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Path Planning Algorithm Development Using Configuration Space Obstacles and 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 construct the algorithms which could be used for simulation of the path planning problem as here we are concentrating only on the gross to plan the robot motion& not on the fine motion planned schemes. Simulation is done using the C++ programming 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 presented at the end of the paper.

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

1. Introduction

By placing a reference point 'r' anywhere on the portable objects, sliding the portable object along the walls of the obstruction, tracing the locus of the reference points r & obtaining the enlarged obstacle (Configuration Space Obstacle is called as the CSO), and moving along the walls of the enlarged obstacle by determining the shortest path using motion heurists, the configuration space process is chosen as one of the methods of planning the gross motion path from the source to the destination. A part's structure or its configurationally aspect is a group of characteristics that define the position of each points on the component in three dimensions. The configuration area is defined as the collection of all feasible mobile part configurations produced around an obstruction [1].

In the case, the configuration spaces of 2 barriers overlaps, there will be no route for the component for its movement; however, when the configuration spaces of the obstacles are increased, a path can be planned. The larger obstructions are called as the CSO's which are obtained by the movement of the portable object around the obstacle. Because translations and rotations are involved in the motion of a part in a plane, we shall look at each one separately, i.e., the CS could be created by the combinations of rotations or translations or both of them [2]. As a result, the configuration space can be searched in two ways: 2 dimensional (x, y) or 3 dimensional (x, y, z). Then, configuration space is 2 dimensional if the polygon component is not permitted to do the rotation& only executing the translations along the obstacles, otherwise it is 3 dimensional. Translational motion is the motions of the

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rigid bodies along a linear fashion or by the method of prismatic motions or telescopic motions or translator motions or sliding motions. The convex type of polygon & the non convex type of polygon are 2 sorts of objects / obstacles that are considered [3].

Nonconvextype of polygon havezig-zag shapes & will be modelled as a group of 2 or more than 2 convex type of polygon. Convex polygons have regular shapes such as square, rectangle, prism, cube, pentagon, hexagon, triangle, parallelogram, etc. In many cases of path planning using gross motion technique, it is little computationally expensive to design or do a planning of the path using the method of only translations, hence rotations have to be taken into consideration. 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 2D, it becomes a 3D. The surfaces of the CSO's are curved in the orientation dimension. Then, rotation of the part is performed about an axis orthogonal to the plane, i.e., about the reference point [4].

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

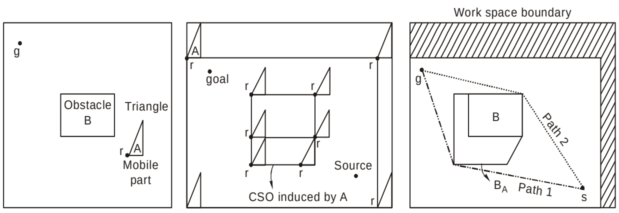

Figure. 1. A work space scenario having 2 polygonal parts which are complex in nature.

Part-A will be the triangle (moving part), next the Part-B will be the rectangle (obstacles); 'r' - ref. pt., B_A - Configuration Space Obstacle

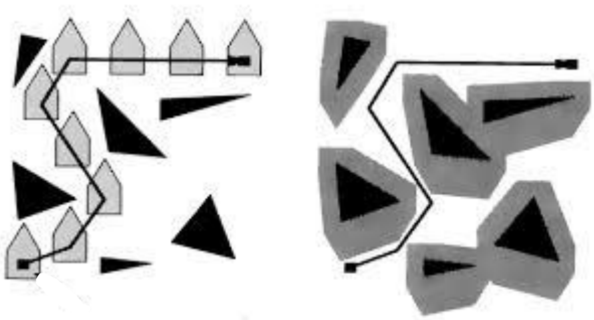

Figure. 2. CS technique of designing the paths from S to G in amidst of obstacles, shaded part (CSO)

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The process of computing a configuration space obstacle BA; given, the polygon A and polygon B can be automated, which will speed up the process of planning the path for movement from the S state to G state. Computing the configuration space obstacles are 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 used in the design of the shortest path by the robots starting from S & ending at G. The simulation results are presented at the end [6].

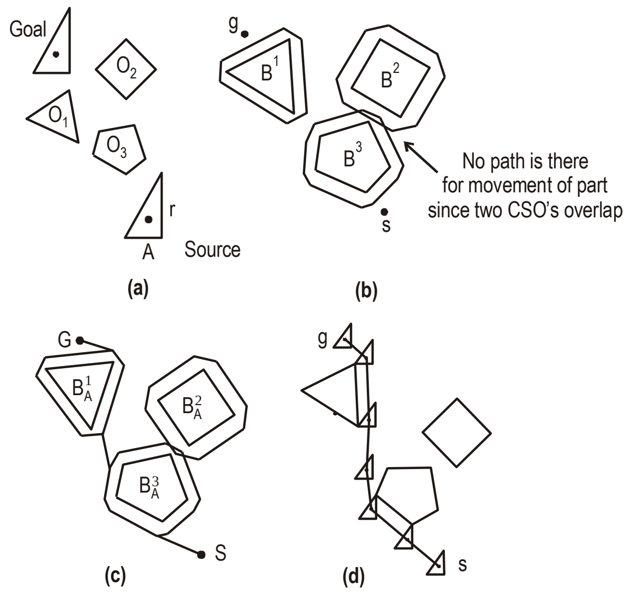

Figure. 3. (a)-(d) To find shortest path using CSO from S to G in spite of obstacles

2. Mathematical modelling of the collision free paths development with the design of obstacles using AI based task planners with EP

In this section, the mathematical model of the design of the path which is free of obstacles is developed using AI based task planners with EP 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 utilized to determine the shortest path & the free paths which are free of obstacle collisions. To start with what is a EP diagram has to be learnt? [7].

Searching all possible free paths in the robot's work environment is one of the most essential methods for solving the gross motion planning problem. The freeways are the spaces between the obstacles through which the robot or object can travel. Along the freeways, translations are conducted, and rotations are performed at freeway intersections and junctions. 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 dependent on the overlapped generalized cone that is consisting of linear spines & that of non increasing type of radius. & this is used for obtaining an obstacle collision path which are free of obstacles, when the robots are moving from S to G [8].

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An EP in free space is enunciated as the loci of the obstacle collision free point (all of them),that are equal in distance from 2 or greater than 2 boundaries of the obstacles, which is displayed in the Figure. No. 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, graph theory, search techniques, and motion heuristics are used to find the shortest path [9].

There are several impediments in the robot's work area. The edges and vertices are the parameters of any obstacle. So, while constructing the EP from S to the G, four basic types of interaction will be occurring. When we encounter many edges and vertices of obstacles on our way from the source to the destination, there will be no collision of the object with the obstacles. The interactions are [10]

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

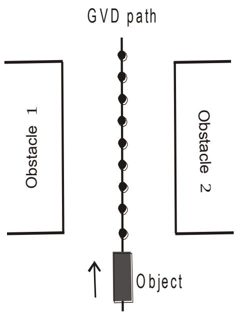

Figure. 4. Obstacles collision free paths (similar to the equidistant paths b/w 2 obstacles)

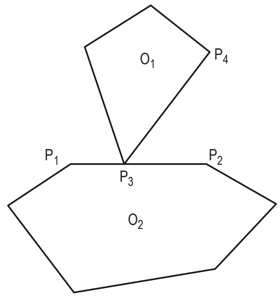

Figure 5. Interactions between a pair of edge of two obstacle O_1& O_2

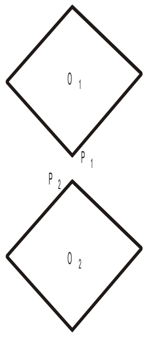

Figure. 6. Interaction b/w a pair of vertices of 2 obstacles O_1 and O_2

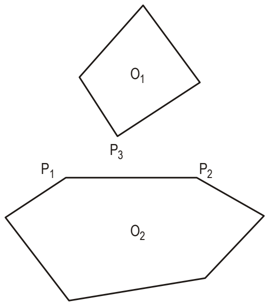

Figure. 7. Interaction b/w a vertex of one obstacle O_1 & an edge of another obstacle O_2

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 are some of the merits and demerits of this concept of the motion planning (gross-GMP) which are being developed & they are [15].

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- It provides pathways for the mobile element that keep it well away from barriers as the route is equidistant or half way b/w the obstructions & thus avoiding the collisions [16].
- This form of path planning employing gross motion methodology is particularly effective when the robot's workspace is sparsely packed with impediments [17].
- The obtained path is the shortest one [18].
- As seen in Figure. 8 [19], the path is free of obstacles and collisions.
- There are no collisions because the path is equidistant from the obstructions [20].
- The strategy also works when WS is congested with closely spaced obstacles, causing the proposed EP graph to become more complex [21].

The mathematics-based model, i.e., the meaning of the obstacle collision free route is developed here. There are several impediments in the robot's work area. The edges and vertices are the parameters of any obstacle. As a result, a variety of interactions occur when the construction of the obstacle free route from source to goal occurs. Because we encounter many edges and vertices of obstacles on our way from the source to the destination, we've simply looked at the interaction between two edges of two barriers in this case, as seen in Figures 5 and 8 [22].

3. Interactions between pair of the edges of two obstacle

This form of edge interaction (interaction between an edge of 1 of the obstacles and 1 edge of other type of obstructions) is depicted in Figures 5 and 8. When the obstructions are like this, how do you design an obstacle-free road from S to G? Consider the two edges P_1P_2 & the edge P_3P_4 of 2 of the obstacles O_1& O_2 shown in Figures 5 and 8.In this case study, the edge P_3P_4will be an edge which interacts with the edge P_1P_2 at the vertex or corner point P_3 [23].

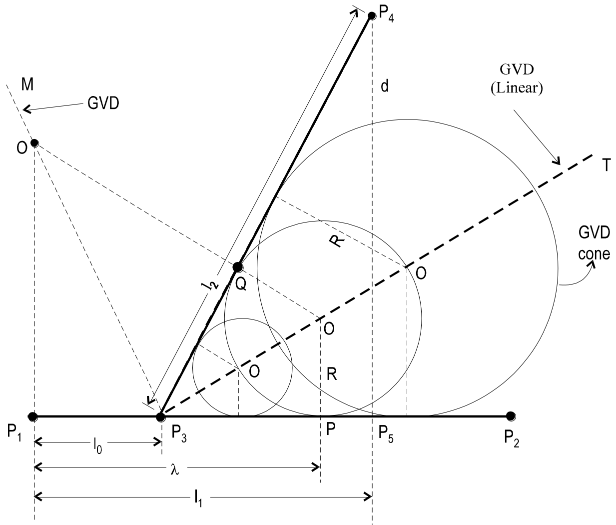

Figure. 8. Interactions b/w pair of edge

The diameter of the obstruction collision free route along the edge P_1P_2 could be described by a piecewise linear f/n of lambda & is provided by the equation below, where the term 'sgn' indicates the signumf/n or sign of the considered parameter l_2& the distances d, l_0, l_1, and l_2 are as indicated in Figure. 8 [24].

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$$R(\lambda) = \frac{(\lambda - I_o)\{I_o - I_1 + sgn(\lambda - I_o)I_2\}}{d} \qquad (1)$$

where P_1P_2 & P_3P_4 are the 2 edge of obstacle O_1 & O_2 which meets at the point P_3, R is the GVD cone radii, λ is the parametric distance which is measured w.r.t. the edges P_1-P_2 from the point P_1, l_0 is the distances from P_1- P_3 along edge P_1P_2, l_1 is the distances from P_1-P_5 along edge P_1P_2., l_2 is the edge P_3P_4 length and d is the $\perp^r$ distance from point P_4 to edge P_1P_2.

With respect to the above radii equation developed in Eq. (1), one can arrive at a point that the 2 case studies can be worked upon with [25]. **Case study 1:** If ($\lambda - l_0$) >zero; i.e., the vertex 'P' will be seen to the point P_3 right; then in that case the distance l_2 will be positive, the function sgn() is +. **Case study 2:** If ($\lambda - l_0$)<zero ; i.e., the points 'P; will be laid to the left of the point P_3 and then the distance l_2 is negative, sgn() is – .

4. Obstacle collision free path design 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].

1. A point P is considered to be lying on the line P_1 P_2 that is radially separated from P_1 by λ.
2. Draw a$\perp^r$ line (dotted) from P.
3. Using the previous equation, calculate the length of this perpendicular line (dotted) & then the length PO is marked, here the length PO will be the radii of the free route which is full free of obstacles & no collision will take place there, the circle being designed with the centre of the circle as O.
4. Draw a circle around O, passing through the points Q and P.
5. Continue in this manner, taking various locations (P) on the edge of the body or obstacle P_1 P_2 that are at varied straight distances from P1.
6. Draw the lines continuously with$\perp^r$ lines being drawn from the point P.
7. Using the method, calculate the length of these $\perp^r$ lines (radii) and draw circles to touch the two edges with their centres.
8. Continue linking all of the obstacle collision-free path circles' centres.
9. When the obstacles' edges are straight lines, then the obstacle free routes from S to G will be straight lines.

5. Interaction b/w a Vertex and an Vertex

The interactions b/w a set of vertices (interactions b/w a vertex of 1 obstacle O_1 and the vertex of another obstacle O_2), as seen in Figures 6 and 9, is the second basic form of interaction. When the obstructions in the work environment are like this, how do you build the EP path from S to G? Consider 2 vertices P_1 and P_2 of two obstacles O_1 and O_2 separated by a distance of d units [27].

In terms of angle α about the vertex P_1, the radius of the EP cone about P_1 can be expressed by an equation which is a function of α given by [28].

$$cos\alpha = \frac{d/2}{R} \text{ and } R(\alpha) = \frac{d/2}{cos\alpha} = \frac{D}{2cos\alpha} \qquad (2)$$

where P_1 and P_2 are the vertices of two obstacles O_1 and O_2, R is the radius of the EP cone, d is distance between 2 vertices P_1 and $P_{2.}$, α is the angle made by the radius of the EP circle with the vertical distance d.

- Draw a line (dotted) from P_1 or P_2 at an angle of α w.r.t. the vertical distance d.
- The radii of the dotted line $R(\alpha)$ is found using the radius formula given by the above equation and get the center point O 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 equidistant path.
- Hence, the interactions b/w pairs of vertices will be alinear line, i.e., the equidistant path QC is linear.
- When $\alpha = 0°$, i.e., draw a line at an angle of $\alpha = 0°$ w.r.t. vertical & the radius is given by $R(\alpha) = \frac{d}{2cos0^0} = \frac{d}{2}$.
- With this radius, a circle could be drawn to pass through 2 points given by P_1 and P_2.

As a result, the interaction of two vertices is a linear path. If the object or the material that is gripped by the gripper or the tool if it proceeds along this equidistant path, QC, the object will almost certainly avoid colliding with the obstacles [29].

6. Interaction b/w a Vertex and an Edge

The third basic type of interaction is the interaction between a vertex and an edge (interactions b/w a vertex of 1 of the obstacles O_1 and a edge of different obstacles O_2) as displayed in the Figure. 7 & 10. When the difficulties are like this, how do you build the SP from S to G?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 $P_1 P_2$ as shown in the Figure. 10 [30].

The radius of the equidistant path cone is given by a mathematical model using a parabolic function of λ as $R(\lambda)$, which is given by:

$$R(\lambda) = \frac{d^2+(\lambda-I_1)}{2d} \qquad (3)$$

An EP between an edge and a vertex can also be expressed relative to the vertex. If α represents the angle about the vertex P_3 measured in the anticlockwise direction from a line perpendicular to the edge $P_1 P_2$; then, the radius of the EP about P_3 can be given by the expression [31].

$$R(\lambda) = \frac{d}{1+cos(\alpha)} \qquad (4)$$

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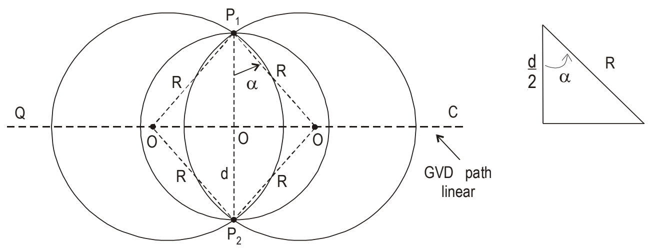

Figure. 9: Third basic type of interaction in an EP-Interaction – vertex & a vertex b/w a pair of vertices P_1 and P_2 separated by a distance of d units

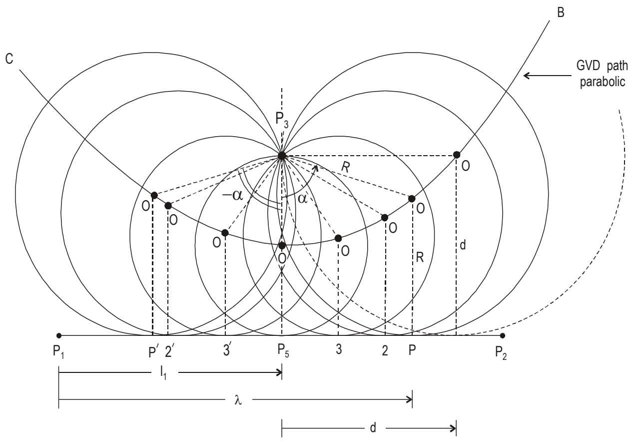

Figure 10. Third basic type of interaction; interaction b/w a vertex P_3& edge $P_1 P_2$

In Figure. 10, P_1P_2 are the edge of obstacle O_2, P3 are the vertex of obstacle O_1, R is the radius of the EP cone, λ is the parametric distance from the edge $P_1 P_2$ to the point P_1, l_1 is the distance from the point P_1 to the $\perp^r$ distance from P_3, d is the perpendicular distance from P_3 to P_1P_2.

7. First method of obtaining the EP using $R(\lambda) = \frac{d}{1+cos(\alpha)}$

- Draw a dotted line at an angle of α from the perpendicular distance d (from the point P_3).
- Compute the radius of the EP circle using the above formula R(α).
- Mark this radius R(α) on the line drawn at an angle of α from the point P_3.
- We get the center point of the EP circle, i.e., O.
- Drop a perpendicular from the point O onto the edge $P_1 P_2$. Let the point be P.
- Draw a circle with the point Obeing the centre and to pass thro' the point P_3 and point 'P'.
- Obviously, $P_3 O = OP = R$, which is the radius of the EP cone.
- The circle will be tangential to the edge $P_1 P_2$.
- Similarly, draw a line at angle of –α, 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 α = 0°, $R(\lambda) = \frac{d}{1+cos(\alpha)} = \frac{d}{2}$, i.e., the mid - point of the vertical line P_3P_5 , O.

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

- Mark a point P at a distance of λ from P_1 along the edge P_1P_2.
- Draw a$\perp^r$ line upwards from P.
- Find the radius R(λ) of the GVD cone using the above equation, get the point O.
- Measure this distance R along the $\perp^r$ distance, so, let it be PO = R(λ).
- A circle could be drawn with the point O as the centre of the circle to pass thro' the point P_3 and point P.
- Obviously, O will be a point on the equidistant path.
- Like this, go on finding the centers of the various circles and join them, then we get the equidistant path.
- When $\lambda = l_1$, then, $R(\lambda) = \frac{d^2+(l_1-l_1)^2}{2d} = \frac{d}{2}$ i.e., the mid-point of the vertical line P_3P_5, O.
- The EP is parabolic in nature and is given by BC.

Hence, the interaction between an vertex and an edge is a parabola [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 robots or the object moves along the shortest route, then, there will be no obstacle's collision with the object or with the robot, because the object / robot is at a safe distance from the obstacles [33].

In any robotic work cell, there will be a number of obstacles. Hence, the route for the robot movement w.r.t. its 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 3DEuclid 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 three basic 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 is a combination of all the 3 basic types of interactions [34].

9. Searching the shortest path using the Motion Heuristics in AI / ML

Motion Heuristics is a search technique used in Artificial Intelligence to find an obstacle devoid route in the robot's free workspace from the S to the destination using search technique, to name a few of them, graph theory, AND orOR graph, chain codings method & the state space search processes (best 1st searches, breadth 1stsearches). Motion heuristics or robot problem solving strategies are search methods that at utilized in the Artificial Intelligence & Machine Learning for finding the route from the starting point to the destination point G. What does the word 'heuristic' signify when it comes to searching? a

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search path that is clear of obstacles and collisions. There are different types of motion heuristics. In order to search for a path which is free of obstacle collision in the workspace of the robots for the movement of the mobile path, various types of search techniques are used, such as (i) state space search techniques, (2) graph theory techniques, (iii) GVD graphs, chain coding, (iv) AND/OR graphs, (v) breadth first search techniques, (vi) best first search techniques, (vii) semantic networks and petri-nets, (viii) D'jekstras algorithm.

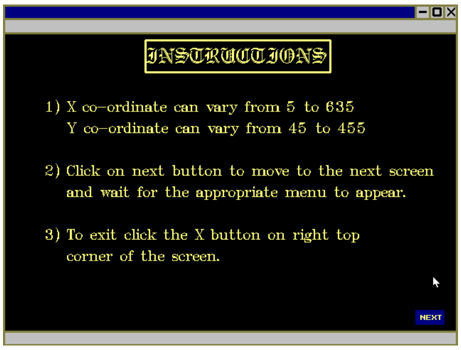

Figure.11. Instruction for entering the rectangular coordinates (using EP method)

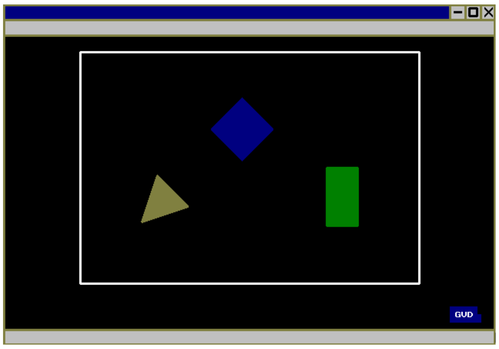

Figure. 12. Instruction for dimensions of the obstacles of any sizes (using EP method)

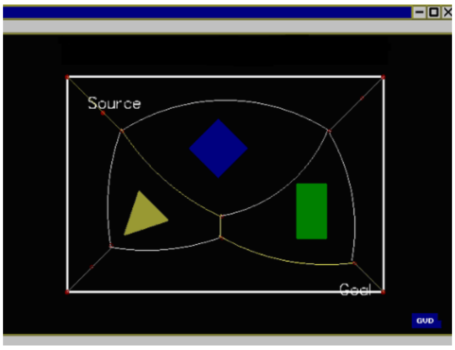

Figure.13. Simulation results depicting all the free path which are existing from the S (using EP method) to the G.

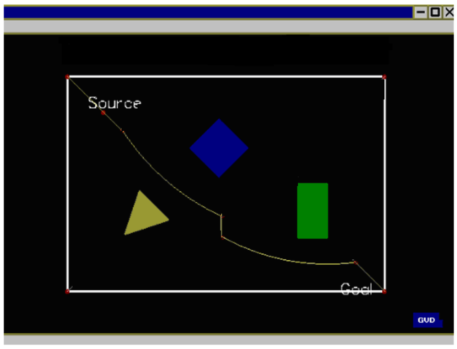

Figure. 14. Simulation result showing the shortest path from S to G designed using MH

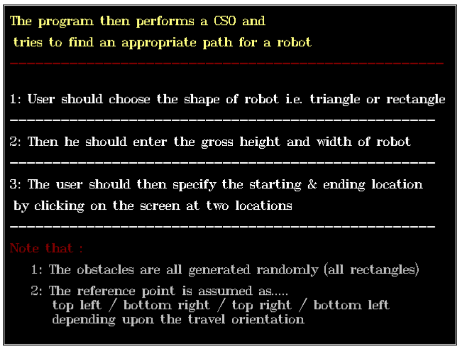

Figure. 15 : Title of the simulation displaying

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

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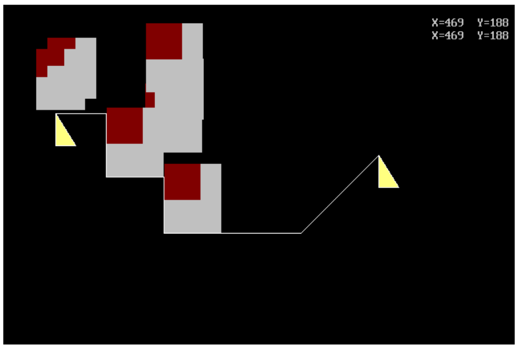

Figure. 17 : Developed shortest path by moving around the obstacle from the S to the G

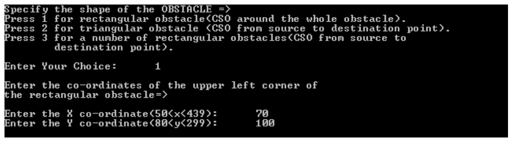

Figure. 18 : Inputting the specifications to the CS method of determining the path-1.

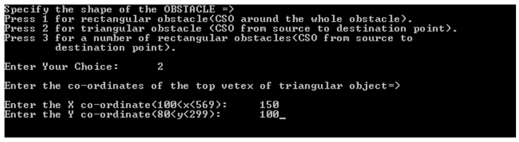

Figure. 19 : Inputting the specifications to the CS method of determining the path-2

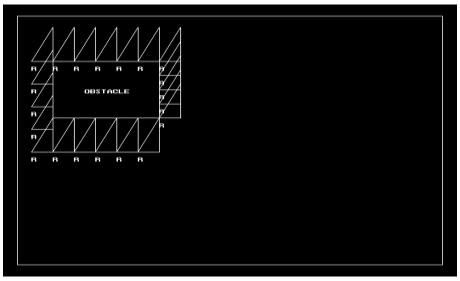

Figure. 20 : Generation of the CSO around the rectangle obstacle

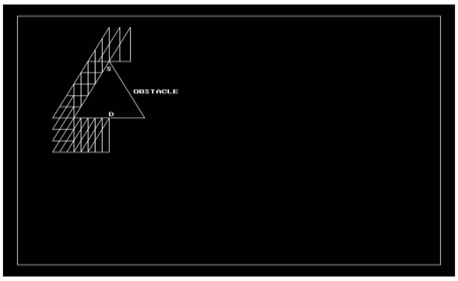

Figure. 21 : Generation of the CSO around the triangle obstacle

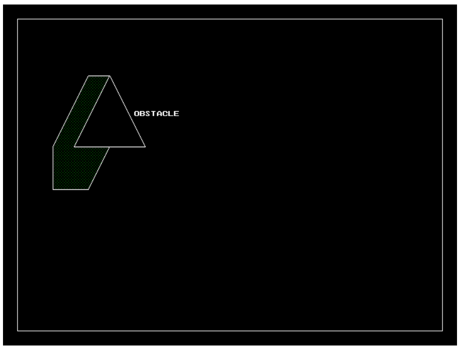

Figure. 22 : Development of CSO around triangle as obstacle

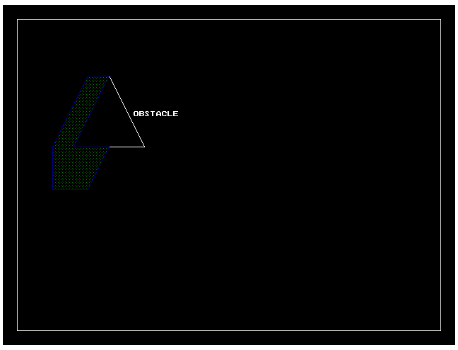

Figure. 23 : Obstacle collision area where the robot should not enter – blue colour

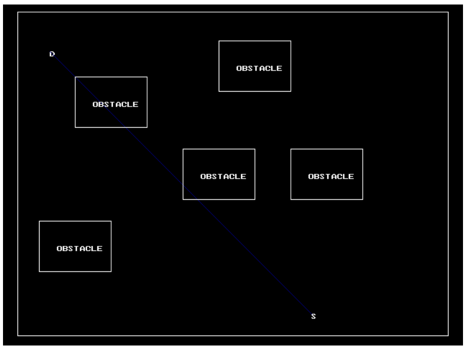

Figure. 24 : Shortest path from source to goal amidst of different obstacles

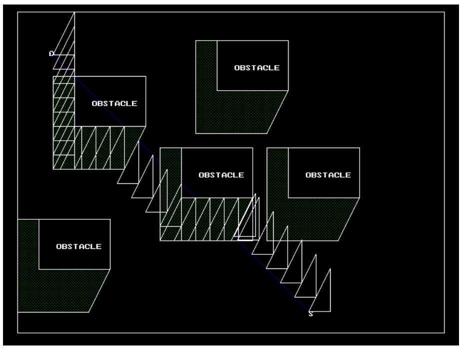

Figure. 25: Finding the shortest path from S to G using CSO

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9.1. State Space Search Techniques: One of the methods of finding the path for movement or to find a answer to the particular robot task question will be for trying out different methods until the desired answer is obtained. 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.

9.2. Graph Theory Search Techniques: In search techniques using graph theory, first, all possible available collision free path which is free of obstacles in the robot's work space 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 for the movement of the robot from the S to the G / destination and is similar to an AND-OR graph in AI. For small graphs (work space consisting of very few obstacles) a solution routes from the starting source state to the destination 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 around the obstacles until the route from the starting scene to the final scene is found. One way to find the path is to make use of search process.

9.3. 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.

9.4. Chain Coding Process: Another way of finding the shortest path is to make use of the chain coding technique, which is used to 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 is the shortest path. In our research work, we have used the chain coding process of finding the shortest route from S to G.

10. Simulation Results

For the purpose of simulations, a robot work space which is filled with obstacles in the 2D plane, especially triangular obstacles is considered. These triangle obstacles are placed on the table or on the floor, which is represented as a 2D rectangular workspace on the computer. We define the source coordinates using the mouse or rectangle coordinates (x_1 , y_1). Similarly, we specify the target coordinates using the mouse or rectangle coordinates (x_2 , y_2).

In order to identify the shortest path using the formula specified in the mathematical model, a computer algorithm is constructed utilising the user-friendly GUI developed in the C++ language. Once the developed algorithm is run, some specs are going to be asked, once the specs are entered, then the results are displayed as shown in the results in the Figs. 11 – 13 respectively. Once, all the available paths are being searched using AI search, then the shortest path is going to be decided by the ML concepts using the pixel coordination method. Artificial Intelligence & Machine Learning (AI-ML) is then employed to discover the short route from S to the target utilizing the motion heuristic methodology. A no. of routes from S to G-target are accessible using this motion heuristics, but it chooses the shortest path, which is illustrated in yellow in Figure. No. 14. Another simulation is carried out which is shown in the Figs. 15 to 17 respectively when the workspace is cluttered with obstacles.

Another example of a simulation case is considered next again using C++, which is designed & simulated using the bounds on the Space of Configuration (CS) as depicted in the simulated results from Figs. 18 to 25 respectively.

Lastly, when the workspace is congested with obstacles, a new way of determining an obstacle collision free routes from the S to G(D) is established using motion heuristic method and a user type of friendly graphical user interface being created in the Matlab Environment. This strategy is comparable to how humans find and seek for paths. The method will also be applied on a RT environment or a system, such as a robots & will be successed in this settings. To find the obstacle collision-free path, Artificial Intelligence is applied, which employs motion heuristics (search techniques).In this research work that is being undertaken 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 the research 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 model is developed and is simulated.

11. Conclusion

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 comes in the motion route (path) from the starting point (S) to the ending point (G) 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, thus the designed robot motion path will be devoid of all the obstacles from S to G & so on and so forth. 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 out such 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 the obstacles is called as the free-ways, translations can be performed along the free-ways & rotations can be performed @ the junction of the free-ways). In our work, we have considered 4 types of interactions of the robot with the obstacle design, i.e., interactions b/w edges, b/w vertices, b/w vertex & edge, combination of all the previous 3 interactions leading to a complex path.

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Mathematical models are developed for all the 3 interactions and 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 and these are written as sub-routines in the program code. From the results of simulation, it could be visualized 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 path planning 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.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The paper background work, conceptualization, methodology, dataset collection, implementation, result analysis and comparison, preparing and editing draft, visualization have been done by first author. The supervision, review of work and project administration, have been done by second author.

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