VOL. 11, NO. 18, SEPTEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

POTENTIAL FIELD METHODS AND THEIR INHERENT APPROACHES FOR PATH PLANNING

Sabudin E. N, Omar. R and Che Ku Melor C. K. A. N. H
Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
E-Mail: he120009@siswa.uthm.edu.my

ABSTRACT

Path Planning is one of the vital aspects in autonomous system. In path planning, safety is important issue that should be taken into account in order to ensure a robot reaches at the target location without collision with surrounding obstacles. Moreover, there are important aspects that need to be addressed in path planning; computational time, optimal path and completeness. One of the popular methods for path planning is Potential field. Potential filed method is capable to overcome unknown scenario, taking into account the realities of the current environment of the robot motion. Two type of forces involved in potential field method; attractive force generated by goals and repulsive force generated by obstacles. However, this method has a major drawback due to local minima problem. This paper reviews the traditional artificial potential field theory that has been modified with variety of algorithms based on potential field method that have been implemented to upgrade the potential function performance in obstacle avoidance and local minima problem.

Keywords: potential field method, path planning.

INTRODUCTION

Path planning for robots is one of the important criteria to be considered in enhancing robot autonomy level. The important rules for ideal path planning are producing a safe and optimal path. As the robot needs to travel from initial location to its goal location, it will face through an obstacles environment consisting of static, pop-up and dynamics obstacles. As a result the robot needs re-plan a new path.

There are many approaches that have been used for path planning including visibility graph, cell decomposition, voronoi diagram, probabilistic roadmap (PRM), rapidly exploring random tree (RRT) and potential field, to name a few.

Potential field method has been used by many researchers in path planning problem because of its simplicity, high safety and elegance. Besides that, it is also suitable for real-time application due to its fast computation time.

In potential field approach, the robot is considered as a point under the influences of the fields produced by goals and obstacles in search space. In this method, there are repulsive force generated by obstacles and attractive force generated by goals. Hence there is less effect at a distance at the stronger force near the goals or obstacles, meanwhile the resultant force on the robot will determine its direction of motion. However, the potential field method has a drawback in producing local minima causing the robot to get trapped (R. Omar and .D-W.Gu, 2009).

PATH PLANNING

Path planning in robotics is the act of finding a path from an initial location to goal location. Path planning problem, basically, is to provide a continuous collision-free path that links an initial point and a target point. The workspace for the robot and obstacle geometry is represented in a 2D or 3D. Besides that, the motion is described as a path in configuration. The algorithm must determine how to move the mobile robot from initial point to goal point without collide with obstacles. Robot path planning usually ignores dynamics and other differential constraints and focuses primarily on the translations and rotations required to move the robot. Recent works, however, do consider other aspects, such as uncertainties, differential constraints, modeling errors, and optimality.

On the other hand, the aspects that need to be addressed in the path planning problem is the computation time, path length and completeness. In dynamic or uncertain environment, the path planning algorithm used must be able to produce a low computational time in real-time applications. Besides that, the path must the shortest in order to reduce fuel and energy consumption. Completeness criterion is fulfilled by an algorithm if it finds a path if one exists.

POTENTIAL FIELD METHOD

Overview of artificial potential field method

Artificial Potential Field (APF) is commonly used in path planning by many researchers because of its advantages such as highly safe, simple and elegance (J. Borenstein and Y. Koren, 1991), (Y. Cen, L. Wang, and H. Zhang, 2007). This method is widely used to overcome unknown dynamic scenario, taking into account the realities of the current environment of the robot motion (J. Antich and a. Ortiz, 2005). Potential field is suitable for real-time applications even with slight modifications. In addition, it also provides a continuous search.

(O. Khatib, 1985) was the first suggested this idea where the robot was treated as a point under the influences of the field generated by goals and obstacles in search spaces. There are two type of force involved in this method; first the repulsive force generated by obstacle and second, the attractive force generated by goals. These forces are stronger near to the obstacle or goal and have less effect at a distance. In this method, the obstacle will impose a repulsive force on a moving object, while the

VOL. 11, NO. 18, SEPTEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

goal location will obtain an attractive force to it. The resultant forces (the sum of all forces) of the fields on the robot are used in determining the direction of the robot's motion and speed of travel while avoiding collision (X. Xu, C. Li, and Y. Zha, 2010).

However there are shortcoming exist in APF such as; a) trap situation due to local minima; b) oscillation in the presence of obstacles; c) no passage between closely spaced obstacles; d) oscillations in narrow passages (Y. Koren, J. Borenstein, 1991).

Consider that the Cartesian coordinate of a robot is $q = (x, y)^T$. So the APF function can be represented as

$$U(q) = U_{att}(q) + U_{rep}(q) \quad (1)$$

where

$U(q)$ = artificial potential field
$U_{att}(q)$ = attractive field
$U_{rep}(q)$ = repulsive field

The attractive force is the negative gradient of attractive field and the repulsive force is the negative gradient of repulsive field. Thus, the artificial force of the robot as shown in Figure-1 is

$$F(q) = -\nabla U(q) = -\nabla U_{att}(q) - \nabla U_{rep}(q)$$
$$F(q) = F_{att}(q) + F_{rep}(q) \quad (2)$$

where

$F(q)$ = artificial force,
$F_{att}(q)$ = attractive force,
$F_{rep}(q)$ = repulsive force.

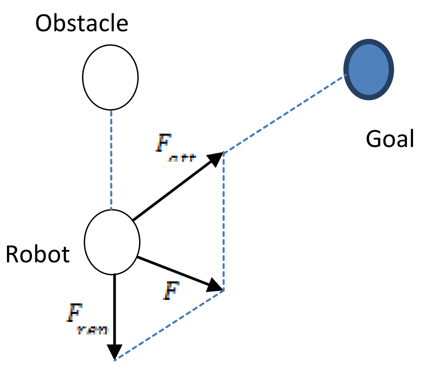

Figure-1. Resultant force of potential function.

The attractive field between robot and goal is assembled to drag the robot to the goal area.

$$U_{att}(q) = \frac{1}{2} \times k_a \times (q - q_d)2 = \frac{1}{2} k_a \rho^2{}_{goal}(q) \quad (3)$$

where

k_a = positive coefficient of gravity for APF,
q = current position vector of the robot,
q_d = current position vector of the target.

$\rho_{goal}(q) = \|q - q_d\|$ is a Euclidean distance from robot's location to the goal location. The attractive force on robot is calculated as the negative gradient of attractive potential field as shown below (G. Li, A. Yamashita, and H. Asama, 2006):

$$F_{att}(q) = -\nabla = -\frac{1}{2} k_a \rho^2{}_{goal}(q) = -k_a (q - q_d) \quad (4)$$

$F_{att}(q)$ is a direct vector toward q_d with magnitude linearly related to the distance from q to q_d. The components of $Fatt(q)$ are the minus directional derivatives of the attractive potential along the x and y directions. Therefore, if the attractive potential takes effect, the components take the following form as

$$F_{att} - x(q) = -k_a (x - x_d) \quad (5)$$
$$F_{att} - y(q) = -k_a (y - y_d)$$

The equations above are the attractive force in the x and y directions.

In the potential function, the robot should be repelled away from obstacles, but if the robot is away from obstacles, it's motion must be taken into account as not affected by obstacles. The repulsion potential function is shown as follows (G. Li, A. Yamashita, and H. Asama, 2006):

$$U_{rep}(q) = \begin{cases} \frac{1}{2} k_b \left(\frac{1}{d(q)} - \frac{1}{d_0}\right)^2, d(q) \leq d_0 \\ 0 \qquad , d(q) \geq d_0 \end{cases} \quad (6)$$

k_b = repulsion gain coefficient,
d = distance between the robot and the obstacle,
d_0 = distance of the obstacle repulsive force field.

When the robot is close to the goal, this function gives the smaller value. In the case of gravity is zero (when the robot has reached the goal), the function will be 0. It is referring to its actual situation.

Let $q_c = (xc, yc)$ be the configuration in obstacle closest to q. Assume $d = \|q - q_c\|$ as the shortest distance between robot and obstacles meanwhile d_0 is the largest impact distance of single obstacle. The repulsion field equation as follows:

$$F_{rep}(q) = \begin{cases} k_b \left(\frac{1}{d(q)} - \frac{1}{d_0}\right) \left(\frac{1}{d^2(q)}\right) \left(\frac{\partial d(q)}{dx}\right), d(q) \leq d_0 \\ 0 \qquad , d(q) \geq d_0 \end{cases} \quad (7)$$

VOL. 11, NO. 18, SEPTEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

$$F_{rep}(q) = \begin{cases} k_b\left(\frac{1}{d(q)} - \frac{1}{d_0}\right)\left(\frac{1}{d^2(q)}\right)\left(\frac{q-q_c}{\|q-q_c\|}\right), d(q) \le d_0 \\ 0 \qquad , d(q) \ge d_0 \end{cases} \quad (8)$$

There is no impact for robot when the distance between robot and obstacle is greater than d_0.

Note that F_{rep-x} and F_{rep-y} are the Cartesian components of the repulsive force, F_{rep}.

$$F_{rep}(q) = \begin{cases} k_b\left(\frac{1}{d(q)} - \frac{1}{d_0}\right)\left(\frac{1}{d^2(q)}\right)\left(\frac{x-x_c}{\|q-q_c\|}\right), d(q) \le d_0 \\ 0 \qquad , d(q) \ge d_0 \end{cases} \quad (9)$$

$$F_{rep}(q) = \begin{cases} k_b\left(\frac{1}{d(q)} - \frac{1}{d_0}\right)\left(\frac{1}{d^2(q)}\right)\left(\frac{y-y_c}{\|q-q_c\|}\right), d(q) \le d_0 \\ 0 \qquad , d(q) \ge d_0 \end{cases} \quad (10)$$

If there are many obstacles in the environment, then the total of repulsive potential field is the sum of all the obstacles' repulsive potential field. The total potential field is

$$U(q) = U_{att}(q) \sum_{i=1}^{n} U_{rep}(q) \quad (11)$$

Note that n is number of obstacles. The sum of the total force of the gravity and repulsion of the robot is expressed as follows:

$$F(q) = F_{att}(q) \sum_{i=1}^{n} F_{rep}(q) \quad (12)$$

An example of view represents the position of initial point and goal point in workspace is shown in Figure-2. Figure-3 illustrates the forces involved in potential function.

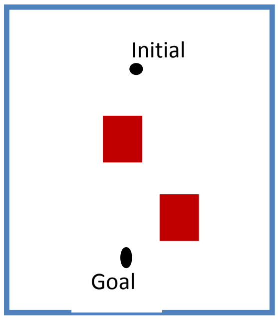

Figure-2. Simple view of position of initial point, goal point and obstacle (red).

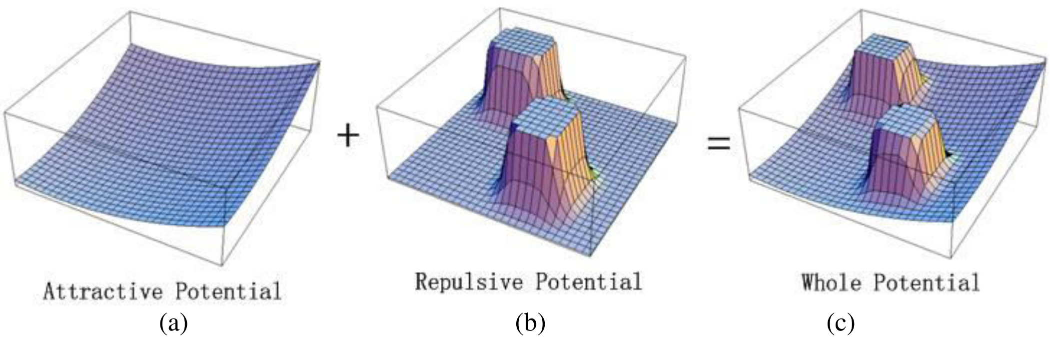

Figure-3. (a)The attractive potential without obstacle (b)The repulsive potential set the highest value to the obstacle (c)Whole potential shows the combination of the two forces to get the final potential field result (taylorwang.wordpress.com, 2012).

Variation algorithm based on potential field method

Potential field method is widely used by many researchers due to its efficient mathematical analysis and simplicity (L. Tang et al. 2010). Besides that, it is also an effective local path planning algorithm (S. Ping, L. Kejie and H. Xiaobing, 2009) and it is suitable for real-time application and can perform well in a dynamic environment. However this potential field method often associated with local minima problem which the robot cannot reach at the goal as desired. In order to solve the problem, some modifications have been done in constructing the potential field method to eliminate the local minima problem.

Virtual force algorithm

In papers of (Borenstein and Koren, 1988,1989) the authors had applied the Virtual Force Field (VFF) method. This method lied in a combination of the potential field method with a certainty grid, which generated a powerful and robust control scheme for mobile robots. In VFF, the robot movement was referred of the direction of the operator. If the robot faced an obstacle, it would avoids the collision with the obstacle that match to the prescribe direction. The direction and speed of the robot in VFF were determined by the virtual attractive and repulsive force. Besides that, the local minimum was automatically detected, thus recovery routine was dependent on a number of different situations and the actions taken were appropriate in the circumstances. The oscillation of the robot motion was settled by damping algorithms (cause a small effect to the robot speed average).

(Borenstein, 1990) had introduced the Virtual Field Histogram (VFH) method as improvements to the existing method of VFF. The algorithm was efficiently computational, thus it was able to conduct a robot through a cluttered environment and unknown obstacle. The robot also could get along the narrow passage at high speed at high speed without oscillation. VFH used a two dimensional Cartesian Histogram that constantly updated continuously and in real time with a variety of sample data by a range sensor on board. The data in Histogram Grid had changed to one dimensional polar histogram that was generated around the robot temporary and created a polar obstacle density around the robot. To ensure the robot was guided parallel to the right direction, the obstacles with the low density which was near to the target was selected.

Harmonic potential function

(J.O Kim and P. K. Khosla, 1992) proposed the Harmonic Potential Function (HPF) in building the potential field for obstacle avoidance. This method was focused to eliminate the trap situation (local minima) even though in clutter environment. In the study, the approach was composed in two steps. First was to focus in building the artificial potential field and second was to develop a control strategy for navigation in the potential filed using harmonic function. To derive the potential field for obstacle avoidance, panel method with harmonic function was used. The panel method was needed to solve the potential flow of a fluid around an arbitrary shaped body in 2D and 3D spaces.

(C. Shi *et al*, 2007) also proposed a Harmonic Potential Field Method (HPF) for Autonomous Ship Navigation. The main idea was adopted from (C.I Connolly *et al*, 1990). The APF had a major drawback “local minima” which relies on the configuration of obstacles and goal. To ensure the route of path planning was proper and collision free, the harmonic function was chosen to generate a free path collision solution. Harmonic functions were the solution to Laplace’s equation. This method had a credit over simple potential field as they were good at solving the local minima problems. However, HPF had a drawback which its computation time increased fast with the grid size and this method also decayed rapidly. This affected the path planning performance when the potential field regions grown.

(C.I. Connolly and J.B. Burns, 1990) used potential field method for constructing path for robots due to its speed. They proposed a global method that produced smooth collision free paths. The potential functions computed solution to a Laplace’s equation in arbitrary n-dimensional domains. The harmonic function using super position and the harmonic function using numerical method was compared. It was found that the superposition of harmonic functions had a drawback which there was no guarantee that obstacle will be avoided in complex or dynamic environments. The numerical solutions for Laplace’s equation were proposed since it was suited for the task of computing solutions with such arbitrary boundary conditions. The Gauss-Seidel iteration was applied in Laplace’s equation. As a result, in producing paths in a robot configuration space, a harmonic function was found suitable because it was computationally efficient. It effectively prevented the spontaneous creation of local minima at a cost of speed for general configurations.

Improved artificial potential field

(C. Tingbin and Z. Qisong, 2013) proposed an improved artificial potential field method as the APF could not adapt to dynamic environment (the target was static). In dynamic environment, the robot was difficult to find an ideal method to detect the goals from the initial point, and control itself from avoiding an obstacles while moving. This proposed method introduced velocity vector to artificial potential field method. The development of this method made the robot able to avoid the obstacles. It also could accurately locate and track the dynamic target. Besides that, this improved approach effectively controlled the robot to reach the goal location while avoiding the obstacles. As a result, it could achieve a good control effect.

DISCUSSIONS

From the various algorithm based on potential field method mentioned above, each algorithm that had been proposed had its advantages and disadvantages. The Virtual Force Field (VFF) methods did not allow the robot to pass through narrow passages. Thus, it affected the instability of motion when traveling within narrow corridor. As a result, the Virtual Force Histogram (VFH) method was proposed to enhance the performance of VFF which could easily pass the narrow passage and could travel in narrow corridors without oscillation

(Borenstein, 1990). This method was developed with low computation complexity, robust, and insensitive to misreading. Besides that, the VFH algorithm was fast and reliable when traversing densely populated obstacle courses.

Harmonic function based on potential field method had proven that it could eliminate the local minima due to potential field drawback. This method computed solutions based on Laplace’s equation by using Gauss-Seidel iteration. This method required low computation time. The path length was proportional to the computation time of entire path produced, thus the interpolation of the gradient for control purposes are performed in constant time (C.I. Connolly and J.B. Burns, 1990).

An Improved Artificial Potential Field method was introduced to remove the local minima in artificial potential field method. This method was simple yet the calculation was fast and could be applied in real-time.

CONCLUSIONS

This paper summarizes various algorithms based on the artificial potential field method for path planning problems. Potential field is a promising method hence it is widely used by researchers in solving the path planning problems since it is simple, elegance and less computational time is required. However potential field suffers from local minima problem, which causes a robot to trap at a particular location before reaching the target point. As stated above, most of the proposed methods that were based on potential fields such as VFF, HPF, VFH and APF tried to address the local minima problem, each with its own advantages and disadvantages. Nevertheless, the research on potential field has not fully explored and is still open especially in addressing the local minima issue.

REFERENCES

C. Shi, M. Zhang, and J. Peng. 2007. Harmonic Potential Field Method for Autonomous Ship Navigation. 2007 7th Int. Conf. ITS Telecommun. pp. 1-6.

C.I. Connolly, J.B. Burns and R. Weiss. (1990). Path planning using Laplace's equation. Proceedings of IEEE International Conference on Robotics and Automation, pp.2102-2106.

C. Tingbin and Z. Qisong. 2013. Robot Motion Planning Based on Improved Artificial Potential Field. pp. 1208-1211.

F. Cheng, W. Ji, D. Zhao, and J. Lv. 2012. Apple picking robot obstacle avoidance based on the improved artificial potential field method. 2012 IEEE 5th Int. Conf. Adv. Comput. Intell. ICACI 2012, no. 2, pp. 909–913.

G.Li, A. Yamashita and H. Asama. 2006. An Efficient Improved Artificial Potential Field Based Regression Search Method for Robot Path Planning. Proceeding of sixth international conference on intelligent systems design and applications (ISDA'06).

H. Chen, X. Wang and Y. Li. 2009. A Survey of Autonomous Control for UAV. 2009 Int. Conf. Artif. Intell. Comput. Intell., pp. 267-271.

Jin Oh Kim, Pradeep K.Khosla. 1992. Real-time Obstacle Avoidance Using Harmonic Potential Functions. IEEE Trans. On Robotic and Automation, vol 8, no 3, 338-349.

J. Borenstein and Y. Koren. 1991. Potential Field Methods and Their Inherent Limitations for Mobile Robot Navigation. no. April, pp. 1398-1404.

J. Antich and a. Ortiz. 2005. Extending the potential fields approach to avoid trapping situations. 2005 IEEE/RSJ Int. Conf. Intell. Robot. Syst., pp. 1386 1391.

J. Borenstein and Y. Koren. 1989. Real-Time Obstacle Avoidance for Fast. IEEE trans. Syst. Man, Cybern. - Part A Syst. Humans, vol. 19, no. 5, pp. 1179-1187.

J. Borenstein and Y. Koren. 1988. High-speed obstacle avoidance for mobile robots. Proc. IEEE Int. Symp. Intell. Control 1988, pp. 382-384.

J. Borenstein and A. T. Laboratories. 1990. Real time Obstacle Avoidance for Fast Mobile Robots in Cluttered Environments. pp. 572-577.

L. Tang, S. Dian, G. Gu, K. Zhou, S. Wang and X. Feng. 2010. A Novel Potential Field Method for Obstacle Avoidance and Path Planning of Mobile Robot. Proceeding of the IEEE.

O. Khatib. 1985. Real-time obstacle avoidance for manipuators and mobile robots. In IEEE Int. Conf. on Robotics and Automation, 500-505.

R. Omar, D.W. Gu. 2009. Visibility line based methods for UAV path planning. 2009 ICCAS-SICE.

S.Ping, L. Kijie, H. Xiaobing, and Q. Guangping. 2009. Formation and Obstacle-Avoidance Control for Mobile Swarm Robots Based on Artificial Potential Field. Proceeding of the IEEE. International Conference on Robotics and Biometics. Guilin, China.

X. Xu, C. Li, and Y. Zha. 2010. Air Traffic Rerouting Planning Based on the Improved Artificial Potential Field Model. pp. 1444-1449.

Y. Cen, L. Wang, and H. Zhang. 2007. Real-time obstacle avoidance strategy for mobile robot based on improved coordinating potential field with genetic algorithm," Control Appl. 2007. CCA 2007. IEEE Int.Conf., no. October, pp. 415-419.

Y. Koren, S. Member, J. Borenstein and A. Arbor. 1991. Potential Field Methods and Their Inherent Limitations for Mobile Robot Navigation. Proc. IEEE, pp. 1398-1404.