destination point.

B. Multi obstacles:

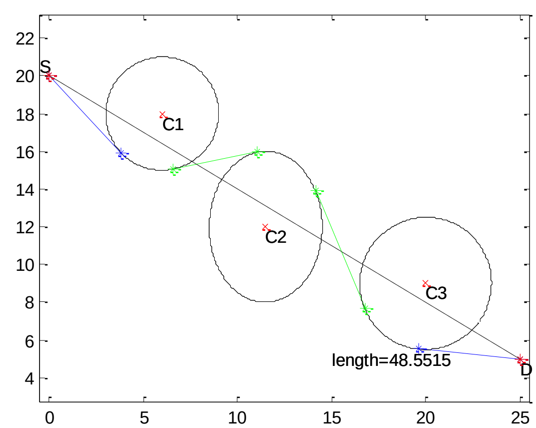
The complexity of path planning problem is further increased by including few other obstacles like polygons (regular/irregular) in the environment. For solving such problems we adopt a CRF (Coordinate reference frame) technique [17]. As CRF is a proven method for polygonal obstacles the time and complexity of evaluation for such complex problems is reduced by using it along with mathematical approach and CG technique thus obtaining the shortest path.



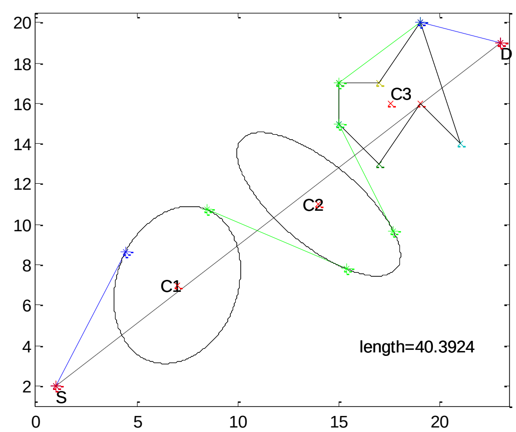
(a)



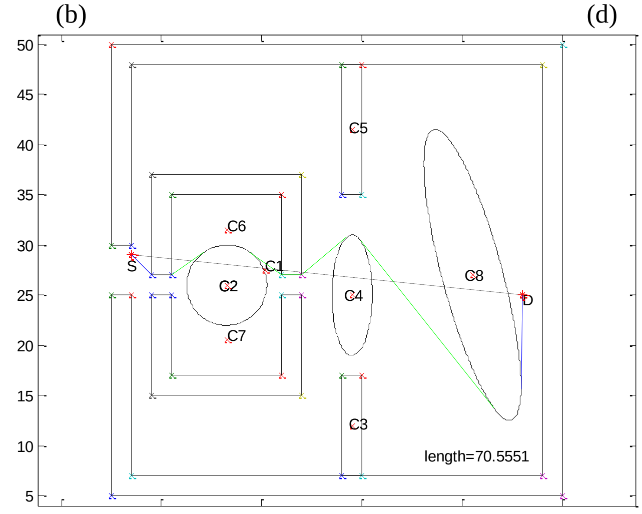
(b)



(b)



(d)



(e)

Fig 3: a, b, c, d, e shows the simulation results for various orientation of the obstacle. Here S, D is the source and destination points. SD is a constrained path which is obstructed by the ellipses. C1, C2, C3, C4, C5, C6, C7, C8 are the centers of the obstacles

As can be seen in fig 3, various kinds of paths have been generated successfully for robot navigation in the presence of multiple obstacles through programming. All the generated paths are the minimum distance paths obtained for the predicted environment.

IV. CONCLUSION

This paper presents a simple technique for solving path planning problem in a known static environment. Initially in the problem the considered obstacles are ellipses and in the later it is combined with polygons. To obtain the path between the two ellipses a unique mathematical expression has been developed from the basic equations and it works for any number of ellipses with various orientations. This has been verified from the simulation results by creating an environment in matlab software through programming. CGA is applied to the approach in the programming for finding the shortest path directly from the source to target point to reduce time of evaluation. CRF technique is used along with CGA and mathematical approach for solving multi-obstacle path planning problem to reduce computational complexity and time. The simulation results prove the effectiveness of the proposed approach in solving the path planning problem.

Future works will involve moving obstacle in dynamic 3D environment where the characteristic features like dimensions and velocity are to be considered to make it realistic. Experimentation can also be conducted in complex environments for the proposed approach in real world applications.

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