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A new methodology of mobile robot navigation: The agoraphilic algorithm

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ABSTRACT

The *Agoraphilic algorithm* is an optimistic approach to reactive path planning for mobile robot platforms. The technique uses virtual, attractive forces derived from the surrounding free space. Fuzzy logic is utilised to limit the ‘free-space’ force so as to promote the movement towards the goal. The algorithm was designed to be a robust technique for reactive navigation that could be implemented without the fuss of tuning the sensitive parameters required for other classical navigation routines. Several simulations plus some preliminary experimental results are presented here to demonstrate the algorithm’s potential.

1. Introduction

The Agoraphilic algorithm implements a lateral approach to obstacle avoidance. It combines both fuzzy logic and potential fields to produce a more robust technique for mobile robot navigation.

Since the introduction of artificial potential field (APF) for robot navigation [1], there have been many attempts at improvement. Although the classical potential field algorithm is relatively simple, there are several severe and well-documented problems associated with the use of APF for mobile robot navigation [2]. These limitations include oscillatory motion and local minima or trap situations. These limitations led researchers to make improvements to the basic APF algorithm. The generalised potential field (GPF) [3], virtual force field (VFF) [4] and vector field histogram (VFH) [2] algorithms are examples of such techniques.

The VFF and VFH algorithms were designed specifically for real-time obstacle avoidance with mobile robots. The VFF method is based on the classical potential field (CPF) techniques and as a result inherits some of the algorithms underlying limitations. The VFH technique does not use potential fields but instead generates a two-dimensional polar histogram of the environment, where each sector in the histogram holds a value representing the polar obstacle density (POD). This reduces the amount of data considerably and yet retains the angular position of the obstacles with respect to the robot. Although the angular data are preserved, the distance to the obstacle is not. This lack of distance information means that the robot cannot effectively use the free space between the obstacle and itself for navigation purposes. This may cause the path planner to fail in some situations. The VFH+supersedes the original algorithm by the fact that the robot’s volume and dynamics are taken into account [5].

Fuzzy logic can be used to overcome the basic limitations of the APFs and improve the overall response by either removing or reducing the oscillations [6,7]. However, local minima and trap situations still remain a problem. The implementation of a global path planner (GPP) is a common solution to the local minima problem [8].

A variety of potential-field-based navigation schemes have been developed to overcome the inherent limitations associated with the potential field methodology. These schemes include the modification of the potential field equations, harmonic functions and dynamic force weighting. A number of algorithms also focus on the addition of other force generators to help drive the robot toward completing the assigned task including the extended virtual force field (EVFF) [9] and vector distance function (VDF) [10].

The EVFF adds a third vector component to the VFF algorithm. The third component is a free-space force (FSF) vector derived from the ultrasonic sensor readings and goal orientation. The direction of the FSF centred on the sensor group that has the greatest average distance reading. The technique was implemented as a purely reactive scheme with the forces derived directly from the sensors readings. The sensor configuration consisted of only forward and side facing sonar, hence the FSF heading is

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limited to the range $(-\pi/2, \pi/2)$. The Agoraphilic algorithm generates the FSF from a local map, giving a more complete picture of the environment.

The VDF utilising discretised FSF weighted by predefined force constants. The VDF is a sensor-based algorithm that defines a mathematical relationship between the effective range of the sensors and the velocity of the robot [10]. The purely reactive scheme uses the current sensor reading to generate the forces. This approach has the characteristic of being overly sensitive to erroneous sonar readings. The number of sensors also creates a highly oscillatory path due to the inability to obtain a good representation of the environment. The statically weighted forces allow the robot to provide a wall-following and goal-tracking behaviour demonstrated only in simulations.

The Agoraphilic algorithm improves upon the previously mentioned algorithms by utilising virtual forces generated only by the surrounding free space. It takes an optimistic view of the navigation problem. The remainder of this paper presents the Agoraphilic algorithm as a local path planner. The work is supported with simulations and experimental results, presented in Section 3.

2. The Agoraphilic algorithm

The Agoraphilic algorithm is virtual-force-based technique that differs from the traditional APF by the fact that it utilises an FSF. The FSF is an attractive force that effectively 'pulls' the robot towards the surrounding areas of free space. To prevent the robot from wandering aimlessly towards any open space, a 'fuzzy' limiting function is applied to essentially focus the force towards the goal.

The Agoraphilic algorithm can be split into several fundamental stages.

1. creation of the free-space histogram (FSH);
2. calculation of the FSFs;
3. generation of the force shaping coefficients;
4. summation of scaled force vectors.

Each of these stages is presented in the following sections.

2.1. Free-space histogram

The FSH is an egocentric polar map representing the distance profile of the surrounding environment. It is used as the basis for generating attractive FSFs and is constructed from the local map. The local map is a modified histogram grid representing a form of short-term memory and is based on the histogram in-motion mapping (HIMM) implemented for the VFF algorithm. Each cell within the map contains a certainty value (CV) indicating the confidence level that the cell is occupied. The mapping algorithm was developed primarily for fast mapping with sonar sensors. The map is updated by incrementing the CV of the cell related to the sensor reading and decrementing any cells along the acoustic axis between the sensor and the occupied cell, with a predefined maximum CV value. The resulting map created as the robot traverses the environment and exhibits the characteristics of a probability distribution map.

This data reduction stage converts the two-dimensional local histogram map into a one-dimensional polar map. The area surrounding the robot is quantised into K neighbouring sectors. Each sector in the polar map or FSH stores the distance to the nearest occupied cell within that sector heading. It effectively gives an indication of distance that the robot can move in a given direction before a collision would occur. The maximum range of the FSH is primarily influenced by the sensor range. The local map is updated for each new sonar reading; however, the FSH is updated from the map every control cycle.

The Agoraphilic algorithm was designed for a differential drive disc-shaped robot. Compensation for the robots' volume is accomplished by enlarging each occupied cell prior to updating the FSH. The radius of each cell is increased to the sum of the robot radius, d_r, and a pre-determined safety factor, d_s. This enlargement technique is based on Ulrich and Borenstein's VFH+algorithm where multiple sectors can be updated for a single occupied cell depending on its proximity [5] (Fig. 1). The sector width, S_w, is given as

$$S_w = \frac{2\pi}{K} \tag{1}$$

The corresponding sectors are derived using Eq. (2). An example free space histogram (FSH) for a sample environment is shown in Fig. 2.

$$\beta_{i,j} = \arctan\frac{y_j - y_0}{x_j - x_0} \tag{2}$$

$$\gamma_{i,j} = \arcsin\frac{r_{r+s}}{d_{i,j}} \tag{3}$$

$$k \cdot S_w \in [\beta_{i,j} - \gamma_{i,j}, \beta_{i,j} + \gamma_{i,j}] \tag{4}$$

where i, j are the cell indices, (x_j, y_j) are local map cell coordinates in the C-space, (x_0, y_0) is the robots current location in the C-space, $\beta_{i,j}$ is the current cell heading, $\gamma_{i,j}$ is the enlargement angle, k is the sector and S_w is the sector width.

This safety factor accounts for the robots' volume and also acts as a smoothing function to dampen any effects caused by the discrete nature of the certainty grid. To reduce the effect of noise and erroneous signals from the sensors, a threshold is applied to the CV of each grid cell. This threshold converts the map into a binary grid, indicating the cells as either *occupied* or *empty*.

A problem with traditional APF techniques is the inability to achieve a goal that is located near a large obstacle [11]. The local minima are caused by the repulsive force from the obstacle masking the attractive force of the goal. The Agoraphilic algorithm's use of the FSH enables greater flexibility in goal placement. It removes this problem by limiting the maximum

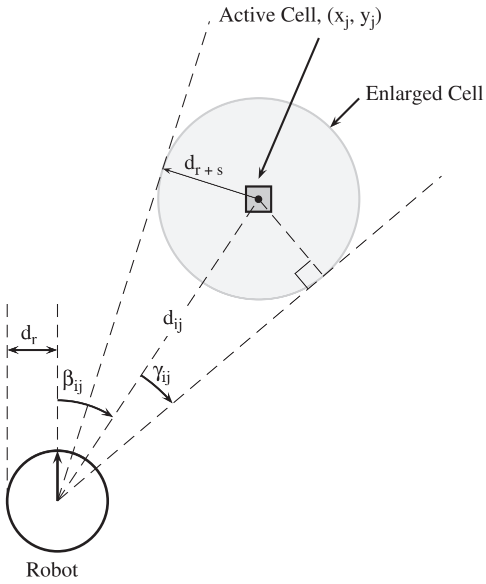

Fig. 1. The safety factor variable assignments.