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Path Planning Algorithm Development using Configuration Space Obstacles & Equidistant Paths using AI & ML

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ABSTRACT

In this research paper, the design & development of the shortest path along with obstacle avoidance (shortest path with obstacle collision free path with avoidance) is presented using the novel approach of what is called as the configuration space method and the Equidistant Path (EP) is carried out using AI & ML concepts. The developed models are used to constructthe algorithms which could be used for simulation of the path planning problem as here we are concentrating only on the grossmotion planning & not on the fine motion planning schemes. Simulations are performed using the C++ language and the results are observed and compared with the work done by others to substantiate the proposed work so that the effectivity of the proposed algorithms are met. Finally, conclusions are presentedat the end of the paper.

Keywords: CSO, Obstacle, Object, Robot, Mid Path, Sensor, Collision, Avoidance, Vertex, Edge.

1. INTRODUCTION

The configuration space method is defined as one of the methods of planning the gross motion path from the source to thedestination by taking a reference point r anywhere on the mobile object and sliding the mobile object along the walls of the obstacle and tracing the locus of the reference point r and obtaining the enlarged obstacle (Configuration Space Obstacle- CSO) and moving along the walls of the enlarged obstacle by determining the shortest path using motion heuristics. A configuration of a part is a set of parameters which uniquely specify the position of each and every point on the part in the 3Dspace. The configuration space is defined as the set of all the possible configurations of the mobile part that is obtained aroundthe obstacle [1].

When the configuration space of two obstacles overlap ; then, there is no path for the part to move and when there is a enlarged configuration space of obstacles, then a path can be planned. The configuration space obstacle is defined as the locusof all the points traced by the reference point r of the mobile object around the obstacle OR the enlarged obstacle is known asthe CSO that is induced by the mobile part around the obstacle. Motion of a part in a plane involves translations and rotations, we will consider translations and rotations of the part one by one, i.e., configuration space can be generated either by translations alone or rotations alone or involving both [2].

Hence, the configuration space may be 2D (i.e., x, y) or 3D (i.e., x, y, z) search. If the polygonal part is not allowed to rotate and performs only translations along the obstacle; then, the configuration space is 2 dimensional, otherwise the configurationspace is 3 dimensional. Translational motion can be defined as the movement (motion) of a rigid body along a straight line or using linear / prismatic / telescopic / translatory or sliding motion.Two types of objects / obstacles are considered, viz., the convexpolygons and the non-convex polygons [3].

The convex polygons are of regular shape such as square, rectangle, prism, cube, pentagon, hexagon, triangle,parallelogram, etc., the non-convex polygons are of irregular shape and they are modeled as a union of

convex polygons. In many cases of path planning using gross motion technique, it is very difficult to plan or design a path using translations alone. Hence, the mobile part has to be rotated if it has to reach the goal.When the mobile polygon is rotated about the reference point r, the CSO is no longer a 2D, it becomes a 3D. The surfaces of the CSO's are curved in the orientation dimension. The rotation of the part is performed about an axis orthogonal to the plane, i.e., about the reference point [4].

The proposed configuration space process of determining the shortest path from S to G is shown in the Fig. 10 (a) (b) (c) respectively. The CS method of designing the path from the source to the goal in amidst of obstacles, shaded part (CSO) couldbe best understood w.r.t. the proposed design in our research work as shown in the Fig. 1 to 3 respectively. To find shortest path using CSO from the source to goal in spite of obstacles, thepath is shown in the Fig. 3. Note that the shortest path is obtainedby moving in between the obstacles as shown in the Fig. 3, fromwhere it is clear that if the 2 CSO's overlap, then there is no pathfor the movement [5].

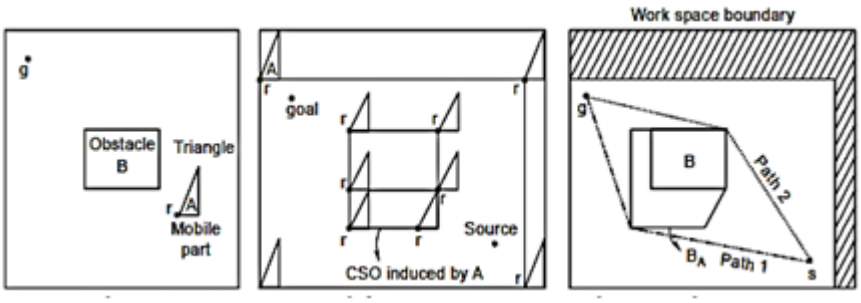

Fig. 1 : A scene with two convex polygonal parts , Part A, triangle - mobile ; Part B, rectangle - obstacle ; r - reference point , B_A - Configuration Space Obstacle

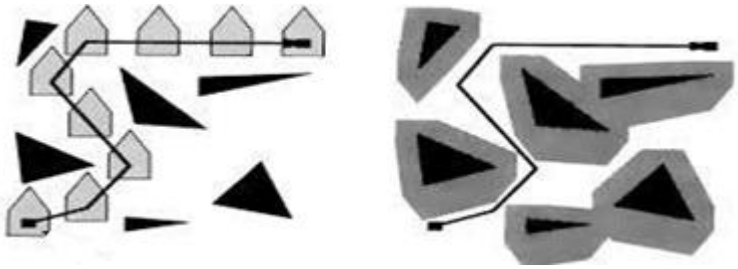

Fig. 2 : CS method of designing the path from S to G in amidstof obstacles, shaded part (CSO)

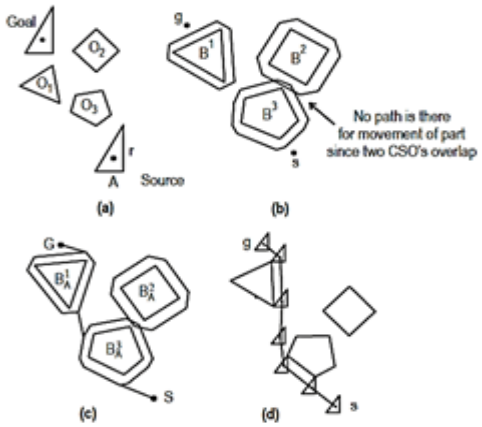

Fig. 3 : (a)-(d) To find shortest path using CSO from S to G inspite of obstacles

The process of computing a configuration space obstacle BA given, the polygons A and B can be automated,

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which will speedup the process of planning the path for movement from the source to the goal state. Computing the configuration space obstacles isa very important step in solving the gross motion path planning problem. Thus, the configuration space obstacles generated by the various moving parts should satisfy the four-configuration space bound equations. It has to be noted that CS method is usedin the design of the shortest path by the robot from the source tothe goal & the simulation results are presented at the end [6].

2. Mathematical Modelling of the Design of the Obstacle Collision Free Path Using AI Based Task Planners with EP

In this section, the mathematical modelling of the design of the obstacle collision free path using AI based task planners withEP is presented along with the simulation results. Here, the mathematical model that is developed for an obstacle collision free path using the AI based task planners is used to find the shortest path & the obstacle collision free path. To start with what is a EP diagram has to be learnt? [7]

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. 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. The freeway method of designing the gross motion path is known as the Equidistant Path (EP). A modified method of GMP is proposed as an effective method of gross motion planning technique which is based on the overlapping generalized cones having straight spines and non - increasing radii. & this is used for obtaining an obstacle collisionfree path in the work space of the robot from source to the goal [8].

An EP in free space 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. 4. An EP gives the path along which the tool-tip p has to move such that it does not collide with the obstacles. Once a EP graph is obtained, the shortest path is found using graph theory techniques, search techniques and the motion heuristics [9].

The robot work space consists of a number of obstacles. Theparameters of any obstacles are the edges and the vertices. So, while constructing the EP from S to the G, four basic types of interactions occur. Because, when we move from the source to the goal, we come across edges and vertices of many obstacles.

The interactions are [10]

1. First type of interaction – Interaction between a pair ofedges (Fig. 5) [11].
2. Second type of interaction – Interaction between a vertex and an edge (Fig. 6) [12].
3. Third type of interaction – Interaction between a pair of vertices (Fig. 7) [13].
4. Fourth type of interaction – EP induced by a skew edge(complex EP) [14].

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4. Fourth type of interaction – EP induced by a skew edge (complex EP) [14].

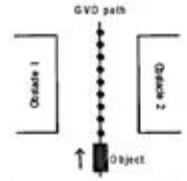

Fig. 4 : Obstacle collision free path (similar to the equidistant path b/w 2 obstacles)

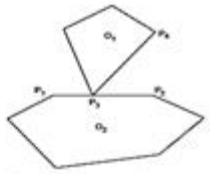

Fig. 5 : Interaction b/w a pair of edges of 2 obstacles O_1 and O_2

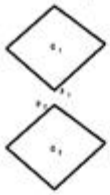

Fig. 6 : Interaction b/w a pair of vertices of 2 obstacles O_1 and O_2

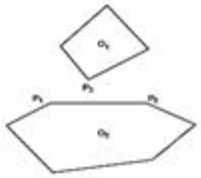

Fig. 7 : Interaction b/w a vertex of one obstacle O_1 & an edge of another obstacle O_2

The first three interactions are in the 2D work space, i.e., in a plane. The fourth interaction is a complex one and is a combination of all the three basic type of interactions. There arecertain advantages of this method of gross motion planning which are being developed & they are [15]

- 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 [16].
- 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 [17].
- The path obtained is the shortest path [18].
- The path is a obstacle collision free path as shown in the Fig. 8 [19].
- The path is equidistant from the obstacles and there is no chance of collisions [20].
- The method also works successfully when WS is cluttered with closely spaced obstacles, as a result of which designed EP graph becomes more complex [21].

Here, 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. So, while constructing the obstacle collision free path from the S to the G, many types of interactionsoccur. Because, when we move from the source to the goal, we come across edges and vertices of many obstacles. Here, we haveconsidered only the interaction between a pair of edges of two obstacles as shown in the Fig. 5 & 8 respectively [22].

3. INTERACTION B/W A PAIR OF EDGES OF 2 OBSTACLES

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. 5 & 8. 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. 5 & 8. Here, P_3P_4 is an edgeinteracting with P_1P_2 at the point P_3 [23]

P_1P_2 ; P_3P_4 - Two edges of obstacles O_1 and O_2 meeting atthe point P_3

R - Radius of the GVD cone.

$\square$ - the distance parameter measured along 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

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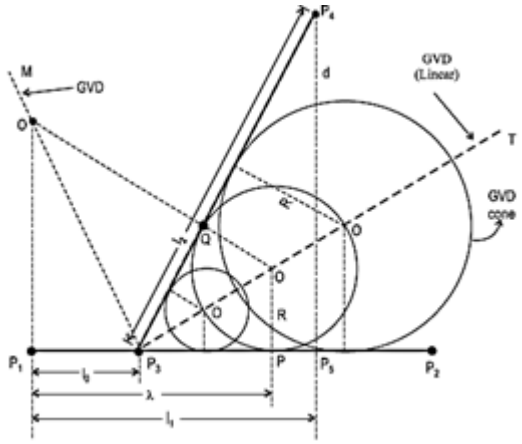

Fig. 8 : Interaction between a pair of edges

The radius of the obstacle collision free path along P_1P_2 can be expressed by a piece-wise linear function of □ and is given by equation below 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. 8 [24].

$$R(\lambda) = \frac{(\lambda - l_0)\{l_0 - l_1 + \text{sgn}(\lambda - l_0) l_2\}}{d}$$

From this developed above equation, we can come to a conclusion that 2 case studies can be worked upon with [25]

Case study 1: If (□ □ l_0) > 0 ; i.e., the point P is lying to right of P3 ; then, l_2 is positive, sgn() is +

Case study 2: If (□ □ l_0) < 0 ; i.e., the point P is lying to the left of P3 ; then, l_2 is negative, sgn() is –

4. DESIGN OF THE OBSTACLE COLLISION FREE PATH FOR THE ABOVE CASE OF 2 OBSTACLE EDGES

The algorithm that is being developed in the construction could be designed as a 9-step algorithm that could be used in the AI based task planner software as follows [26].

- Consider a point P any where on the line P_1P_2 and which is at a radial distance of □ from P_1.
- Draw a □^{r} line (dotted) from P.
- Find the length of this line □^{r} line (dotted) by using the above.
- equation 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_1P_2 and which is at a radial distance of different □'s from P_1.
- Go on drawing □^{r} lines from P.
- Go on finding the length of these □^{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.

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5. INTERACTION B/W A VERTEX AND AN VERTEX

The second basic type of interaction is the interaction between a pair of vertices (interaction between a vertex of one obstacle O1 and the vertex of another obstacle O2) as shown in Fig. 6 & 9. How to construct the EP path from S to G when the obstacles are like this in the work space ? Consider 2 vertices P1 and P2 of two obstacles O1 and O2 separated by a distance of d units [27].

P_1 and P_2 - Vertices of two obstacles O_1 and O_2.

R - Radius of the EP cone.

d - Distance between 2 vertices P1 and P2.

□ - Angle made by the radius of the EP circle withthe vertical distance d.

In terms of angle □ about the vertex P1, the radius of the EP cone about P1 can be expressed by an equation which is a functionof □ given by [28]

$$\cos\alpha = \left(\frac{d/2}{R}\right)$$

&

$$R(\alpha) = \left(\frac{d/2}{\cos\alpha}\right) = \left(\frac{d}{2\cos\alpha}\right)$$

- Draw a line (dotted) from P_1 or P_2 at an angle of □ w.r.t. the vertical distance d.
- Find the radius of this dotted line R(□) using the radius formula given by the above equation and get the center pointO of the EP cone. Let the radius be $P_1O = P_2O = R$.
- With this radius R and center as O, draw a circle passing through the points P_1, P_2.
- Like this, go on finding the center points of the circles.
- Join the center points of all the circles, we get the equidistantpath.
- Hence, the interaction between a pair of vertices is a straightline, i.e., the equidistant path QC is linear.
- When □ = 0°, i.e., draw a line at an angle of □ = 0° w.r.t. vertical & the radius is given by

$$R(\alpha) = \left(\frac{d}{2\cos 0^\circ}\right) = \frac{d}{2}$$

- With this radius, draw a circle to pass through the points $P_1$and P_2.

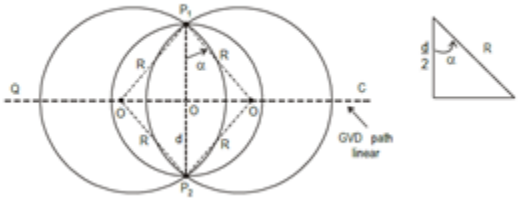

Fig. 9 : Third basic type of interaction in a EP-Interaction – vertex & a vertex b/w a pair of vertices P_1 and P_2 separated by adistance of d units

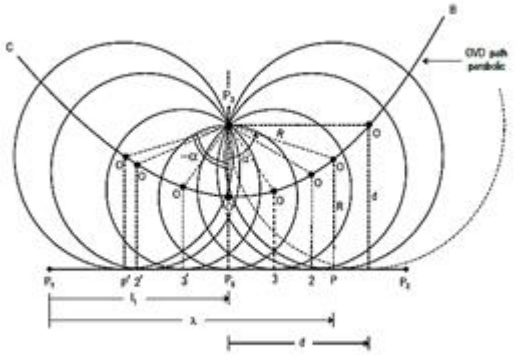

Fig. 10 : Third basic type of interaction ; interaction b/w a vertex P_3 & edge P_1P_2

Hence, the interaction between a pair of vertices is a straight line. If the robot or the object held by the tool / gripper moves along this equidistant path, QC, then definitely, there would be no collision of the object with the obstacles [29].

6. INTERACTION BETWEEN A VERTEX AND AN EDGE

The third basic type of interaction is the interaction between a vertex and an edge (interaction between an vertex of one obstacle O_1 and an edge of another obstacle O_2) as shown in Fig.7 & 10. How to construct the SP from S to G when the obstacles are like this ? Consider an edge P_1P_2 of one obstacle O_2 and an vertex P_3 of another obstacle O_1 which is located at a perpendicular distance of d units from the edge P_1P_2 as shown in the Fig. 10 [30].

P_1P_2 - Edge of obstacle O_2.

P_3 - Vertex of obstacle O_1.

R - Radius of the EP cone.

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

l_1 - Distance from the point P_1 to the □[r] distance from P_3.

d - Perpendicular distance from P_3 to P_1P_2.

The radius of the equidistant path cone is given by a mathematical model using a parabolic function of □ as R(□),

$$R(\lambda)=\left[\frac{d^2+(\lambda-l_1)}{2d}\right]$$

A EP between an edge and a vertex can also be expressed relative to the vertex. If □ represents the angle about the vertex P_3 measured in the anticlockwise direction from a line perpendicular to the edge P_1P_2 ; then, the radius of the EP about P_3 can be given by the expression [31]

$$R(\alpha)=\left[\frac{d}{1+\cos(\alpha)}\right]$$

7. FIRST METHOD OF OBTAINING THE EP USING THE EQUATION

$$R(\alpha)=\left[\frac{d}{1+\cos(\alpha)}\right]$$

- Draw a dotted line at an angle of □ from the perpendicular distance d (from the point P_3).
- Compute the radius of the EP circle using the above formula R(□).
- Mark this radius R(□) on the line drawn at an angle of □ from the point P_3.
- We get the center point of the EP circle, i.e., O.

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- Drop a perpendicular from the point O onto the edge P1 P2 Let the point be P
- Draw a circle with O as center to pass through the points P3 and P.
- Obviously, P3 O = OP = R, which is the radius of the EP cone.
- The circle will be tangential to the edge P1 P2.
- Similarly, draw a line at angle of –□, get the center of the circle O□ using the formula and get the point P□ & then repeat this for different angles, get the circles, join all the center points, we get the shortest path.
- Obviously, P3 O = OP = R, which is the radius of the EP cone.
- The circle will be tangential to the edge P1 P2.
- Similarly, draw a line at angle of –□, get the center of the circle O□ using the formula and get the point P□ & then repeat this for different angles, get the circles, join all the center points, we get the shortest path.
- When □ = 0°,

$$R(\alpha)=\left[\frac{d}{1+\cos(\alpha)}\right]=\left[\frac{d}{1+\cos(0^\circ)}\right]=\frac{d}{2},$$

i.e., the mid - point of the vertical line P3P5 , O.

- The shortest path is parabolic in nature and is given by BC and the robot or the tool-tip moves along this parabolic path.

8. SECOND METHOD OF OBTAINING THE SP USING THE EQUATION

$$R(\lambda)=\left[\frac{d^2+(\lambda-l_1)^2}{2d}\right]$$

- Mark a point P at a distance of □ from P1 along the edgeP1P2.
- Draw a □r line upwards from P.
- Find the radius R(□) of the GVD cone using the aboveequation, get the point O.
- Measure this distance R along the □r distance, so, let it be PO= R(□).
- With O as center, draw a circle to pass through the points P3 and P.
- Obviously, O will be a point on the equidistant path.
- Like this, go on finding the centers of the various circles andjoin them, then we get the equidistant path.
- When □ = l1, then,

$$R(\lambda)=\left[\frac{d^2+(\lambda-l_1)^2}{2d}\right]=$$

$$R(\lambda)=\left[\frac{d^2+(l_1-l_1)^2}{2d}\right]=\left(\frac{d}{2}\right)$$

- i.e., the mid-point of the vertical line P3P5 , O.
- The EP is parabolic in nature and is given by BC.

Hence, the interaction between an vertex and an edge is aparabola [32].

Finally, to conclude, all the 3 types of interactions that are to be taken while constructing the EP is discussed briefly. Thus, we have seen that in the 2 cases, case (i) and case (ii), the shortest path is a straight line, while in another case, i.e., case (iii), it is parabolic in nature. If the robot or the object moves along the shortest path, then there is no collision of the object or the robot with the obstacles, because the object / robot is at a safe distancefrom the obstacles [33].

In any 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 various obstacles that occur along

the path. Hence, the three types of basic interactions discussed above will not be sufficient to plan a path in the three dimensional Euclidean space.A combination of the above three types of basic EP's is required.Such a path obtained is known a complex EP which is a combination of the 3 types of the basic interactions. Thus, complex EP's can be constructed using combination of the threebasic types of EP's discussed above. A best example of a complex EP can be the EP induced by a skew edge. i.e., the obstacle lying in the 3D space. So, a complex equidistant path isa combination of all the 3 basic types of interactions [34].

9. SEARCHING THE SHORTEST PATH USING THE MOTION HEURISTICSIN AI / ML

Motion Heuristics is defined as 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. 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. The word 'heuristic' means to search, what to search ? an obstacle collision free path to search. There are different types of motion heuristics. In order to search for a obstacle collision free path in the workspace of the robot for the movement of the mobile path, various types of search techniquesare used, such as [35]

- State space search techniques,
- Graph theory techniques.
- GVD graphs, Chain coding,
- AND/OR graphs,
- Breadth first search techniques,
- Best first search techniques
- Semantic networks and petri-nets,
- Dijekstras algorithm

State Space Search Techniques : One of the methods of finding the path for movement or finding a solution to a particular robot task problem is to try out various possible approaches until we happen to produce the desired solution. This uses a trial and error approach search technique. To discuss the state space method of search technique, the concept of states, operators, state variables, state variable vector, state transition matrix, etc., has to be studied.

Graph Theory Search Techniques : In search techniques usinggraph theory, first, all possible available obstacle collision free paths in the work space of the robot are obtained using the equidistant path method using the four types of interactions. An EP graph is then obtained which is an equivalent graph of nodes,arcs and segments. A EP graph is a single line diagram which consists of nodes or junctions or pseudo nodes, line segments (linear) and arcs (parabolas) and gives the information about all possible routes / paths to move from the source to the goal / destination and is similar to an AND-OR graph in AI.

For small graphs (work space consisting of very few obstacles), a solution path from the initial source state to the goal state can be easily obtained by inspection. A complex graph can be drawn when there are a number of obstacles in the workspace of the robot. Hence, for a complicated graph (work space consisting of more number of obstacles), a formal search process is needed to move through the free work space in between the obstacles and aroundthe obstacles until a path from an initial state to a goal state is found. One way to find the path is to make use of search process.

D'jekstras Algorithm : In this algorithm, weights are given to different paths and the shortest path is obtained by using the search techniques and that too the path which has the least weight.

Chain Coding Process : Another way of finding the shortest path is to make use of the chain coding technique, which is usedto find the length of the open curve or closed curve in pixels. Initialize the pixel count to zero at the

starting point (source). Find all the paths from the source to the goal. Go on counting the total number of pixels along all the paths once you leave the starting point, i.e., the pixel count which is initialized to zero at the starting point goes on incrementing by one till it reaches the destination point. That path which has got the least pixel count isthe shortest path. In our research work, we have used the chain coding processof finding the shortest path from the source to the goal.

10. SIMULATION RESULTS

We consider a workspace cluttered with obstacles in the 2D plane, 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. Using the mouseor using a rectangular coordinates, we specify the source coordinates (x_1 , y_1). Similarly, using the mouse or using rectangular coordinates, we specify the destination coordinates (x_2 , y_2).

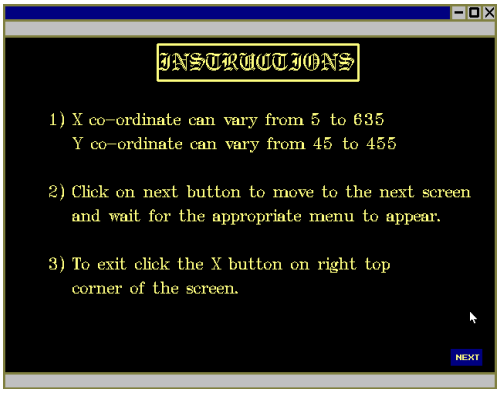

Fig. 11 : Instruction for entering the rectangular coordinates(using EP method)

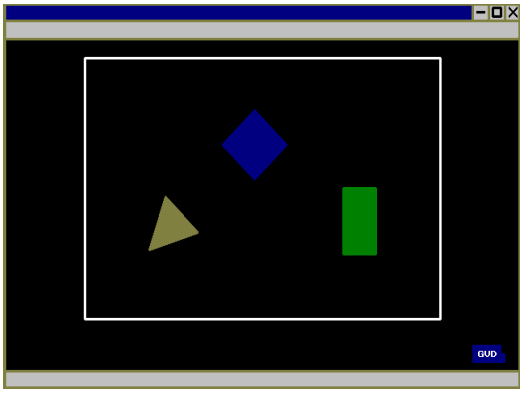

Fig. 12 : Instruction for dimensions of the obstacles of any sizes(using EP method)

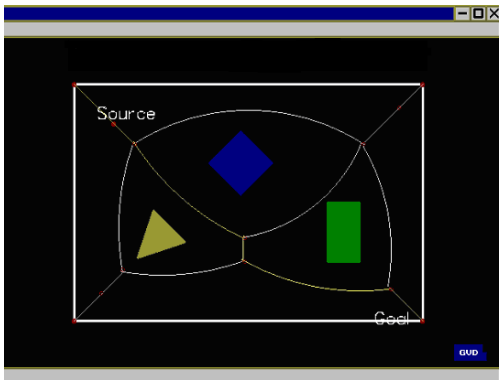

Fig. 13: Graph showing all the available free designed shortest path from S toG

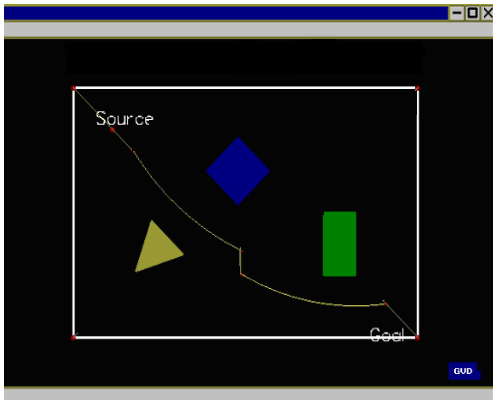

Fig. 14: Simulation result showing the using MH from S toG (using EP method) paths

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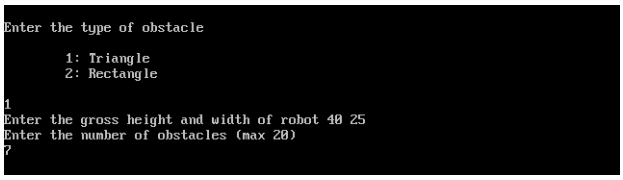
Fig.15: Title of the simulation displaying



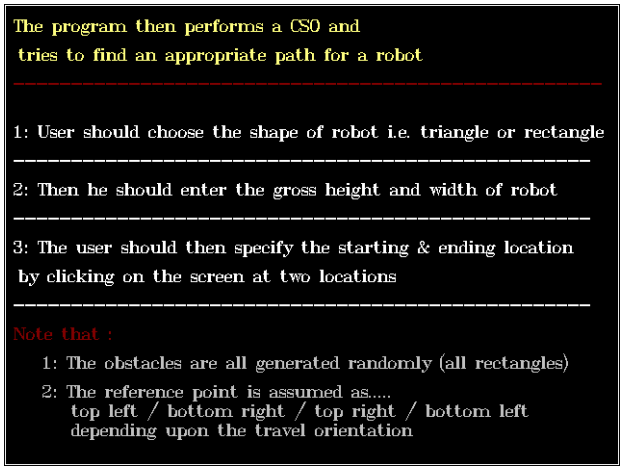


Fig.

Fig. 16: Inputting specifications to the robot path planning(starting & destination coordinates

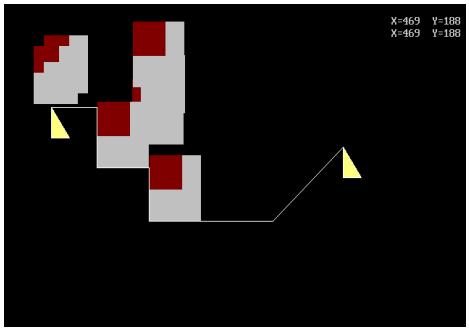


Fig. 17 : Developed shortest path by moving around theobstacle from the S to the G

Another example of a simulation case is considered next again using C++, which is designed & simulated using the boundson the Configuration Space as follows in the simulated results from Figs. 18 to 25 respectively.

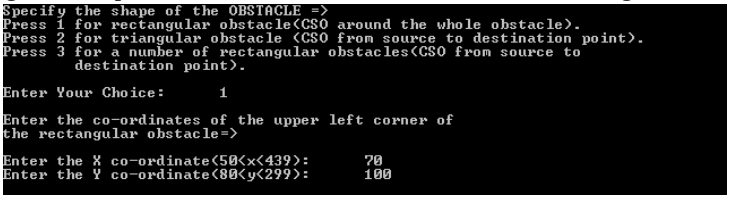


Fig. 18 : Inputting the specifications to the CS method ofdetermining the path-1

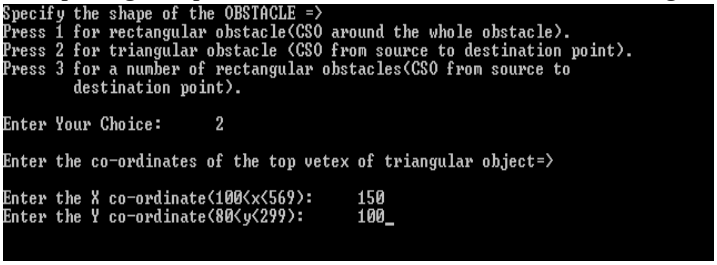


Fig. 19 : Inputting the specifications to the CS method ofdetermining the path-2

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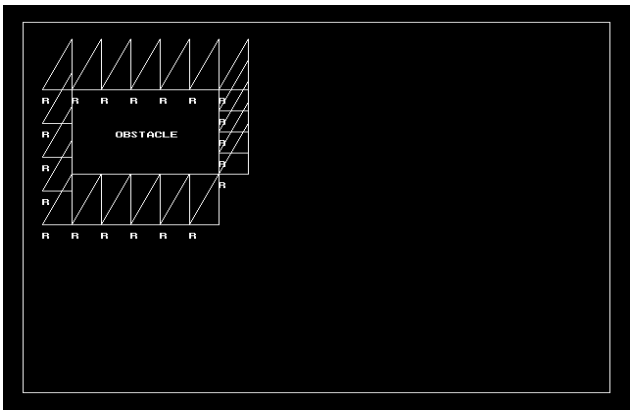


Fig. 20 : Generation of the CSO around the rectangle obstacle

Finally, to conclude, a new 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 the Matlab Environment. This method is similar to the method of finding / searching a path by the humans. The method is also going to be implemented on a real time system, say a robot & is going to be made a success in the RT environment. Thus, the Artificial Intelligence which uses motion heuristics (search methods) is used to find the obstacle collision free path. In this research work that is beingundertaken by me under the supervision of my supervisor. Here, in this first contributory work, I have just portrayed the outline of the research work that is going to be taken up in the course of theresearch work w.r.t. how to use & develop AI & ML based systems using software tools to achieve the desired task by the robot. One work on the development of the mathematical modelis developed and is simulated.

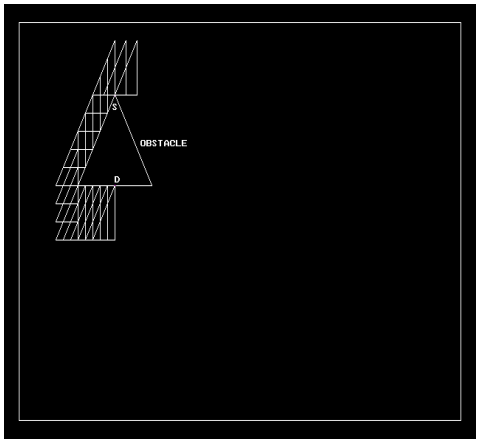


Fig. 21 : Generation of the CSO around the triangle obstacle

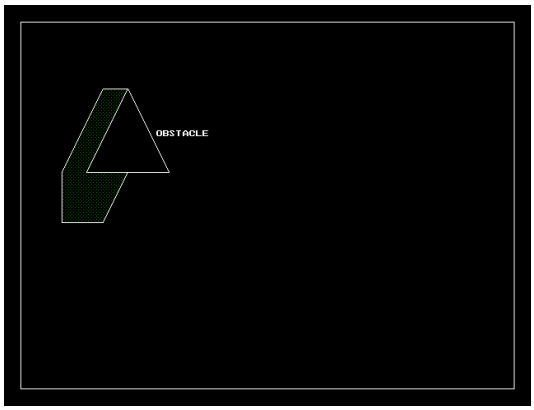
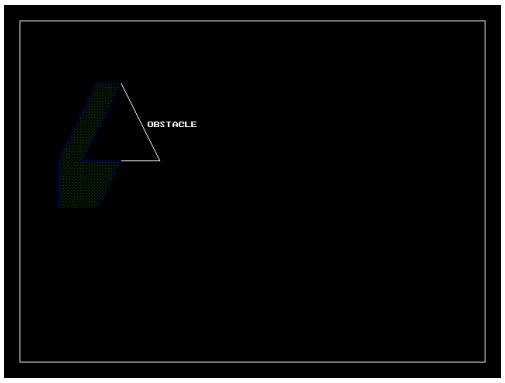


Fig. 22 : Development of CSO around triangle as obstacle



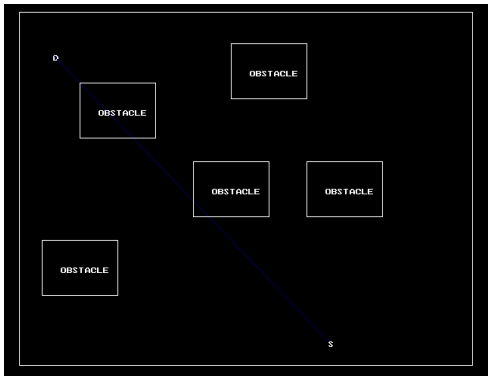


Fig. 23 : Obstacle collision area where the robot should notenter – blue colour

Fig. 24 : Shortest path from source to goal amidst of different obstacles

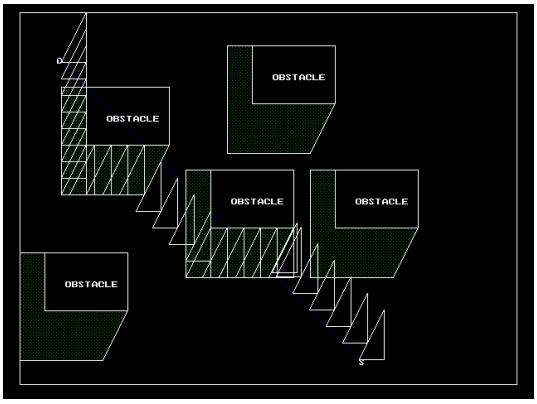


Fig. 25: Finding the shortest path from S to G using CSO

11. CONCLUSIONS

A brief conceptual design into the design of path planning in the 2 dimensional work space of the robot was developed & presented in this research paper. Two important designs were presented, one was using the configuration space method & the other was using the equidistant method.

In the configuration space method, the design is done using the bounds on the configuration space of the obstacles that comesin the path of motion from the source to the goal and using the search techniques, all available routes by the robot from the source to the goal is found out using the chain coding method avoiding all the obstacles in its path of motion. A CSO is designed around the obstacle such that this will be acting as the buffer zone, which gives an information that the object or the robot should not enter this zone & if enters, it will be in very close proximity with the obstacle & chances of collision will be more. At the most, the robot or the autonomous vehicle can just touch the boundary of the CSO only, which is a constraint.

In the equidistant path method, the path design is carried outsuch that the robot moves exactly in between the obstacles as a result of which the chances of collision will be highly remote as the robot will be using the free-way method (the space in b/w theobstacles is called as the free-ways, translations can be performedalong the free-ways & rotations can be performed @ the junctionof the free-ways). In our work, we have considered 4 types of interactions of the robot with the obstacle design, i.e., interactionsb/w edges, b/w vertices, b/w vertex & edge, combination of all the previous 3 interactions leading to a complex path.

Mathematical models are developed for all the 3 interactionsand these models are used in the C++ code for the simulation purposes. The simulation works very well for a workspace limited to the screen size of the PC/Laptop. Codings are developed incorporating all the obstacle avoidance strategies andthese are written as sub-routines in the program code. From the simulation results, it could be seen that the robot selects the shortest path using motion heuristics as this concept is also discussed in brief in this research paper. It has to be noted that in this research paper, the simulations are carried out in such a way that we have considered only stationary obstacles and not the moving obstacles. If the obstacles are moving, then the pathplanning will become more difficult as we will not be knowing in which direction the obstacle will be moving as such 2 case studies have to be performed, viz., obstacle moving along with the robot & the obstacle moving in the opposite direction of the robot movement.

References

[1]. Zhihao Chen, Redouane Khemmar, Benoit Decoux, Amphani Atahouet, Jean-Yves Ertaud, “Real Time Object Detection, Tracking, and Distance and Motion Estimation based on Deep Learning: Application to Smart Mobility”, *2019 Eighth International Conference on Emerging Security Technologies* (EST), Colchester, United Kingdom,

10.1109/EST.2019.8806222. hal-02343350, Jul 2019.
[2]. Z. Zhao, P. Zheng, S. Xu and X. Wu, "Object Detection With Deep Learning: A Review", *IEEE Transactions on Neural Networks and Learning Systems*, vol. 30, no. 11, pp. 3212-3232, doi: 10.1109/TNNLS.2018.2876865, Nov. 2019.
[3]. L. Jiao et.al., "A Survey of Deep Learning-Based Object Detection", *IEEE Access*, vol. 7, pp. 128837-128868, 2019.
[4]. Yakup Demir, "Object recognition and detection with deep learning for autonomous driving applications", Simulation: *Transactions of the Society for Modeling and Simulation International*, pp. 1–11.
[5]. Mukesh Tiwar, Dr. Rakesh Singhai , "A Review of Detection andTracking of Object from Image and Video Sequences", *International Journal of Computational Intelligence Research*, ISSN 0973-1873 Vo. 13, No. 5, pp. 745-765, 2017.
[6]. Jahanzaib Shabbir, and TariqueAnwer , "A Survey of Deep Learning Techniques for Mobile Robot Applications", *Journal oflatex class files*, Vol. 14, No. 8, Aug. 2015.
[7]. Bae H., Kim G., Kim J., Qian D., Lee S., "Multi-Robot Path Planning Method Using Reinforcement Learning", *Journal of Applied Sciences*, vol. 9, issue 15, pp. 30-57, 2019,
[8]. Nguyen, Khang, Huynh, Nhut T., Nguyen, Phat C., Nguyen, Khanh-Duy, Vo Nguyen D., Nguyen, Tam V., "Detecting Objects from Space: An Evaluation of Deep-Learning Modern Approaches", *Journal of Electronics*, vol. 9, no. 4, pp. 583, 2020.
[9]. Alessandro Foa, "Object Detection in Object Tracking System for Mobile Robot Application", *Jour. of TRITA-SCI-GRU 2019:090 MAT-E*, 2019:46.
[10]. https://medium.com/@jonathan_hui/ssd-object-detection-single- shot-multibox-detector-for-real-time-processing-9bd8deac0e06
[11]. https://www.educba.com/deep-learning-algorithms
[12]. https://pathmind.com/wiki/deep-reinforcement-learning
[13]. https://towardsdatascience.com/a-beginners-guide-to-q-learning-c3e2a30a653c
[14]. https://www.wikipedia.org
[15]. Dr. T.C.Manjunath, "Fundamentals of Robotics", 5th Edition, *Nandu Publishers, Mumbai*, Inida, 2005.
[16]. Robert, J.S., Fundamentals of Robotics : Analysis and Control, *PHI*, New Delhi., 1992.
[17]. Fu, Gonzalez and Lee, Robotics : Control, Sensing, Vision and Intelligence, *McGraw Hill, Singapor*e, 1995.
[18]. Luh, C.S.G., M.W. Walker, and R.P.C. Paul, "On-line computational scheme for mechanical manipulators", *Journal of Dynamic Systems, Measurement & Control*, Vol. 102, pp. 69-76, 1998.
[19]. Yoshikawa T., "Analysis & Control of Robot Manipulators with Redundancy", *Proc. First Int. Symp. on Robotics Research, Cambridge, MIT Press*, UK, pp. 735-748, 1984.
[20]. Whitney DE., The Mathematics of Coordinated Control of Prosthetic Arms and Manipulators, *Trans. ASM J. Dynamic Systems, Measurements and Control*, Vol. 122, pp. 303-309, 1972.
[21]. Whitney DE., Resolved Motion Rate Control of Manipulators andHuman Prostheses, *IEEE Trans. Syst. Man, Cybernetics*, Vol. MMS-10, No. 2, pp. 47-53, 1969.
[22]. Lovass Nagy V, R.J. Schilling, Control of Kinematically Redundant Robots Using {1}-inverses, *IEEE Trans. Syst. Man, Cybernetics*, Vol. SMC-17, No. 4, pp. 644-649, 1987.
[23]. Lovass Nagy V., R J Miller and D L Powers, An Introduction to the Application of the Simplest Matrix-Generalized Inverse in Systems Science, *IEEE Trans. Circuits and Systems*, Vol. CAS-25, No. 9, pp. 776, 1978.
[24]. D. Xin, C. Hua-hua, and G. Wei-kang, "Neural network and genetic algorithm based global path planning in a static environment," *Journal of Zhejiang University Science*, vol. 6A, no. 6, pp. 549–554, 2005.
[25]. C. Yang, H. Jianda, and W. Huaiyu, "Quadratic programming- based approch for autonomous vehicle path planning in space," *Chinese Journal of Mechanical Engineering*, vol. 25, no. 4, pp. 665–673, 2012.
[26]. J.-H. Liang and C.-H. Lee, "Efficient collision-free path-planningof multiple mobile robots system using efficient artificial bee colony algorithm," *Advances in Engineering Software*, vol. 79, pp.47–56, 2015.
[27]. A. Hidalgo-Paniagua, M. A. Vega-Rodríguez, J. Ferruz, and N. Pavón, "Solving the multi-objective path planning problem in mobile robotics with a firefly-based approach," *Soft Computing- A Fusion of Foundations, Methodologies and Application*s, vol. 21, no. 4, pp. 949–964, 2017.
[28]. Y. Koren and J. Borenstein, "Potential field methods and their inherent limitations for mobile robot navigation," *Proceedings ofthe IEEE International Conference on Robotics and Automation*, pp. 1398–1404, Sacramento, CA, USA, April 1991.
[29]. H. Seki, S. Shibayama, Y. Kamiya, and M. Hikizu, "Practical Obstacle Avoidance Using Potential Field for A

Nonholonomic Mobile Robot with Rectangular Body," in *Proceedings of the 13th IEEE International Conference on Emerging Technologies And Factory Automation*, pp. 326–332, Hamburg, Germany, 2008.

[30]. M. Y. Ibrahim and L. McFetridge, "The Agoraphilic algorithm: Anew optimistic approach for mobile robot navigation," *Proc. of the 2001 IEEE/ASME International Conference on Advanced Intelligent Mechatronics Proceedings*, pp. 1334–1339, Como,Italy, July 2001.

[31]. J. Borenstein and Y. Koren, "The vector field histogram—fast obstacle avoidance for mobile robots," *IEEE Transactions on Robotics and Automation*, vol. 7, no. 3, pp. 278–288, 1991.

[32]. B. You, J. Qui, and D. Li, "A novel obstacle avoidance method for low-cost household mobile robot," *Proceedings of the 2008 IEEE International Conference on Automation and Logistics* (*ICAL*), pp. 111–116, Qingdao, China, September 2008.

[33]. D. Fox, W. Burgard, and S. Thrun, "The dynamic window approach to collision avoidance," *IEEE Robotics and AutomationMagazine*, vol. 4, no. 1, pp. 23–33, 1997.

[34]. O. Brock and O. Khatib, "High-speed navigation using the globaldynamic window approach," *Proceedings of the 1999 IEEE International Conference on Robotics and Automation*, ICRA99, pp. 341–346, May 1999.

[35]. J. Hong and K. Park, "A new mobile robot navigation using a turning point searching algorithm with the consideration of obstacle avoidance," *The International Journal of Advanced Manufacturing Technology*, vol. 52, no. 5–8, pp. 763–775, 2011.