Reading report
A survey of robotic motion planning in dynamic environments[1]

Dharmin Bakaraniya

June 3, 2018

Abstract

Robot Motion Planning (RMP) has been a thrust area of research in computing due to its complexity, since RMP in dynamic environments for a point robot with bounded velocity is an NP-hard problem. This paper is a critical review of the major contributions to RMP in dynamic environments. Between 1985 and 2015 the focus has changed from the classical approach to a heuristic approach. For velocity based motion planning in dynamic environments, ICS AVOID (Fraichard and Asama, 2004, also see Section 2.4.4) is the safest approach which means that this method have the capability of for an autonomous robotic system to avoid collision with the obstacles in the environment. Other important approaches include artificial potential field based, artificial intelligence based, probabilistic based RMP and applications in areas of Agent systems and computer geometry. Classification of the RMP literature on the basis of the techniques and their performance has been attempted.

1 Summary

- A planner that can find the optimal path if one exists and reports null when a path does not exist will take exponential time in terms of degree of freedom of the robot. This makes robot motion planning in dynamic environment a NP complete problem.

- With bounded velocity and arbitrary obstacles, motion planning for a point robot in a plane is intractable and NP hard.

- The authors divide robot motion planning for dynamic environment in several parts

  - *Artificial potential field*

    * Whole map is a field. Goal has an attrative force while obstacles have repulsive force. The resultant force being applied on the robot will have a direction and magnitude.
    * This resultant force is used to calculate the direction and speed of the robot.
    * The robot is considered a point mass and it is able to perceive the position and velocity of the obstacles. The obstacles are convex polygon. Only one obstacles is close to the robot.
    * An *avoilability measure* can be employed which is a function of distance to closest obstacles and relative velocity of that obstacle. This function computes the possibility of collision.
    * Potential field approach has a famous problem of local minima. This has been addressed multiple time. It has also been extended to handle moving obstacles and moving target.

  - *Accessibility graph*

    * Obstacles are considered polygons. They are assumed to move in a fixed direction at constant velocity. The target is also moving.
    * A graph is generated from a point to the moving target. This graph goes through the obstacles as well. If the robot can move faster than obstacles then the algorithm returns a time optimal path with complexity $O(n^2 \log n)$ (where n is number of vertices in the graph).

  - *Configuration space, state time space*

    * Robot is considered to take a configuration from its configuration space. A configuration is position and orientation of the robot in global frame.
    * If a configuration of robot results in collision, then it is called configuration space obstacles. Union of all such region is called configuration space obstacle region. All remaining configuration form free configuration space.
    * Thus finding path is searching in free configuration space for a continous set of configurations from start to goal.
    * State time space is an extention of configuration space which considers time varying environment. It also allows to integrate dynamic constraints.

2

– *Velocity based approaches*
  * The authors explain that the problem of motion planning can be divided into 2 part. First being the computation of kinematic trajectory and the second is finding the closest solution to the kinematic solution after applying dynamic constraints.
  * *Velocity obstacle*
    · Collision of robot with moving obstacles are determined by projecting a collision cone. Velocity obstacle of that obstacle for our robot is calculated by shifting the collision cone with velocity of obstacle. If the velocity of robot lies in this cone, then the robot will collide with that obstacle.
    · The robot then chooses a velocity outside that cone to avoid obstacles and move towards its target. During this step, it only considers velocities that are allowed by kinematic and dynamic constraints.
    · The robot and all the obstacles are considered circular. The obstacles always move with constant linear velocity.
  * *Dynamic velocity space*
    · Dynamic velocity space is a velocity time space which incorporates not only dynamic object velocity of all obstacle but also robot constraints.
    · Configuration space is mapped to velocity space with the help of calculation of estimated arrival time.
    · Heuristics based on least travel time and shortest path can be applied.
  * *Dynamic window approach*
    · Only circular path are considered which do not result into collision. The search space is a window in velocity space. The size of this window is determined by robot constraints that allow motion within certain time period.
    · The goal of the robot is to maximize the translation velocity while moving towards its goal and avoiding obstacles.
    · Time varying dynamic window (TVDW) and global dynamic window (GDW) and Non linear velocity obstacles extend this approach to remove certain deficits.
  * *Inevitable collision state*
    · ICS is a state where the robot will collide no matter what control input.

- · ICS-AVOID is an algorithm which avoids collision by never going into ICS.
- · This algorithm performs best compared to dynamic window and velocity obstacle when give the same amount of information.

∗ *Partial motion planning*

- · It needs a model of the environment. The model can be build using sensor information as well.
- · The algorithm iteratively searches the state time space till timeout. At timeout, it returns te best trajectory that it was able to find from the tree it created.
- · The trajectory may be incomplete so a whole collision free path is not guaranteed. But all the partial trajectory that are calculated can be ensured to have no ICSi.

∗ *Directive circle*

- · Differential drive has a moving target and the environment is cluttered with static and moving obstacles.
- · A directive circle is drawn around the robot in velocity space and the obstacles is boundary are connected with the robot. If the circle intersect with those lines, then the robot will collide.
- · This approach performs better than offline planners and provides near optimal paths. It has safety issues in narrow passage and cannot deal with abrupt change in velocity of obstacles.

∗ *Differential constraints*

- · A differential drive robot is considered here. Robot state space is represented as a graph with nodes as reachable state and edges as motion control.
- · The states are dynamically created given current sensor information and motion commands. This way it incorporates dynamic environment and robot constraints.
- · The states are denser near the robot and scarce at distance. This improves the performance on online execution. It reacts quickly to changing environment.

∗ *Graphic processor unit*

- A function similar to dynamic window is optimized by this approach using parallel processing. The approach senses the environment and replans the trajectory every iteration using graphical processors.
- It does not require any information about the obstacles a priori. The approach provides a bound on responsiveness and quality of the planner with increasing number of processor.

* *Search tree algorithm, LP minimization*
  - It is applied on UAV to avoid collision with other UAV.
  - UAV in collision course are ordered in queue. Each UAV is then prompted to state their strategy which is optained with the help of Search tree algorithm.
  - It considers the distance traveled by each vehicle after each iteration and tries to minimize the number of iteration to avoid collision as fast as possible.

* *Atomic obstacle and dynamic envelop*
  - As long as the robot is moving along a curved trajectory in xonfiguration space, collision free motion is guaranteed.
  - This approach does not need shape and velocity of the obstacles.

* *Temporal and spatial reshaping*
  - The algorithm applies 2 steps to produce a 3D collision free path. First step is to obtain collision free path through kinematic sampling based motion planning and second step it to transform that path into dynamically executable one.
  - Temporal reshaping controls the velocity while spatial reshaping controls the trajectory.

* *Safe time interval*
  - The approach tries to minimize the number of safe time step in its trajectory.
  - A safe time step is a state in configuration space that has no collisions but one step in an adjacent state will lead to a collision.

* *Rendezvous guidance technique*
  - The robot has a moving target and has to travel in an environment with static and moving obstacles.

- The algorithm first determines the state of obstacles and robot and determines the feasible velocities. It then calculate rendezvous line and rendezvuos set. It selects the common velocity.

- Rendezvous line is from position of robot to velocity of target. Rendezvous set is all point on rendezvous line.

   ∗ *Real time adaptive motion planning*

- It is same as *atomic obstacle and dynamic envelop* but for robots with large degree of freedom.

- It performs in real time to optimize trajectories.

   ∗ *Predictive temporal motion planning*

- The environment is represented in terms of occupancy grids but they are extended to have time dimension.

- This approach tries to unify planning, mapping and obstacle avoidance.

- By considering the current motion of the obstacles, their future positions are estimated and the robot use motion command to avoid those positions

- The authors compare different approaches in velocity based motion planning section and state that ICS, DVS and VO account the dynamic nature of the environment the most. DW, ICS and DVS consider the dynamic and kinematic constraints the most. ICS addresses the uncertainty due to perception.

2 Scientific contributions

- A survey of the state of the art in robot motion planning for dynamic environment addressing all the approaches in last 30 years.

3 Scientific deficits

- The comparision between most of the approaches is not provided.

- The approaches are not explained in a understandable way.

- Even the comparision between few approaches that is provided does not have an objective measure. Those comparision does not contain any proof of the claims.

- Mention of unrelated topic in the middle of approaches.

References

[1] Article (mohanan2018a) Mohanan, M. & Salgoankar, A. "A survey of robotic motion planning in dynamic environments", *Robotics and Autonomous Systems* 2018.