A New Dimension towards the Determination of Shortest Path for Robots using Convex Polygons

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ABSTRACT

In this paper, a optimal path planning algorithm using motion heuristics coupled with search problem is designed for a robot in a workspace full of obstacles which are polyhedral and consisting of different types of objects. Both in the simulation as well as in the real time is considered herewith. A new method of finding an obstacle collision free path from the source to the goal when the workspace is cluttered with obstacles is also developed using motion heuristics using an user friendly GUI developed in C++. The method presented is similar to the method of finding / searching a path by the humans when he / she is moving in a vehicle from the source to the destination. The method was also implemented on a real time system, say a robot and was successful. Artificial Intelligence which uses motion heuristics (search methods) is used to find the obstacle collision free path. Also, the shortest path from the source to the destination is also determined by making use of various types of sensing techniques. Here, we have presented the chain coding method of obtaining the shortest path form source to goal. Also, the mathematical development & the graphical design of the path is also incorporated in the research work undertaken in this paper & three equations are formulated. The parameters are taken into consideration while designing the path in between the obstacles are the vertices & edges of the different types of obstacles that occur in the path of motion when the robot is traversing from the source to the goal. Three types of interactions are considered while designing the path, viz., interaction between vertex of one obstacle & the other, interaction between edge of one obstacle & the other, interaction between an edge of one obstacle & the vertex of another obstacle. The main advantages of the designed path are it generates paths for the mobile part that stays well away from the obstacles ; since, the path is equidistant or midway between the obstacles and avoids collision with the obstacles, this method of planning the path using gross motion technique is, it is quite effective especially when the workspace of the robot is sparsely populated with obstacles, the path obtained is the shortest path, the path is a obstacle collision free path, the path is equidistant from the obstacles and there is no chance of collisions.

obstacle collision free path (motion) from the source to the goal in the free work space of the robot by using search technique in Artificial Intelligence using simulation in C++ & in Matlab. The work done in this paper is the simulation of the algorithm developed in [1].

Keywords Robot, Motion heuristics, Search problems, Chain coding, Shortest path.

1. INTRODUCTION

A typical robot problem solving consists of doing a household work ; say, opening a door and passing through various doors to a room to get a object. Here, it should take into consideration, the various types of obstacles that come in its way, also the front image of the scene has to be considered the most. Hence, robot vision plays a important role. In a typical formulation of a robot problem, we have a robot that is equipped with an array of various types of sensors and a set of primitive actions that it can perform in some easy way to understand the world [37]. Robot actions change one state or configuration of one world into another. For example, there are several labeled blocks lying on a table and are scattered [40]. A robot arm along with a camera system is also there [38]. The task is to pick up these blocks and place them in order [39]. In a majority of the other problems, a mobile robot with a vision system can be used to perform various tasks in a robot environment containing other objects such as to move objects from one place to another ; i.e., doing assembly operations avoiding all the collisions with the obstacles [1].

The paper is organized as follows. A brief introduction about the work was presented in the previous paragraphs. Section 2 gives the interpretation of the design of the obstacle collision free path. The mathematical interpretation is developed in the section 3 with its graphical design. Motion heuristics is dealt with in section 4. The section 5 shows the simulation results. The conclusions are presented in section 6 followed by the references.

2. INRERPRETATION OF THE DESIGN OF THE OBSTACLE COLLISION FREE PATH

One of the most important method of solving the gross motion planning problem is to go on searching all the available free paths in the work space of the robot [35]. The space in between the obstacles is referred to as the freeways along which the robot or the object can move. Translations are performed along the freeways and rotations are performed at the intersection / junctions of freeways [36]. This is an efficient method of obtaining an obstacle collision free path in the work space of the robot from source to the goal and is defined as the locus of all the points which are equidistant from two or more than two obstacle boundaries as shown in the Fig. 1 [37]. Once, the obstacle collision free paths are obtained from then source to the goal, then, the shortest path is found using graph theory techniques, search techniques and the motion heuristics [2].

There are certain advantages / disadvantages of this method of gross motion planning. They are

- It generates paths for the mobile part that stays well away from the obstacles ; since, the path is equidistant or midway between the obstacles and avoids collision with the obstacles [3].
- This method of planning the path using gross motion technique is, it is quite effective especially when the workspace of the robot is sparsely populated with obstacles [34].
- The path obtained is the shortest path [33].
- The path is a obstacle collision free path [31].
- The path is equidistant from the obstacles and there is no chance of collisions [30].

The method also works successfully when the workspace is cluttered with closely spaced obstacles, as a result of which the designed graph becomes more complex [4].
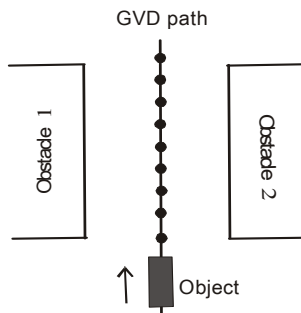

Fig. 1: Obstacle collision free path

3. MATHEMATICAL DEVELOPMENT & GRAPHICAL DESIGN OF THE PATH

Here, in this section, we develop the mathematical interpretation of the obstacle collision free path. The robot work space consists of a number of obstacles. The parameters of any obstacles are the edges and the vertices [29]. So, while constructing the obstacle collision free path from the **S** to the **G**, many types of interactions occur [28]. Because, when we move from the source to the goal, we come across edges and vertices of many obstacles [5]. Here, we have considered only the interaction between a pair of edges of two obstacles as shown in the Fig. 2 [27], [1].
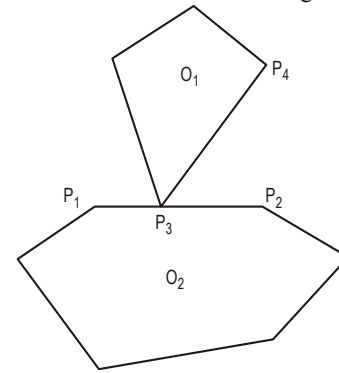

Fig. 2 : Interaction b/w a pair of edges of 2 obstacles O_1 & O_2

In this type of interaction between a pair of edges (interaction between an edge of one obstacle with an edge of another obstacle) as shown in the Fig. 2 [26]. How to construct the obstacle collision free path from S to the G when the obstacles are like this ? Consider two edges P_1P_2 and P_3P_4 of two obstacles O_1 and O_2 as shown in the Fig. 2. Here, P_3P_4 is an edge interacting with P_1P_2 at the point P_3 [6], [25].

P_1P_2 ; P_3P_4 - Two edges of obstacles O_1 and O_2 meeting at the point P_3 [1]

R - Radius of the GVD cone.

λ - Be the distance parameter measured along the edge P_1P_2 measured from P_1.

l_0 - Distance from P_1 to P_3 along P_1P_2.

l_1 - Distance from P_1 to P_5 along P_1P_2.

l_2 - Length of P_3P_4.

d - Perpendicular distance from P_4 to P_1P_2.

The radius of the obstacle collision free path along P_1P_2 can be expressed by a piece-wise linear function of λ and is given by Eq. (1), where **sgn** denotes the signum function or the sign of the particular parameter l_2 and d, l_0, l_1 and l_2 are as shown in the Fig. 3 [7], [24], [1].

$$R(\lambda) = \frac{(\lambda - l_0)\ \{l_0 - l_1 + \mathbf{sgn}(\lambda - l_0)\,l_2\}}{d}\ . \tag{1}$$

From this equation (1), we can come to a conclusion that [8] If $(\lambda - l_0) > 0$; i.e., the point P is lying to the right of P_3 ; then, l_2 is positive , sgn ( ) is +.

If $(\lambda - l_0) < 0$; i.e., the point P is lying to the left of P_3 ; then, l_2 is negative , sgn ( ) is −
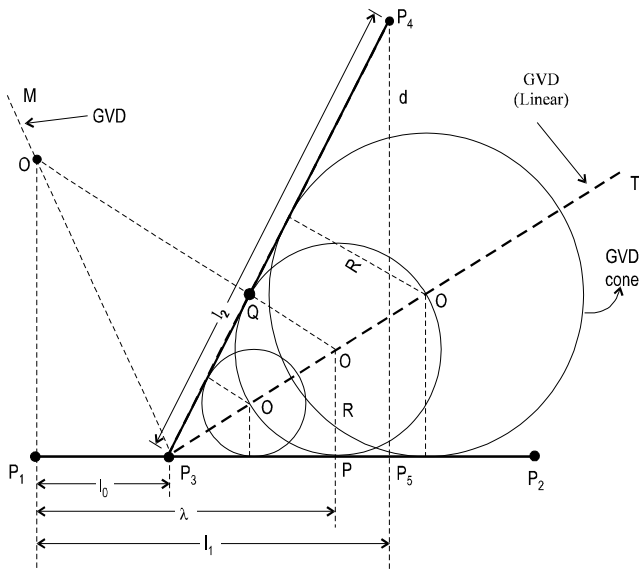
Fig. 3 : Interaction between a pair of edges

First Method of Obtaining the obstacle collision free path :

Consider a point P any where on the line $P_1 P_2$ and which is at a radial distance of λ from P_1. Draw a $\perp^r$ line (dotted) from P [9]. Find the length of this line $\perp^r$ line (dotted) by using the Eq. (1) and mark the length (PO), where PO is the radius of the obstacle collision free path circle with O as the center. With O as center, draw a circle to pass through the points Q, P. Like this, go on taking different points (P's) on the line $P_1 P_2$ and which is at a radial distance of different λ's from P_1. Go on drawing $\perp^r$ lines from P. Go on finding the length of these $\perp^r$ lines (radii) using the formula, with their centers, go on drawing circles to touch the two edges. Go on joining all the centers of the obstacle collision free path circles. Thus, we get the obstacle collision free path from the source to the goal when the obstacles edges are straight lines [1].

Second Method of Obtaining the obstacle collision free path :

Bisect the angles P4 P3 P2 and P4 P3 P1 to get different point (O's). With these points as centers, draw the circles with the radii as the perpendicular distances [11]. Join the centers of all the circles, we get the obstacle collision free path, which is nothing but the angle bisector P3 T [12]. Similarly, we get another angle bisector P3 M along which the robot or the object would move, the path being perpendicular to the previous path [10], [1].
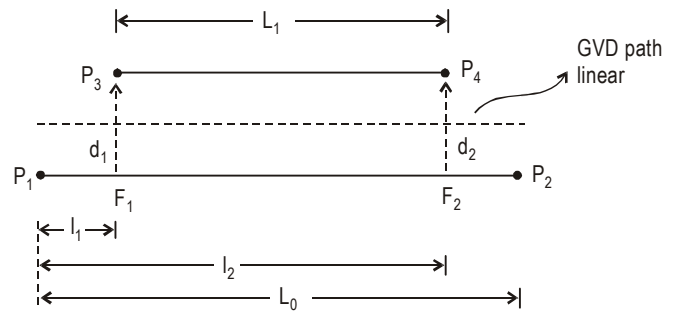

Fig. 4 : When the two edges $P_1 P_2$ and $P_3 P_4$ are parallel

Third Method of Obtaining the obstacle collision free path - *Special Case of Interaction Between Two Edges :*

When two edges P1 P2 and P3 P4 are parallel as shown in the Fig. 4, the obstacle collision free path is the mid-way path between the two edges of the obstacles [24]. Hence, to conclude, the interaction between a pair of edges is linear or a straight line [13]. If the robot or the object held by the tool / gripper moves along the obstacle collision free path, then definitely, there would be no collision of the object or the robot itself with the obstacles [14], [1].

Fourth Method of Obtaining the obstacle collision free path : Interaction Between a Vertex and an Edge

This is the second basic type of interaction while constructing a path between the vertex of an obstacle and an edge of another obstacle as shown in Fig. 6. Here, P1P2 is an edge and P3 is a vertex which is located at a perpendicular distance of d units from the edge P1P2 . The parameter λ represents the distance along the edge P1P2 measured from P1 .

The radius of the GVD is given by

$$R(\lambda) = \frac{d^2 + (\lambda - 1_1)^2}{2d} \quad \text{or} \quad R(\alpha) = \frac{d}{1 + cos(\alpha)}. \quad (2)$$

When $\lambda = 1_1$ or $\alpha = 0$; $R(\alpha) = R(\lambda) = \frac{d}{2}$, i.e., midpoint of the perpendicular distance d .

Draw a line at an angle of α from the point P3 . Find the radius using the formula $R(\alpha)$. Measure the length of the line as $P3O = R(\alpha)$. With O as the center and P3O as radius , draw a circle passing through the point P3 . This circle touches the line P1P2 at the point P . Similarly , draw a line at angle of $-\alpha$, get the center of the circle O' and the point A'. Repeat this for different angles , get the construction circles , join the center points of all the circles. We get the shortest path.
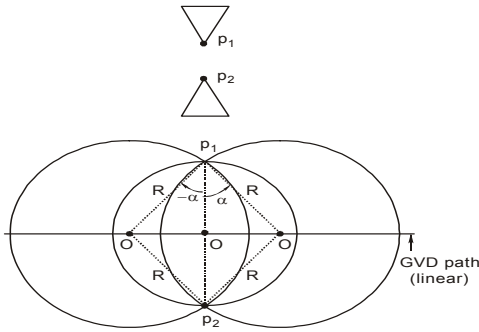
Fig. 5 : Interaction between 2 vertices of obstacles

Consider a point P at a distance of λ from P1 . Draw a ⊥r upwards from P . Find the radius of the GVD cone using the formula R(λ) . Measure this distance R along the ⊥r distance . Let it be PO = R(λ) . With O as center and PO as radius , draw a circle to pass through P . Like this, go on finding the centers of all the various circles . Join them . We get the GVD path . Therefore , the interaction between a vertex and a edge is a parabola .

Fifth Method of Obtaining the obstacle collision free path : Interaction Between a Pair of Vertices of 2 obstacles

This is the third basic type of interaction that has to be taken into consideration while constructing the GVD. P1 and P2 are two vertices of two obstacles which are separated by a distance of d units as shown in Fig. 5. Draw a line from P1 or P2 at an angle of α . Find the radius of the GVD cone using the radius formula $R(\alpha) = \frac{d}{2\cos\alpha}$. Let it be P1O = P2O = R(α) . With R(α) as radius and O as centre , draw a circle to pass through the points P1 and P2 . Like this , go on finding the center points of all the circles . Join the center points of all the circles , we get the shortest path. Hence, the interaction between a pair of vertices is a straight line . When α = 0 , it is $\frac{d}{2}$, i.e., the mid point .

Sixth Method of Obtaining the obstacle collision free path - Complex path :

This is a path induced by a skew edge → combination of all the 3 basic types of interactions .

In a robotic work cell , there will be a number of obstacles . Hence , the path for the movement of the robot tool from the source to the goal comes across a number of edges and vertices of the different obstacles that comes along the path . Hence , the three types of interactions discussed above will not be sufficient to plan a obstacle collision free path in the 3D Euclidean space . A combination of the above three types of 3 paths is required. Such a diagram obtained is known as a complex path and is a combination of all the three types of the basic path's .

For example , consider the problem of finding a complex path induced by a skew edge P1P2 of one obstacle with the second edge P3P4 of another obstacle

as shown in the Fig. 7. Path between vertex P1 and edge P3P4 to the left and to the right of P1 is a parabola . Path between edge P1P2 and edge P3P4 to the left and to the right of P1P2 is a straight line. Path between vertex P2 and edge P3P4 to the left and to the right of P2 is a parabola .

Thus , a complex path is a combination of linear and parabolic paths . The path will consists of straight line segments and arcs and is also called as a complex graph .

4. MOTION HEURISTICS

Motion heuristics is the method of searching an obstacle collision free path in the free work space of the robot from the source to the destination by making use of search techniques such as the graph theory (AND / OR graphs), chain coding techniques and the state space search techniques (best first search, breadth first search) used in Artificial Intelligence [23]. The search techniques used in AI to find the path from the source S to the goal G are called as motion heuristics or the robot problem solving techniques [15]. The word 'heuristic' means to search , what to search ? an obstacle collision free path to search [16].
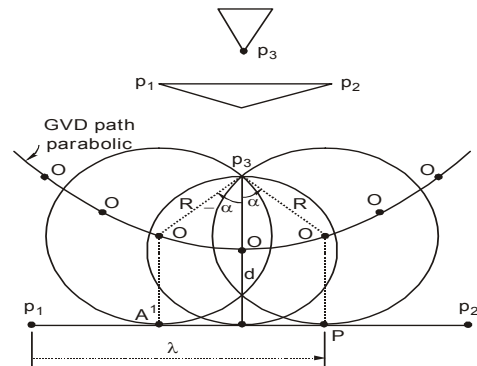

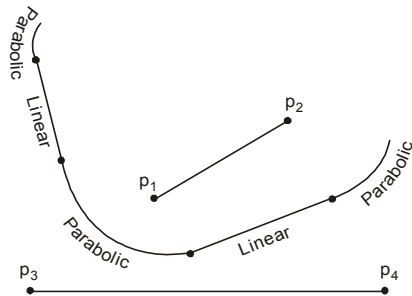Fig. 6 : Interaction b/w vertex P3 & edge P1 P2

Fig. 7 : A complex GVD

Fig. 9 : Graph showing all the available free paths from S to G

5. PROBLEM SIMULATION & SIMULATION RESULTS

We consider a workspace cluttered with obstacles, especially triangular obstacles. These triangular obstacles are placed either on the table or on the floor, which is simulated on the computer as a 2D rectangular workspace [22]. Using the mouse or using a rectangular coordinates, we specify the source coordinates (x_1 , y_1) [17]. Similarly, using the mouse or using rectangular coordinates, we specify the destination coordinates (x_2 , y_2) [18].

A computer algorithm is written using the user-friendly language C++ to find the shortest path using the formula given in Eq. (1). The results of the simulation are shown in the Figs. 5 and 6 respectively [19]. The motion heuristics used in Artificial Intelligence is used to find the shortest path from the source to the goal [21]. Using this motion heuristics, a number of paths are available from the source to the goal, but it selects a shortest path which is the path shown in yellow color in the Fig. 6 [20], [1].
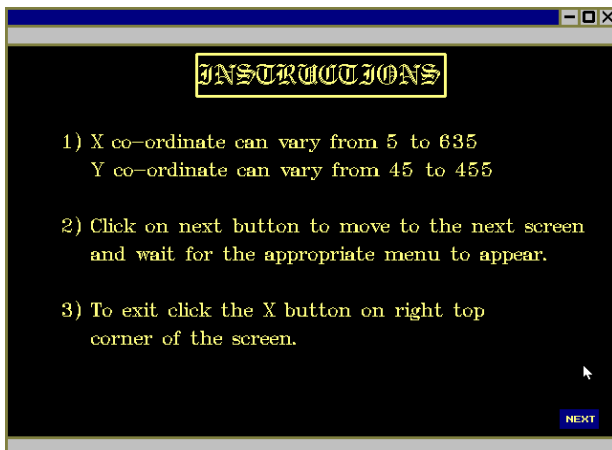
6. CONCLUSION

A method of finding an obstacle collision free path from the source to the goal when the workspace is cluttered with obstacles is developed using motion heuristics using an user friendly GUI developed in C++. This method is similar to the method of finding / searching a path by the humans.

The method was also implemented on a real time system, say a robot and was successful. Thus, the Artificial Intelligence which uses motion heuristics (search methods) is used to find the obstacle collision free path.

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Fig. 8 : Instruction for entering the rectangular coordinates

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the significant contribution to the research (amongst all the researchers in all disciplines) in IIT Bombay. He was also instrumental in getting Research centres along with M.Tech programs in the colleges where he has worked so far. Apart from which, he had brought couple of grants for the conduction of various events like workshops & conferences where he worked. He visited Singapore, Russia, United States of America and Australia for the presentation of his research papers in various international conferences. His biography was published in 23rd edition of Marquis's Who's Who in the World in the 2006 issue. He has also guided more than 2 dozen projects (B.Tech. / M.Tech.) in various engineering colleges where he has worked so far apart from guiding a couple of research scholars who are doing Ph.D. in various universities.

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