An evolutional artificial potential field algorithm based on the anisotropy of omnidirectional mobile robot

Cao Qixin*, Leng Chuntao, Huang Yanwen
Research Institute of Robotics, Shanghai Jiaotong University, 800 Dongchuan Road, Min Hang, Shanghai, P. R. China, 200240

ABSTRACT

The traditional artificial potential field (APF) method is widely used for motion planning of traditional mobile robot, but there is little research about the application to the omnidirectional mobile robot (OMR). To propose a more suitable motion planning for OMR, an evolutional APF is presented in this paper, by introducing the revolving factor into the APF. The revolving factor synthesizes the anisotropy of OMR and the affect of dynamic environment. Finally simulation is carried out to demonstrate that, the evolutional APF is a high-speed and high-efficiency motion planning by comparing with the traditional APF, and the advantages of OMR is exerted.

Keywords: Artificial Potential Field, Omnidirectional Mobile Robot, Motion Planning, Anisotropy, Revolving Factor

1. INTRODUCTION

Due to its simplicity and mathematical elegance, APF is widely used for the collision-free path planning. Originally the APF developed by Khatib (1986) was used in stationary environment. However, because environments are dynamic in many real-world implementations, in the past decade, APF has been improved to suit the extensive environments. For example, Zhang (2002) proposed an evolutionary APF in which both the velocity and the acceleration were considered. Extending the approach, the kinematic and dynamic constraints of the robot were taken into account when choosing a motion. Also an artificial coordinating field was introduced to APF by Jing (2004), i.e. a coordinating force was used for coordinating the APF.

Different from traditional mobile robot, OMR can achieve any translation along arbitrary direction without rotation, which results in agile performance. The maximum velocity and acceleration is different while it moves in a different direction, this is called anisotropy. Especially owing to the affect of different applications, the arrangements of the omnidirectional wheels are not symmetrical generally, which makes the anisotropy to be much more distinct. Accordingly, the motion planning of OMR along different directions results in different trajectories and motion efficiency. And the research of collision-free path planning is very necessary for OMR.

Wu (2004) presented the research about motion planning of OMR in Ph.D. dissertation. Using the ability of translation along arbitrary directions, a coordinating velocity in the vertical direction of motion was introduced to adjust the movement for the safe route, but the anisotropy of OMR was not considered in the motion planning. To achieve a high-speed navigation, Brock (1999) considered the agile performance of OMR, and proposed a global dynamic window approach. But considering the OMR as isotropy, the advantage of OMR was not exerted fully. APF can also be applied in OMR. Ge (2002) proposed a new APF method in dynamic environment where the goal and the object are moving, and made a motion planning for OMR with the method. But the anisotropy of OMR was also not taken into account.

The motion planning of OMR along different directions result in different trajectories and motion efficiency, meanwhile the speed is an important indicator for path planning. To achieve a high-speed navigation, it is necessary to improve the APF for the application to OMR.

Due to the agile performance and anisotropy, considering the affect of the dynamic environment, a new evolutionary APF algorithm, based on the revolving factor ($e^{j\theta}$), is proposed in this research. As a coordinating function, the algorithm synthesizes the characteristics of the velocity and acceleration of OMR, and the relative velocity (among

*qxcao@sjtu.edu.cn; phone 86-21-34206790; fax 86-21-34206790

ICMIT 2007: Mechatronics, MEMS, and Smart Materials, edited by Minoru Sasaki,
Gisang Choi Sang, Zushu Li, Ryojun Ikeura, Hyungki Kim, Fangzheng Xue, Proc. of SPIE
Vol. 6794, 67942C, (2007) · 0277-786X/07/$18 · doi: 10.1117/12.784488

the robot, the obstacle and the goal), to coordinate the APF force. With the ability of translation along arbitrary direction, the trajectory in this research is composed of piecewise translation motion. The evolutional APF algorithm presented in this research was applied to the OMR developed in our laboratory. Simulations and experiments have proved that the revolving factor when used as a coordinating function and applied in APF is effective.

2. PROBLEM STATEMENT

The basic principle of APF is to construct attractive potential fields around the goal to attract the robot and to construct repulsive potential fields around the obstacles to force the robot away. The attractive force, $\boldsymbol{F}_{att}$, from the attractive potential field and the repulsive force, $\boldsymbol{F}_{rep}$, from the repulsive potential fields drive the robot to its goal position as defined in (1).

$$\begin{aligned} \boldsymbol{F}_{att} &= mD_{rg}\boldsymbol{n}_{RG} \\ \boldsymbol{F}_{rep} &= -n(1/D_{ro} - 1/D_0)/D_{ro}^{\ 2}\boldsymbol{n}_{RO} \end{aligned} \tag{1}$$

Where m and n are the constants of attractive and repulsive potential field respectively. D_{ro} is the Euclidean distance between the robot and the obstacle. D_{rg} is the Euclidean distance between the robot and the goal. $\boldsymbol{n}_{RG}$, $\boldsymbol{n}_{RO}$ are the unit vectors pointing from the robot to the goal and the obstacle respectively. D_0 represents the limited distance of the potential field influence.

Recently, mostly of the research about OMR were confined to the low level control, such as kinematics and dynamics modeling. As a holonomic mobile robot, for the simplicity of movement, there is little research about the motion planning for OMR. To improve the application of APF for OMR, the traditional APF must be improved. Meanwhile, because the dynamic information of obstacle and goal is not taken into account in the traditional APF, it is not a high-efficiency motion planning. Therefore, on the basis of the traditional APF, combining the characteristics of OMR, and taking into account of the dynamic information of obstacles and goal, a suitable motion planning for OMR is proposed.

A 4-wheel OMR designed in our laboratory was used in this research, the arrangement of omnidirecional wheels is shown in Fig.1. But the results of this research also can be applied to other kind of OMRs.

Fig. 1. Arrangement diagrams of omnidirectional wheels

3. EVOLUTIONAL APF BASED ON ANISOTROPY

The maximum velocity that the robot can achieve is different when the robot moves in a different direction, and the performance of acceleration in different direction is also distinct. This is called anisotropy[8]. Due to the anisotropy, the motion along different direction is different, and the corresponding motion efficiency is also different. In many occasions, the high-efficiency in motion planning with collision-free is also required. To find a short trajectory, a high-speed, stable-acceleration, collision avoidance motion planning with high efficiency is the objective of this research.

3.1 Maximum velocity along different directions

Based on the kinematics of OMR, the velocity of the OMR was analyzed in Leng (2006). According to the results, the maximum velocity of OMR can be defined as (2) (owing to the symmetry, only $0 \sim 90^{o}$ is indicated), and the velocity curve is presented in Fig.2. As shown in Fig.2, the maximum velocity along 60^{o} is the minimum, and the velocity along 0^{o} is the maximum. The maximum velocity from 0 to 60^{o} is constantly getting smaller, and the case from 60^{o} to 90^{o} is opposite.

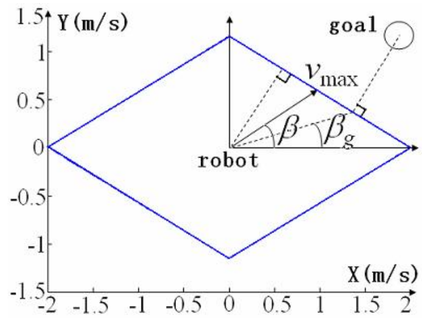

Fig. 2. Maximum velocities along different directions

$$v_{\max} = 4\left(\tan^2\beta + 1\right)\Big/3\left(\tan\beta + \sqrt{3}/3\right)^2 \qquad \beta \in \left[0,\ 90^{\circ}\right] \tag{2}$$

The speed is an important yardstick for motion planning. Owing to the existence of anisotropy, it can not be guaranteed that the motion direction determined by the traditional APF is the best direction. To be high-speed motion, while the direction of potential field force is in 0 to 60^{o}, it should be rotated θ_v toward the direction of 0 degree using the revolving factor; while the direction of potential field force is in 60^{o} to 90^{o}, it should be rotated θ_v toward the direction of 90^{o} using the revolving factor. Accordingly the motion can be achieved with much more high-speed. According to the velocity curve, closing to 0 degree, the little change of motion direction will result in great change of the maximum velocity. Therefore, the coordinating angle resulted from the maximum velocity can be modeled as (3). Where k_{v1}, k_{v2} are coordinating parameters. $v_{0^{o}}$ and $v_{90^{o}}$ are the maximum velocities in the directions of 0^{o} and 90^{o} respectively.

$$\theta_v = \begin{cases} k_{v1}\left(1 - v_{\max}/v_{0^{o}}\right) & \beta \in \left[0, 60^{\circ}\right) \\ k_{v2}\left(1 - v_{\max}/v_{90^{o}}\right) & \beta \in \left[60^{\circ}, 90^{\circ}\right) \end{cases} \tag{3}$$

For a high-efficiency motion planning, not only the high-speed but also the length of the path should be taken into account. Because only while $\theta_v < \beta - \beta_g$ (β, β_g are shown in Fig.2), the motion path can be shorter than the originally. Only in this case, when the robot goes to the next control cycle, the distance from robot to goal is nearer. To achieve the goal of high-speed and short motion path, the coordinating angle should not be bigger than β_g. Thus while $\beta > \beta_g$, k_{v1}, k_{v2} are both less than 0, otherwise both greater than 0.

3.2 Maximum accelerations along different directions

Owing to the special characteristics of omnidirectional wheel, the maximum accelerations along different directions are distinct, and it is related with the arrangement of omnidirectional wheels.

$$a_{\max} = K\big/\cos\left(\beta - 30\right) \quad where \begin{cases} K = k_1 & 0 \le \beta < 60^{o} \\ K = k_2 & 60^{\circ} \le \beta \le 90^{o} \end{cases} and \ \ k_1 \ne k_2 \tag{4}$$

According to the dynamics of OMR, the maximum accelerations along different directions can be defined in (4)[8], and the maximum acceleration curve is shown in Fig.3. For the symmetry, only the maximum accelerations from 0 to 90^{o} were indicated. To achieve high-speed motion, it is better to run at a higher acceleration. Meanwhile, with practical experience, it is obvious that the more maximum acceleration is, the more stable movement in this direction will be, and also the less slip will be. Thus for reduction of slip, the robot should move in the direction with much more maximum acceleration as possible. As shown in Fig.3, the maximum acceleration is continuously minishing in the direction from 0 to 30^{o}. At 30^{o} the maximum acceleration gets to the minimum. And then, it is continuously increasing in the direction from 30^{o} to 90^{o}. To keep the impact of revolving factor act tardily, the coordinating angle resulted from the maximum acceleration can be modeled as (5). Where $a_{0^{o}}$ and $a_{90^{o}}$ are the maximum accelerations in the directions of 0^{o} and 90^{o} respectively. And k_{a1}, k_{a2} are coordinating parameters.

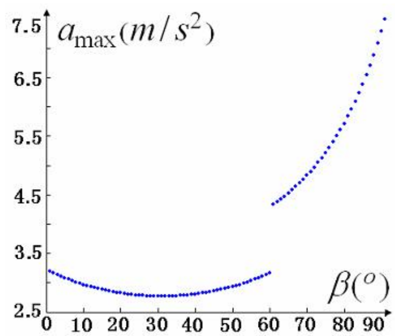

Fig. 3. Maximum accelerations along different directions

$$\theta_a = \begin{cases} k_{a1}\, a_{\max} \big/ a_{0^o} & \beta \in \left[0, 30^o\right) \\ k_{a2}\, a_{\max} \big/ a_{90^o} & \beta \in \left[30^o, 90^o\right) \end{cases} \tag{5}$$

4. EVOLUTIONAL APF WITH DYNAMIC ENVIRONMENT

In order to accurately and effectively avoid the obstacles and reach the goal, the revolving factor in addition to considering the anisotropy of OMR, the impact of the dynamic information of obstacles and goal are also important. The consideration of relative movement among robot, obstacles and goal will be better to improve the efficiency.

4.1 Effect of obstacles

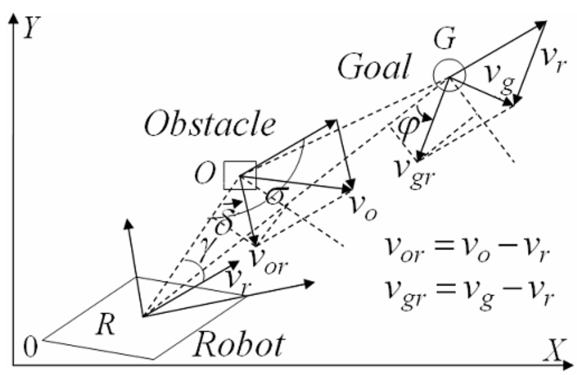

Fig. 4. Effect on APF caused by relative movement

As shown in fig.4, suppose that the velocity of robot is v_r , the velocity of obstacle is v_o , and the velocity of goal is v_g . The relative velocity between robot and obstacle is v_{or} , and the relative velocity between robot and goal is v_{gr} . γ is the angle between v_r and OR. δ is the angle between v_{or} and OR. σ is a supplementary angle of γ . φ is the angle between v_{gr} and RG. All these angles take counter-clockwise as positive direction. In the use of revolving factor to coordinate the APF force and to achieve much more high-speed motion planning, consideration of dynamic information of obstacles is very important. When δ is less than σ , the obstacle is moving to the direction of robot movement, i.e. the behavior for avoiding collision is necessary; And when δ is greater than σ , the obstacle is moving away from robot, i.e. the behavior for avoiding collision is not necessary.

When the distance between the robot and the obstacle is less than some threshold, it should avoid them deceasing, and also the appearance of the obstacle in the direction of robot movement should be avoided. Obviously when the distance between the robot and the obstacle is greater than some threshold, there is no need to avoid collision. To achieve the above objective, we can increase the velocity in the vertical direction of OR, which means to increase the coordinating angle. Without the threat of obstacles, the velocity in the vertical direction of OR should be defined depending on the improving the speed of motion planning. At the relative velocity v_{or} , the time needed when robot runs into obstacle and the time needed when obstacle moves to the direction of robot movement, are noted as an impact factor to define the coordinating angle. And it can be modeled as (6). Where n_1 and n_2 are the coordinating parameters.

$$\theta_{rel-O} = n_1 D_{or} \big/ \left(v_{or} \cos \delta \right) + n_2 D_{or} \gamma \big/ \left(v_{or} \sin \delta \right) \tag{6}$$

4.2 Effect of the goal

In order to reach the goal with much more high-efficiency, i.e. the motion planning is not a simple tracking but an effective interception, the relative movement tendency between robot and goal should be considered. It is obvious that the coordinating angle depends on the velocity component of v_{gr} in the vertical of RG, i.e. the faster the velocity component is, the bigger the coordinating angle will be. And with the coordinating angle resulted from the movement of goal, the robot can predict the future position of goal and directly go to there. When the velocity component of v_{gr} in the direction of RG is small, the time spent for the distance of RG will be short, accordingly the coordinating angle should be small. According to the above analysis, to capture the goal with high-efficiency, the coordinating angle resulted from the relative velocity between robot and goal can be modeled as (7). Where n_3 and n_4 are the coordinating parameters.

$$\theta_{rel-G} = n_3 v_{gr} \sin \varphi + n_4 D_{rg} \big/ \left(v_{gr} \cos \varphi \right) \tag{7}$$

Therefore, for a short trajectory, a high-speed, stable-acceleration, collision avoidance motion planning with high efficiency, it can be achieved by adjusting the coordinating parameters, i.e. by adjusting the proportion of impact factor, the perfect trajectory can be achieved. With above analysis, finally the total APF force ($\boldsymbol{A}$) is shown in (8).

$$\boldsymbol{A} = \left(\boldsymbol{F}_{att} + \boldsymbol{F}_{rep} \right) \bullet e^{j\left(\theta_v + \theta_a + \theta_{rel-O} + \theta_{rel-G}\right)} \tag{8}$$

5. RESULTS OF SIMULATION

In respect of APF, there are different approaches to get the velocity to control the motion of robot. In this research to exert the advantage of OMR, the total APF force only determines the direction of robot motion. Due to the security reasons, the robot runs at maximum velocity while far away from the obstacles, and it decelerates while the distance from obstacles is smaller than some threshold, with the velocity in proportion to the relative distance. And when the robot does not run at maximum velocity, the revolving factor will not function.

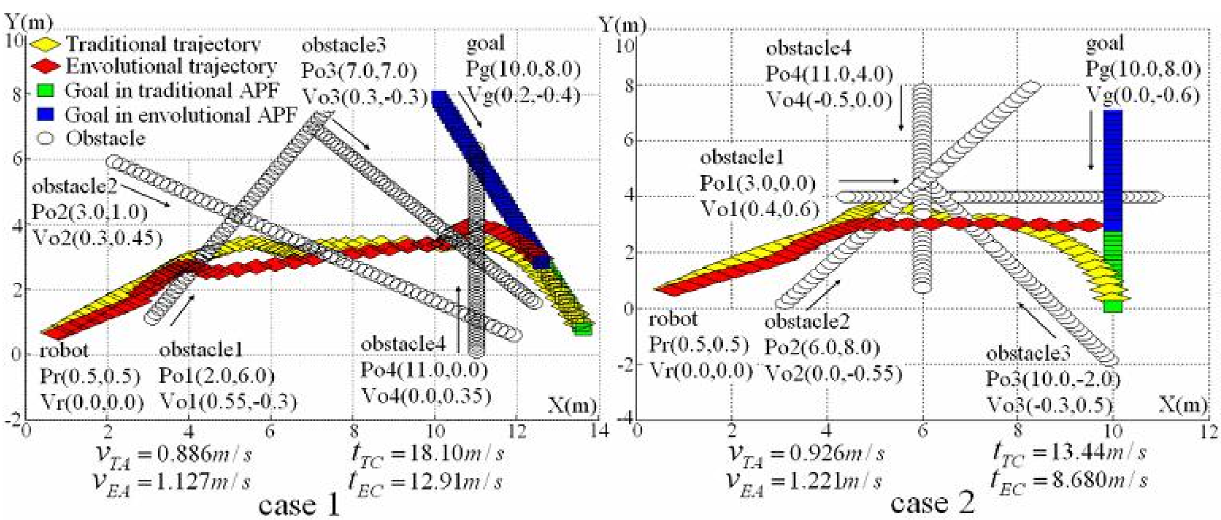

Fig. 5. Results of simulation

In this research, the velocity for controlling the motion of robot is modeled as (9). Where v_{max} is the maximum velocity in the direction of the final APF force, and k_o is the coordinating parameters.

$$v = \begin{cases} v_{max} & D_{ro} \geq D_0 \\ k_o \dfrac{D_{ro}}{D_0} v_{max} & D_{ro} < D_0 \end{cases} \tag{9}$$

The simulation is carried out in Matlab7.0. The main purpose of the simulation is to validate the effect of the evolutional APF by comparison with traditional APF. The OMR as shown in Fig.1 was used in the simulation. The maximum velocity of robot is 2m/s, accelerations along different directions are defined as (4), where $k_1 = 2.77$, $k_2 = 3.75$.During the simulation, assume that the obstacles and the goal move at constant velocities, and the initial values are set as shown in Fig.5. The coordinating parameters are set as $m = 0.4$, $n = 0.3$, $k_{v1} = k_{v2} = 0.5$, $k_{a1} = k_{a2} = 0.1$, $n_1 = n_2 = n_3 = 0.1$, $n_4 = 0.005$, $D_0 = 1m$, $k_o = 1$. Two cases are presented in this section, as shown in Fig.5, and the average velocities of evolutional APF (v_{EA}) and consumption time (t_{EC}) compared with traditional APF (v_{TA}, t_{TC}) are also indicated in Fig.5. From the results of the simulation, it can be proved that the evolutional APF by introducing the revolving factor is a high-speed and high-efficiency motion planning.

6. CONCLUSION

According to the characteristics of OMR, i.e. anisotropy, and taking into account the dynamic information of obstacles and goal, the traditional APF was improved by using the revolving factor. Therefore, a high-efficiency motion planning which can exert the advantages of OMR is proposed in this research.

The key item of this research is to design a motion planning suit for OMR, and the consideration with respect to the disadvantages of APF such as local minimum problem is not pursued here. The information of location and velocity used in the simulation was assumed accurately. But in realistic applications, the values are often measured by sensors with uncertainties. Therefore, for a further study we will pursue our research in these areas.

REFERENCES

1. O. Khatib, "Real-Time Obstacle Avoidance for Manipulators and Mobile Robots," *International Journal of Robotics Research,* 5(1), 90-98(1986).
2. Q. Zhang and Y.M. Yang, "Soccer robot collision avoidance control based on evolutionary artificial potential field," *Robot,* 24(1), 12-15(2002).
3. X.J. Jing, Y.C. Wang and D.L. Tan, "Artificial coordinating field based real-time coordinating collision-avoidance planning for multiple mobile robots," *Control Theory &Applications,* 21(5), 757-764(2004).
4. S.S. Ge and Y.J. Cui, "Dynamic motion planning for mobile robots using potential field method," *Autonomous Robots,* 13(3), 207-222(2002).
5. J. Wu, *Dynamic Path Planning of an Omni-Directional Robot in a Dynamic Environment,* Ph.D. Dissertation, Ohio University, Athens, 2004.
6. O. Brock and O. Khatib, "High-speed navigation using the global dynamic window approach," *Proceedings of IEEE Conference on Robotics and Automation,* 1(341-346), IEEE, Piscataway, NJ, USA, Detroit, 1999.
7. C.T. Leng and Q.X. Cao, "Velocity Analysis of Omnidirectional Mobile Robot and System Implementation," *IEEE International Conference on Automation Science and Engineering,* (81-86), Shanghai, 2006.
8. C.T. Leng and Q.X. Cao, "Study on Anisotropy of 4-wheeled Omnidirectional Mobile Robot," *CAAI transactions on intelligent systems,* 2(3), 45-51(2007).