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Motion Planning in the Area of Robotics and Automation

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ABSTRACT

Motion Planning is computational problem of geometry to find continuous and optimal path from source to destination in multidimensional environment. Today's automation world for industry 4.0 works on multiple technologies where robotics is core part of industry 4.0. To achieve optimal solution with robotics and automation motion planning is crucial area of research. This paper proposes study about motion planning sampling-based algorithm and latest research and development of new variant of probabilistic roadmap algorithm in which researcher achieve optimal solution and reduce time complexity. Main logic behind PRM algorithm is learning phase and query phase. In learning phase, construction of basic road map take place and in query phase, different techniques are used to reach destination by optimal path for different environment.

Keywords : A*, Autonomous robot, D*, Motion Planning, Path Planning, Probabilistic Roadmap, PRM, Robotics

I. INTRODUCTION

A. Robot Motion Planning:

Robot Motion planning is a problem of finding continuous path from source to destination without collision with any obstacles. This problem consists various task i.e. configuration of own space, find out possible paths form source to destination, avoid obstacles and control motion [1]. It is geometry computation of multidimensional workspace. Various techniques are used to find path, but the goal is to find out collision free optimal path. Autonomous robots are characterized as perform any task without intervention of human or any supervision. System should intelligent enough which can detect any obstacle and avoid it. It should keep safe distance with obstacle and also manage it when pass through narrow area. To work efficiently, full or partial knowledge of surrounding environment gives better decision-making ability to robot which is known as sampling-based technique. Figure [1] shows demonstration of robot motion planning.

B. Configuration Space:

Configuration space can be described as a space where robot will be placed. Whole place divided into grid of x and y direction where value of x and y must be calculated according to size configuration of robot plus value of default distance from any obstacle. Further figure [1] shows grid-based configuration space.

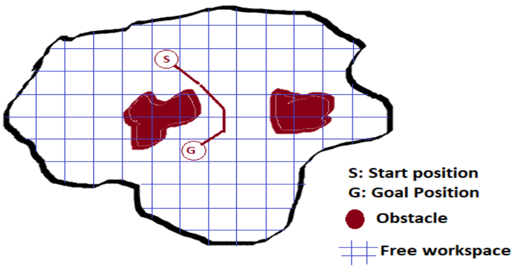

Fig.1: Grid based configuration space and motion planning

C. Types of search:

Search is a problem of finding sequence of nodes which leads to goal node. There are two main technique exists as follow.

- **Informed search**

This technique work based on prior information given as an input. Heuristics about path will increase optimality which is calculated based on prior information. This study uses informed search technique.

- **Uninformed search**

This technique will search path without any prior information. It will keep on searching until it gets goal location. This technique uses "Breath first search" or "Depth first search".

II. APPLICATION AREA

A. Robotics

Robotics is field of engineering, science and technology which produces machine called robots that can replace human activity. Robots are use to assist human as it can perform repeated task, hazardous task, and easily work in pandemic situation without causing any harm to others. Motion planning is core of robotics by which intelligence can be applied. Motion planning in robotics is used to compute continuous path from source to destination and control its motion. Autonomous robots are intelligent enough to take decision according to condition without human intervention or supervision.

B. Computer Graphics

Computer graphics is combination of data structure, graphics algorithm, and languages where data structure suitable for computer graphics, algorithm used to picture generation and transformation and languages are high level language for object. In Computer graphics, motion planning termed as Rasterization is used to draw object which gives coordinate values from start position to end position. Two types of techniques are used in computer graphics i.e. random scan and raster scan. In random scan technique, mathematical functions are used to calculate position and path where in raster scan technique line by line search take place and plot pixel and interlacing is used.

C. Computer Geometry

Computer geometry is branch of computer science dedicated to geometry algorithms which deals with multidimensional work spaces. In Computer geometry, motion planning is used to move object from source to destination which is part of robotics.

D. Animation.

Animation is method of manipulating figures of image where image appears as moving image. Motion planning in Animation is used to move image from original position to manipulate figures. Animation deals with viewport coordinate which is part of world coordinates.

III. METHODOLOGIES

A. Planning problem

Planning problem includes configuration of start position and goal position, geometry description of robot and configuration of work space. Work space converted into grid-based area on x and y axis. According to size of robot, it traverses through nodes of configured free work space and also need to maintain safe distance with any obstacles.

B. Layer Architecture

Layer architecture or ecosystem describes how robot internally works from upper layer to lower layer. How robot takes input data, path planning, collision avoidance and control velocity or motion. This layer architecture divided into 3 part i.e. planning layer, collision avoidance and controller. Each layer divided as per working area. Figure [2] describes layer architecture.

- **Planning layer**

This layer works on informed search, where map of work space is already configured. As per instruction data will be processed and queue of node generated as an output. This queue consists nodes from where optimal path routes. In this phase, data arrival time is not crucial therefore low frequency channel can be used.

- **Collision avoidance**

In second layer, system does collision detection and avoidance. Robot equipped with sensor which identifies obstacles which arrives in between defined route. After detection of any obstacle local planner need to calculate alternate path to reach goal position which is known as collision avoidance. This layer is highly sensible for time constraint data must be reached within time constraint therefore high frequency channel must be used. One major challenge is uncertainty due to sensor data which may cause any accident so that sensor data must be accurate and reliable.

- **Controller**

In third layer, as any obstacle detected controller need to be activated and control speed or velocity. Controller must reply with time constraint and perform action. Controller is responsible for controlling activity of robot.

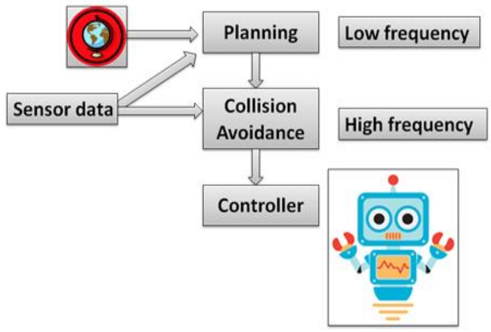

Fig.2: layer architecture

IV. ALGORITHMS AND METHODOLOGIES

A. Environmental map configuration

Environmental maps can be represented by grid-based map, topological map or geometric map but grid-based map is commonly used which describes workspace by x and y coordinates. It is easy to use and implement. This study uses grid-based map where grid value can be obtained by size of robot and default distance from obstacle. All sampling-based algorithm commonly uses grid environmental map.

Algorithm uses 4 way or 8-way movement for robot from current grid means robot can choose next from surrounding 4 or 8 adjacent grid nodes. This study uses 8-way configurations. Following figure [3] shows 4 way and 8-way movement.

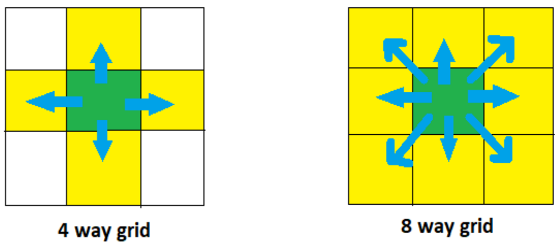

Fig.3: Grid based movement

B. Sampling Based Algorithm

- **Dijkstra's algorithm.**

It is greedy algorithm used to find shortest path from graph. Being greedy in nature it changes route as per situation. At every step it finds vertex which is not included in path and having minimum cost. It generates SPT (Shortest Path Tree) as an output. Time complexity of Dijkstra's algorithm is O(n^2) which can be reduced to O(n log n) using heap binary tree. Figure [4] shows demonstration.

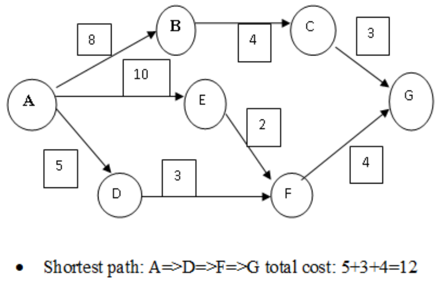

Fig.4: Greedy algorithm

- **A***

A* algorithm is used to search path based on graph. It is extension to Dijkstra's algorithm. It is widely used due to its completeness and optimality. It keeps searching towards goal location if any path moves away from goal location it leaves that route. Base formula for this algorithm is f(n)=g(n)+h(n), where g(n) is actual cost for source to nth node and h(n) represents estimated cost from nth node to next node. Key challenge for this algorithm is to calculate optimal heuristics which will lead to reduce time complexity. Main drawback is space complexity O(n^m) in worst case. It stores information about all nodes in memory. Figure [5] shows demonstration of A* algorithm.

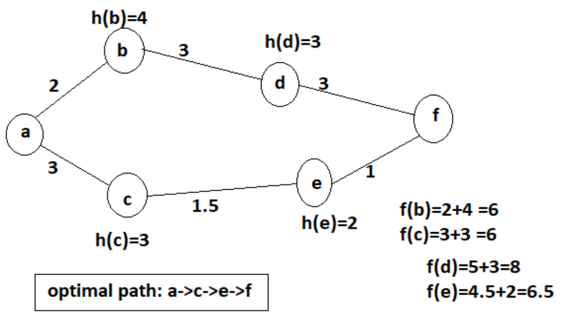

Fig.5: A* algorithm

- **D***

D* algorithm works based on assumption for example assuming that there is no obstacle in work space and calculate path. If any obstacles comes in between path then using heuristic function calculate new shortest path. Here h(n)=0 in first phase. Heuristic comes into picture only when any obstacle detected. It works on unknown workspace and store information about visited nodes.

- **Rapidly exploring Random Tree(RRT)**

RRT used to take sample nodes from voronoi region and build possible path using graph so that it reaches goal position. Voronoi region means cluster based region where it rapidly explore tree for unsearched area and stores information about node. It works on the basis of more you have information better get solution.

- **Probabilistic Roadmap(PRM)**

PRM technique is different than RRT as PRM takes sample node from work space and build graph which is called as road map used to travel through region.

As both are working on sample nodes but RRT build graph tree to reach goal position where PRM uses graph as road map. PRM divided into two phases i.e. construction phase and query phase. In construction phase PRM builds road map for region and in query phase it finds best route for given goal location. Since last 8 to 9 year it is under research and so many new variants available which differ in case of optimality. Mostly all variants use same algorithm steps for construction phase but it differs in query phase.

Here we have discussed new variant of PRM which works first on construction phase and then query phase. In query phase first algorithm finds side in which robot will travel using line slope. For calculating line slope m=(deltaY/deltaX) is used where deltaY is Ygoal - Ystart and deltaX is Xgoal – Xstart. Slope of line will indicate direction for path. Value of m works based on 45' line, if value is equals to 1 then path exactly moves through 45' else if value of m greater than 1 then path moves above 45' else if value of m is less than 1 then path moves below 45'. Second case if line is straight then one of the value of delta x and delta y must be zero. If delta x is zero then line must be horizontal and if delta y is zero then line must be vertical. After getting value of robot have 4 possible direction which will further distinguish by value of goal node coordinates i.e. if (+x,+y) then direction must be north-east, else if (-x,-y) then direction must be south west, else if (+x,-y) then direction must be south east and if (-x,+y) then direction must be north west. Time complexity of this algorithm is O(n) for worst case. Figure [6] and Figure [7] shows calculation of direction demonstration.

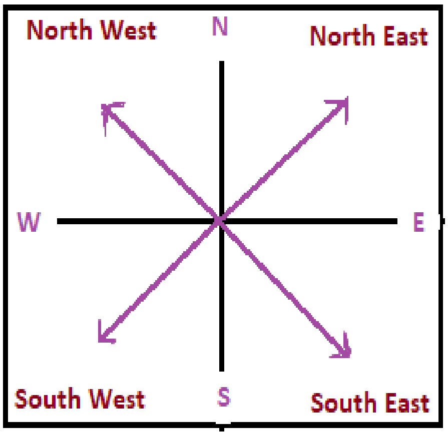

Fig.6: Direction demonstration

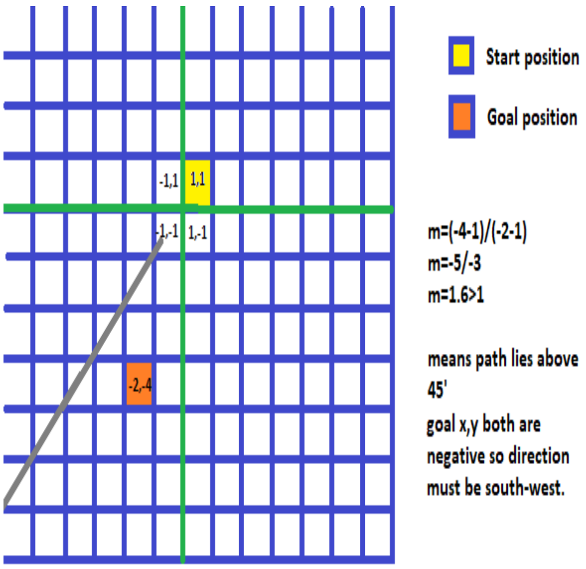

Fig.7: Calculate goal direction

After turning robot in that direction algorithm pick all nodes from V which falls under radius of current node and pick cheapest node having edge in E from current node to cheapest next node. It repeats this process until reaches to the goal node. In this path finding process if sensor senses any obstacle in between then controller controls speed of robot and algorithm finds nearest cheapest node falls in radius of current node for the route to destination. Following figure [8] and figure [9] demonstrate this algorithm.

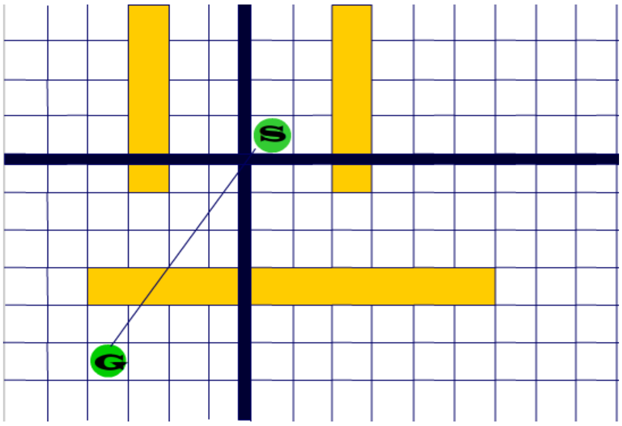

Fig.8: PRM initial state

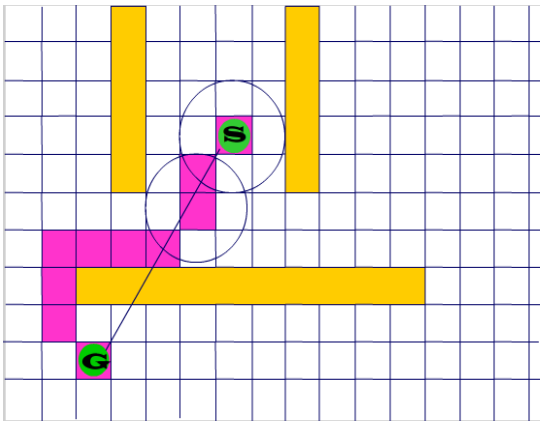

Fig.9: PRM final state

- **Flowchart**

This flowchart figure [10] describes new variant of PRM algorithm.

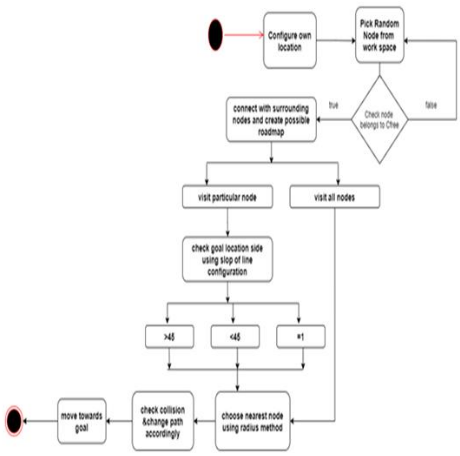

Fig.9: Proposed Flowchart

- **Algorithm**

Construct Roadmap:[10]

[V: vertices, E: Edges, H: heuristic cost, C: work space, c: random node, r: radius, G: priority queue]

Let: V ← ∅; E ← ∅;

1. Loop
2. c ← c ∈ Cfree
3. V ← V ∪ {c}
4. Nc← Nc ∈ V
5. for all c0 ∈ Nc, in order of increasing distance from c do
6. if c0 and c are not connected then
7. if the local planner finds a path between c0 and c then
8. add the edge c0c to E

Query phase:

1. s (x0 , y0) ∈ V (start position)
2. g (x1 , y1) ∈ V(goal position)
3. m=(y1-y0)/(x1-x0)
4. choose direction according to m, turn robot in direction
5. cur ← s
6. while(cur != g)
7. pick all v ∈ V((cur)r) and add in G min heap
8. next ← Groot
9. loop cur next !∈ E or detected any dynamic obstacle remove Groot and construct min heap
10. if cur next ∈ E
    cur ← next
11. update H(cur next)
12. stop

V. TOOLS AND TECHNOLOGIES

A. Arduino Tools and technology

Arduino is open source electronics platform which easily integrate hardware and software. Easy to use and develop similar to C programming. Arduino boards able to read data from sensor activating and controlling motor etc.

B. Sensor

To work in dynamic environment, need to use sensor to detect any obstacles and configure work space. It provides intelligence to take decision according to condition.

VI. CURRENT/LATEST R&D IN THE FIELD

The probabilistic roadmap is leading research topic since last eight years. It gives number of variants implemented by different environment. Basic idea behind this algorithm is Construction phase where taking random node from work space and roadmap is created for future use. Second in query phase, check for shortest path taking input from path built in construction phase.

Chen, J. et all [14] proposed P-PRM algorithm by implementing algorithm for narrow passage testing with success rate 90.0. Having base of PRM algorithm P-PRM is improved version. Researchers experimented and simulated in 2D environment and demonstrated success rate.

Development and testing of generalized wave-front algorithm by Yonghua Zhang [15] which is based on A* and RRT (Rapidly exploring Random Tree). This algorithm combines multiple targets sets and multilevel grid cost. Due to A* algorithms' completeness and optimality and optimal RRT algorithm gives smooth and safer path around obstacles.

VII. CONCLUSION

This study covers informed search algorithm and comparison of its performance and also gives new variant of probabilistic road map algorithm which focuses on optimal solution which is primary measurement of any algorithm. Future scope of this variant will be reduce space complexity of algorithm though it reduces time complexity up to some level as it is based on PRM and smartly guess direction of destination. If direction of path found successfully then it reduces search complexity. Optimal solution gives safe, shortest and fastest accessible path which is main goal of this variant. In future work, implementation and testing of algorithm in actual autonomous robot.

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