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Online path replanning of autonomous mobile robot with Spline based algorithm

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Abstract. The two- dimensional path planning with obstacle avoidance for autonomous mobile robot in indoor environment moving with constant speed is presented. The objective is to find the collision free path form partially known area by giving a desired start and goal positions and their orientations from range sensor data. When possible, the shortest path can be firstly created offline from known information data like the robot navigation module or given map. Following the pre-calculated path, if the sensor attached to mobile robot that receives the signal in range of 3-5 meter in 180 degree around it in driving direction; we can extract the geometry and make sure that whether it is the obstacles. In case of finding one, we recalculate the new sub-path using the piecewise rational Bezier curve from current point to the new determination point and its heading direction connected with others sub-path from that point to goal. Each sub-path is recalculated when it meets the obstacles in between. At the connection point of each pieces must be overcome the curvature discontinuity problem in order to have smooth steering angle of the actuator. From this algorithm, we get the satisfactory path with smooth curve along the entire route in order to take gradually rate of change of steering angle for future path control algorithm in considerations. This method also guarantee that the robot is able to safety moves towards the goal using its knowledge and sensor information or prove that the robot can not move anyway in case of not possible to reach it

Keywords: Path Planning, Autonomous mobile robot, Piecewise rational Bezier curve, smooth path

1. Introduction

Nowsdays, there are a great deal of the research and knowledge in the field of intelligent autonomous robotics including car-like vehicle areas. They are concerning with sensing, thinking and actuating especially by themselves. One should be able to acquire, fuse, process, act and fulfill its tasks automatically. The effort is now focus on the development of autonomous robot that robot can investigate an unexplored place with sensor data reading such as odometry, sonar, laser scanner and camera. It can also possess a model of its environment and be able to determine its position in such environment. Additionally the path planning aims at providing an optimal path from an initial to goal position, preventing collision or so called obstacle avoidance and tracking of moving object.

Our complete robot's tasks following fig. 1, starts in certain environment while receiving a sensor information which its function acts like human's eye. Afterthat it will be calculated with mathematics method and computational efforts in order to get the map and in the same time we know where the robot locates. Working with partially known map of the surrounding, we'd like to plan the path where the robot can run without collision with some constraints from the given start point to goal. How such path can be generated is the topic that will be presented in this paper. During the time the robot moves with the volocity and can steer the direction following the pre-determine path. Unfortunately, the unknown obstacle may be appear during the time and the robot recieves this information by sensor like laser scanner and have to recalculated the way with our constraint that it move from point to point with curvature continuity because it effects the steering angle. Finally we also study the motion control by using both kinematics and kinetics model

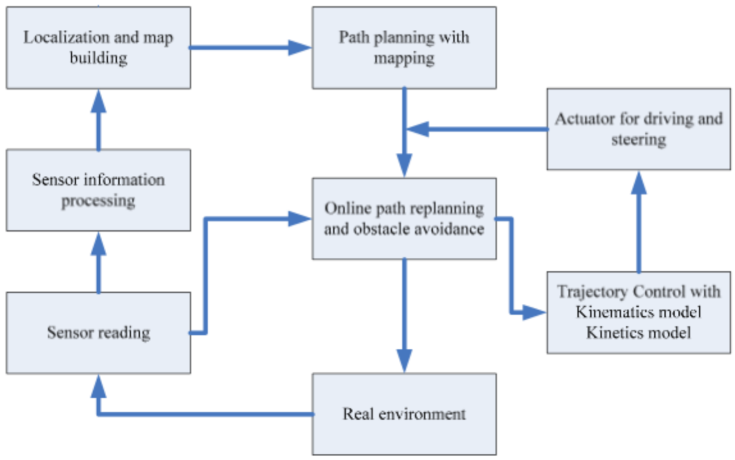


Fig.1 Autonomous mobile robot tasks

Path planning and navigation are the process of getting a feasible and safe trajectory from the start or so call current position of robot to the goal. In our problem, it is firstly planned offline for the robot which lead the robot to its destination assuming that the environment is perfectly know and stationary. In this research, it aims at solving the mobile robot problem running in indoor environment using the geometric based. If we know exactly the environment figure, there is no doubt to create the optimal path that the robot can move with the constraints like the shortest path. Unexpectedly, in real cases, the locations of the obstacles are not known in advance but it is assisted by the sensor when these are within a sensor range. The robot changes its path when it senses the danger areas. By this condition the shortest path should not be longer exist. Then give the next question if one of path is better than the other.

The generalized process of our path planning method are shown in figure 2. It starts with initialization the system and then the path can calculate by given the target points espectially the start, goal and there can be the via points with the direction of the robot or the orientation of each points with or without map data and inconsistent the change of steering angle or namely the curvature of the path is concerned. We let the robot run along the pre-planning path until the obstacles are sensed and the path will be tangled into the object. By this condition the new points is determined and in consequently the path will replan until it reaches the goal for completing its task.

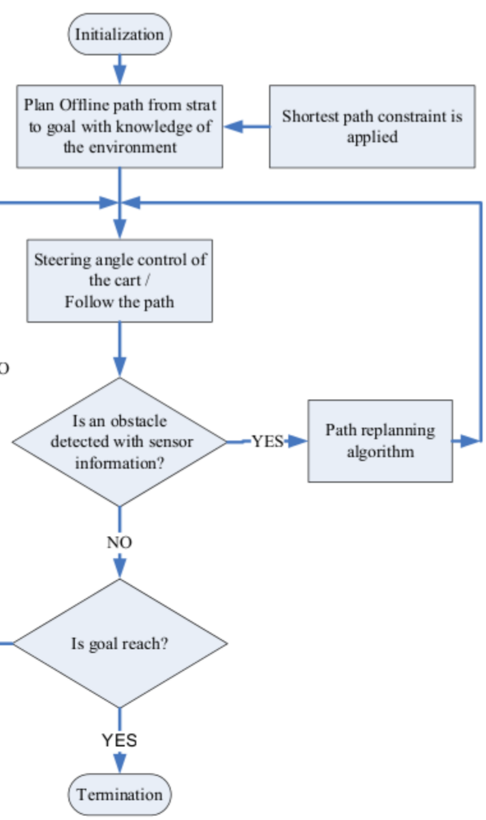


Fig. 2 Generalized path planning method

Two-dimensional data provided by a radial laser range scanner is concerned with two-dimensional information. That means, from that data, we have got the information approximating the shape of the environment, and the update process will involve a correspondence problem between segments from the current map and segment from the local map obtained at each position. Precise position estimation is required in order to refer both representations to a cartesian coordinate system with parametric equation.

Many techniques regarding the geometric based have been pioneered for this topic such as Hong et al [1] presented the vision based path planning based on inverse perspective mapping theory concerning kinematics model of its. The pathways are planned under uncertain environments according to real-time information single visual sensor captured. Liang et al [2] proposed the method that they considered of curvature constraint and length minimization. It considers the family of curvature-constrained curves constituted by two cubic spirals to achieve reorientation, in connection with upto three straight line segments as inflection points of cubic spirals for length minimization The shortest path for nonparallel configuration pair can be searched from all feasible paths of the family generated by linear programming optimization over the length of each segment via the selection of potential intermediate configurations. .While Erkorkmaz et al [3] shows how the quintic spline interpolation works for fitting the points applied to the tool path generation for reducing the feed rate fluctuation in high-speed interpolation. The generated tool path should be without encountering any feed fluctuation or discontinuity. Yang et al [4] considered path planning with continuous curvature condition for UAVs in cluttered environment. They tried to consider cubic spline interpolation and cubic B-spline. Rather than smoothing over all waypoints at once, smoothing can be applied piecewise on consecutive way like Dubin's path that can generate a shortest path between two postures in the plane for a vehicle having limited curvature. The drawback is that its curvature is not continuous at the joints connection the lines and arcs. For this problem clothiods are good alternative to generate a curvature continuous path but they are not very flexible in matching the conditions placed at the end point of the path. Berglund et al [5] studied how to plan the smooth path and obstacle avoiding using quartic uniform B-spline curves for autonomous mining vehicle, minimizing curvature variation, and staying at least at a proposed safety margin distance from the walls. The three dimensional collision free path is also present such as Hachour [6]. The presented 3D path planning that allows a robot to navigate through static obstacles and finding the path. The path connection the start points to the target point can be interpolated with non-uniform rational B-splines to obtain a smooth curves. With the previous work from Boonporm [7], the path planning with the piecewise hermite spline is presented. There are some studies that tried to compare some method of path planning for optimizing some criteria like Yang et al [8] tried to compare various type of path for near optimal solution based on a piecewise polynomial parameterization of all feasible trajectories. Different performance indexes are defined to obtain optimal solutions in terms of the reduced control energy and path length.

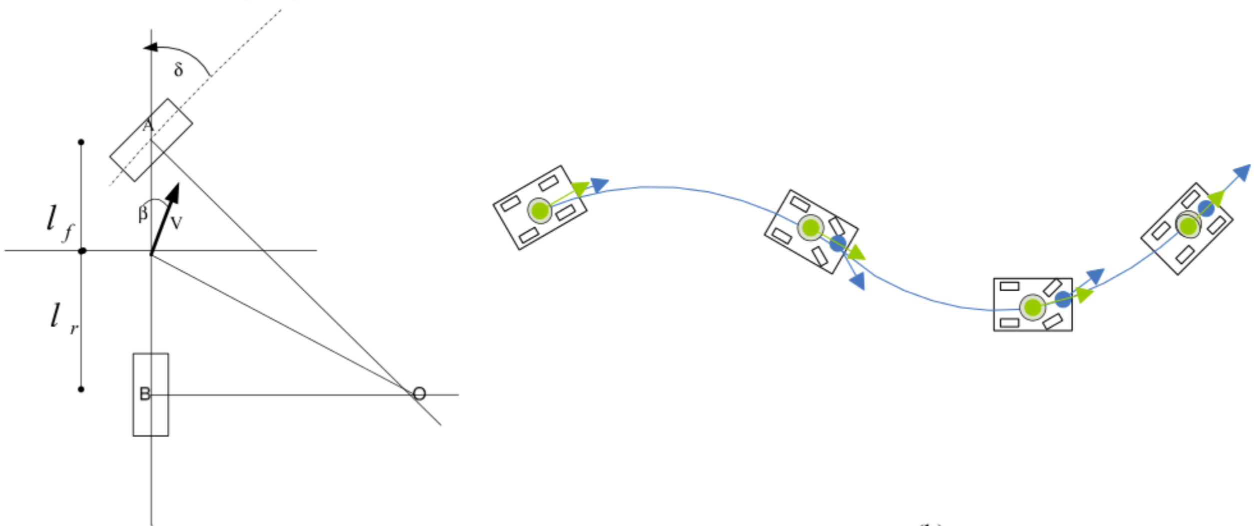
2. Spline generation and criteria

The problem of generating a smooth curve through an ordered set of two-dimensional points is one that often arises in computer graphics, CAD/CAM application, robotics and etc. The curves generated can represent sketching, contour lines or other graphical objects. The requirements for a suitable curve generator include simplicity of specification, smoothness, ease of calculation and locality. Simplicity of specification is achieved by requiring that the curve must pass through the given data points. This requirement allows the method to be used to reconstruct time or space sub-sampled curves such as robot travelling paths. The smoothness criterion requires that the generated curves be visually pleasing when displayed on the output device. The locality requirement means that only a few neighboring points are needed to calculate a curve segment. Ease of calculation requires that the algorithm be simple and fast enough to be implemented on a microprocessor. Spline curves is the mathematic representation that allow the user draw and control the shape of complex curve by using the control points but instead of interpolating curves, that means spline do not pass exactly to control points. To avoid this problem the piecewise spline is introduced but unfortunately there are different polynomial functions for different parts of the curve so that we have to consider the continuity at the connection point.

Answering the question why it should be curvature continuity because we need that robot can run as smooth as possible. We look at figure 3(a) that is simplified lateral kinematics bicycle model of the robot that we can find the relationship between steering angle and the curvature of the path in equation 1 while figure 3(b) shows the path with steering angle and robot velocity

$$\frac{\tan\left(\frac{\alpha}{2}\right)}{l_f + l_r} = \frac{1}{\rho} = \kappa \tag{1}$$

Where α is steering angle, ρ is radius of curvature and κ is curvature



(a) (b)

Fig 3 (a) Steering angle with robot bicycle model (b) Path planning using spline concerning steering angle Green-velocity vector, blue-steering direction

To match our criteria about control point in both position and orientation, we consider first the easiest type of spline. The Hermite spline is applied to this problem as piecewise third degree spline. Each polynomial consists of two control points and two control tangents. The drawbacks are that it can not fulfill our wish for curvature continuity and the curve is not flexible enough. Next we consider the Bezier curve with four points that normally can extract the points form Hermite curve.

Although our problem run on 2D Cartesian coordinate x-y, we found that using the explicit relation between x and y is sometimes has some pitfall e.g if the path is plan linearly parallel or nearly to y direction, that give us large amount of sensitivity, ill condition and divide by zero problem. For this reason parametric curve with parameter t lies in each section $[0,1,2,3,...,m]$ is taken into account, where m is the number of interval. From this condition we define an arbitrary parameter interval of Bezier curve $t \in [t_0, t_1]$ equation (2)

$$C(t) = \frac{\sum_{i=1}^{3} \binom{3}{i} (t_1 - t)^{3-i} (t - t_0)^i P_i}{(t_1 - t_0)^3} \tag{2}$$

The curve is said to be C^2 continuous at the breakpoint t if $C_i^{(j)}(t) = C_{i+1}^{(j)}(t)$ for all $0 \le j \le m$

Form the equation above, we found any problem that the calculated path is penetrate into the object. To solve this we conduct the path with the scalar weight w_i . Then the curve equation become (3) for providing more control over the shape of a curve and it knows as a rational Bezier curve because the blending functions are rational polynomials

$$C(t)=\frac{\sum_{i=1}^{3} w_i \binom{3}{i} (t_1-t)^{3-i} (t-t_0)^i P_i}{\sum_{i=1}^{3} w_i \binom{3}{i} (t_1-t)^{3-i} (t-t_0)^i} \tag{3}$$

The first and second derivative for the rational curve $P_{[t_o \quad t_i]}(t)$ at the endpoint can be calculated as equation (4) and (5) respectively

$$P'(0)=\frac{w_1}{w_0}\frac{n}{t_1-t_0}(P_1-P_0) \tag{4}$$

And $P''(0)=\frac{w_2}{w_0}\frac{n(n-1)}{(t_1-t_0)^2}(P_2-P_0)-\frac{w_1}{w_0}\frac{nw_1-w_0}{w_0}\frac{2n}{(t_1-t_0)^2}(P_1-P_0)$ (5)

Where n=3

The curvature κ of the parametric curve is

$$\kappa=\frac{|\dot{x}\ddot{y}-\dot{y}\ddot{x}|}{[\dot{x}^2+\dot{y}^2]^{3/2}} \tag{6}$$

Let two curve segments $P_{[t_0\, t_1]}$ with the point P_1 P_2 and P_3 and $Q_{[t_1\, t_2]}$ with the point Q_0 Q_1 and Q_2 are to be C^2 Continuity we must have condition C^0 that the two adjacent curves share the common endpoint, C^1 that they have the same tangent and C^2 that they have the same second parametric derivative at that endpoint both magnitude and direction. The satisfactory condition of C^1 and C^2 are presented in equation (7) and (8) respectively.

$$\frac{3}{t_1-t_0}(P_3-P_2)=\frac{3}{t_2-t_1}(Q_1-Q_0) \tag{7}$$

$$\frac{6}{(t_1-t_0)^2}(P_3-2P_2+P_1)=\frac{6}{(t_2-t_1)^2}(Q_2-2Q_1+Q_0) \tag{8}$$

The determination of intermediate points and their orientation can be chosen by the information from range finder reading. Since we get a number of points that we can extract the geometry and classified that they are obstacle objects, the robot cannot go more follow the path. The both end point of the extract geometry can be the via point of the robot then we look where is possibly near the goal point and choose that point to be the endpoint of sub-path. The orientation at the via point is considered to be small curvature variation and equal at the joining point. From the orientation and size of it or the weight, we can extract this data like the conversion from Hermite spline to Bezier curve with weighting function that we mention above. The advantage is that we can control better shape of piecewise spline and reduce the chance of the path will tangle into the object

3. Path Simulation Result

As mention above in this example scene with the known obstacle 1, and given start point and goal with their orientation or heading of robot is calculate the path and let the robot run until point C that the sensor make sure that there is the obstacle 2 stayed transverse to the path. We recalculated the new path at point C that we tried to maintain the curvature between the start to point C and the next curve from point C to goal. The porcupine in figure 4 shows the curvature of the path.

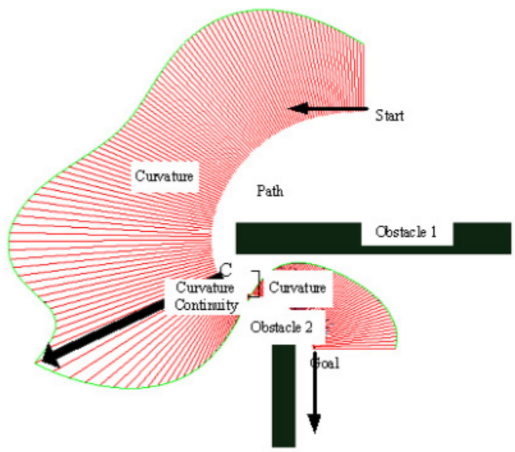


Fig. 4 Path planning with curvature calculation

4. Summaries

In this work we present the path planning algorithm by using rational Bezier curve interpolation in two dimensional partially unknown environment. The algorithm guarantee that the path can reach the goal or otherwise if it is not possible, the robot has to stop and return the message. First we let the robot go the the offline pre planning trajectory and if the sensor sense the obstacle, it must be replanning with the criteria of shortest arc length at the instant and smooth path. The latter have further effect on motion planning with considering the steering angle with kinematics and kinetic model.

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