Fuzzy Virtual Objects for Real-Time Moving Control of Mobile Robot in Dynamic Environments

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Abstract: - The fuzzy virtual object is proposed based on fuzzy modelization of the moving objects in dynamic environments. The fuzzy virtual object is defined as a fuzzy set whose membership function contains the objects’ motion information. It provides a basis of motion control for mobile robots in dynamic environments. A new method of real-time fuzzy robot control is proposed based on the fuzzy environment modelization with fuzzy virtual objects. In the computer simulation experiment, the proposed method can efficiently implement robot navigation in the dynamic environment with both moving obstacles and moving target.

Key-Words: - Mobile robot control, fuzzy virtual object, fuzzy modelization, dynamic environment

1 Introduction

The mobile robot is an important research area in robotics. Motion planning is one of the key problems in mobile robot control, which is required to be real-time and optimal in real world applications. Robot navigation in dynamic environments is one of the challenging tasks, which is a problem of high complexity.

Many robot navigation techniques are model-based, in which establishing an environment model is the first and basic step for robot path planning. Typical techniques include the artificial potential field and the grid-mesh method\textsuperscript{[1-5]}. However, the dynamic environment has moving objects, which makes the environment time-varying and therefore invalidates the traditional path planning methods applied in static environments. New methods are needed for effective and efficient modelization of dynamic environments.

The model of the static environment only contains the objects’ position information. The planning methods based on such model can not get any motion information about the objects, which makes them invalid in dynamic environment. Therefore, the more motion information included in the environment model, the more beneficial to efficient path planning in dynamic environments. The fuzzy theory is a powerful tool to deal with problems with uncertainty\textsuperscript{[6-9]}. In this paper, the fuzzy virtual object is proposed to represent moving objects in dynamic environments. The fuzzy virtual object is an extension of traditional concept of objects, which is defined as a fuzzy set including the object’s motion information in its membership function. Moreover, a real-time fuzzy control method is proposed for the dynamic environment based on the fuzzy modelization. Simulation experiments indicate that efficient robot control can be achieved in dynamic environments by the proposed method.

2 The Fuzzy Virtual Object

The dynamic environment contains both moving obstacles and a moving target. Each moving object has its specific property of motion, which is always unknown to the control system. This causes much uncertainty of the environment, which makes the robot navigation a complex task.

The fuzzy theory has been proved to be a suitable tool to deal with uncertainty in real world applications\textsuperscript{[7,8]}. In this paper, fuzzy concept is introduced to represent the uncertainty caused by the objects’ motion. Each object’s motion status is represented by the membership function of a fuzzy set, which contains the motion information such as current position, moving speed and direction.

The fuzzy virtual object is defined as the fuzzy set whose membership function represents the object’s status of motion. It is a representation of an object with its motion information. To represent the object’s motion status, the membership function is defined according to the following principles:
(1) The membership function is a two-dimensional continuous function defined on the robot’s workspace.
(2) The membership function only has non-zero value in a neighboring area around its current position \((x_c, y_c)\), and it is zero elsewhere. This principle derives from the spatial local search idea, which ignores the influence of distant obstacles in navigation. This can largely simplify the problem and makes the method efficient, especially in dynamic environments.
(3) The membership function is a convex function and has its peak value at the object’s current position \((x_c, y_c)\), which is the membership function’s kernel. The function decreases as getting away from the kernel. This principle is based on the following fact: in path planning, the object has less influence at points farther from it.
(4) For those points that have the same distance from the kernel, the nearer the point from the object’s moving direction, the larger the membership function value at that point. At the point on the moving direction, the higher the speed, the larger the membership function value. This principle is based on the following fact: in path planning, an object has larger influence to the points on its moving direction. And the larger the speed, the larger the influence.

In this paper, according to the above principles a conic function is used as the prototype of the membership function:

\[
z(x, y) = \begin{cases} 
1 - \sqrt{\frac{(x - x_c)^2 + (y - y_c)^2}{R^2}} & \text{if } \sqrt{(x - x_c)^2 + (y - y_c)^2} < R \times f(\vec{V}, \vec{D}) \\
0 & \text{if } \sqrt{(x - x_c)^2 + (y - y_c)^2} \geq R \\
\end{cases}
\]

where \((x_c, y_c)\) is the object’s coordination. \(R\) is the circular neighboring area’s radius, within which the function has non-zero value. Fig. 1 shows the prototype of the membership function.

When establishing the membership function of a fuzzy virtual object, the prototype function is adjusted to contain the motion information. A fuzzy virtual object’s membership function is defined as:

\[
z(x, y) = \begin{cases} 
1 - \sqrt{\frac{(x - x_e)^2 + (y - y_e)^2}{R^2}} & \text{if } \sqrt{(x - x_e)^2 + (y - y_e)^2} < R \times f(\vec{V}, \vec{D}) \\
0 & \text{if } \sqrt{(x - x_e)^2 + (y - y_e)^2} \geq R \\
\end{cases}
\]

where \(\vec{V}\) is the object’s velocity vector and \(\vec{D}\) is the vector from the object’s current position \((x_c, y_c)\) to \((x, y)\). Function \(f\) is a direction factor, which is defined according to the following principle:

(1) \(f > 0\).
(2) \(f\) decreases with the increasing of the included angle between vector \(\vec{V}\) and \(\vec{D}\).

In the simulation experiments, \(f\) is defined as follows:

\[
f(\vec{V}, \vec{D}) = 1 + \lambda \times \cos(\alpha)
\]

where \(\lambda\) is a constant satisfying \(0 < \lambda < 1\). \(\alpha\) is the included angle between \(\vec{V}\) and \(\vec{D}\).

Fig. 1 shows the membership function of a fuzzy virtual object. The support of the function is the region including the object’s current position and its possible locations in the near future. The function value decreases slower on its moving direction than the other directions, which indicates that in the near future the object is more possible to appear in the area on its current moving direction. Therefore, the membership function of a fuzzy virtual object is the possibility distribution of the object’s position in the near future. It provides important information for path planning. All the membership functions of the fuzzy virtual objects make up the model of the dynamic environment.

**Fig. 1** The prototype of the membership function

**Fig. 2** The membership function of a fuzzy virtual object (the direction of the arrow in the figure shows the object’s moving direction)

### 3 Real-time Moving Control of Mobile Robot Based on the Fuzzy Object
After the environment model is established, path planning is carried out based on the model. There are two different techniques to perform path planning: global path planning and local path search. According to the time-variant property of dynamic environments, local search is used to make navigation effective and efficient. Local search makes decisions according to local spatio-temporal information, which makes it preferred in dynamic environments. Local path search decides which direction to follow currently according to the information within a certain neighboring area of the robot. All the local moves form a complete path when the robot reaches the goal point. To simplify the problem, the moving direction is discretized into eight directions: \{east, west, north, south, northeast, northwest, southeast, southwest\}. Each direction is represented by its azimuth $\theta$.

To decide which direction to follow at every decision step, a fuzzy synthetic evaluating method is used based on the environment model. Fuzzy synthetic evaluation can solve decision problems that involve more than one factors to consider[7]. In direction decision, there are two basic factors:

1. Whether following a direction will lead to a collision with an obstacle.
2. Whether following a direction can lead the robot to the target.

The fuzzy synthetic evaluation for a direction is defined as the sum of all the objects’ membership function values of the points in the area on that direction. The evaluation value of a direction $\theta$ is as follows:

$$V(\theta) = \sum_{p \in D_\theta} [a \times A_t(p) + b \times \sum_{j=1}^{M} A_o(j)(p)]$$

where $V(\theta)$ is the fuzzy synthetic evaluation of $\theta$, $D_\theta$ is a sector area whose axis has $\theta$ as its angle of inclination. $p$ is a point in the workspace. $A_t(p)$ is the value of the target’s membership function on point $p$. $A_o(j)(p)$ is the value of the $j$-th obstacle’s membership function on point $p$. $M$ is the number of the obstacles. $a, b$ are two weights balancing the two basic factors considered in the problem: target-approach and obstacle-avoid. Since $A_t(p)$ contains the target information and $A_o(j)(p)$ contains the obstacles’ information, $a$ is assigned a positive value and $b$ a negative value.

The evaluation value of a direction reflects the benefit of following that direction for both target-approach and obstacle-avoid purpose. At each decision step, the direction with the maximum evaluation value is chosen as the direction to be followed. The decision result $\theta_s$ is defined as:

$$\theta_s = \arg \max_{\theta} (V(\theta))$$

If more than one direction have the same maximum evaluation value, the conflict is resolved by a random selecting process among the equally optimal directions.

4 The Experimental Results

The flowchart of the fuzzy control for robot navigation is shown in Fig. 3. The method is a local search process, which updates the environment’s model and makes decision at every decision step. It requires real-time performance of the model-establish and decision-making process. To meet the real-time requirement, in the experiment only a certain neighboring area of the robot is considered to make decision. In the experiment, only consider a neighboring area is proved to be enough to make good decisions. This is named as the method’s spatial local property, which greatly simplifies the search process and reduces computation. Therefore, real-time fuzzy control can be achieved.

In the computer simulation experiment, three moving obstacles are included. Real-time motion control of the mobile robot is archived to avoid collision and reach the target. In the experiment, the moving robot’s direction occasionally oscillates between two adjacent directions. This phenomenon is caused by the relatively coarse discretization of moving directions. The oscillation diminishes with more elaborate discretization of direction in the experiment.

Fig. 4 shows the case of a successful obstacle-avoid navigation. The region within the circle shows the situation that the robot changes its moving direction to avoid collision with the obstacle. A series of experiments have been carried out, with random initial positions of the obstacles and the goal point. In the experiments, the method can successfully achieve the obstacle-avoid purpose all the time, and shows real-time performance.

5 Conclusion

In this paper, fuzzy concept is introduced for environment modelization to represent the uncertainty in dynamic environments. The fuzzy virtual object is proposed to represent moving objects, which includes the motion information in the membership function. The principles of defining the membership function are proposed. Fuzzy modelization of dynamic environments can be achieved based on the fuzzy virtual object with the
fuzzy environment model. A real-time fuzzy control method is presented for robot navigation by fuzzy synthetic evaluation. The result of the simulation experiments indicates the effectiveness and efficiency of the proposed control method. Future research will investigate the application of fuzzy virtual object in other applications of mobile robots besides the navigation task.

References: