TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 9, September 2014, pp. 6682 ~ 6690
DOI: 10.11591/telkomnika.v12i9.6265

Kinect and Optimization Algorithm Based Mobile Robot Path Planning in Dynamic Environment

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Abstract

Based on environmental awareness and effective path planning algorithm, effective robot path planning can be achieved. In this paper, the Kinect sensor, the latest vision sensing technology, is used to perceive the obstacles and terrain information in dynamic environment in real-time, which enables robots to realize effective path planning tasks in complex dynamic environment. Using the real-ime RGB image and 3D image produced by the Kinect sensor, the mobile robot peripheral environment information can be probed. The improved artificial potential field path planning algorithm is optimized by genetic trust method. As a result, it can solve the local minimum points and target unreachable problems in the traditional artificial potential field algorithm. Moreover, it can effectively improve the real-time performance of the algorithm, and eventually realize the optimization of real-time path planning tasks for a robot in dynamic environment. Finally, the experimental system is set up to verify the effectiveness of the proposed methods.

Keywords: *kinect sensor, artificial potential field, genetic trust region, path planning, mobile robotics*

1. Introduction

Path planning technology is one of the core issues of intelligent mobile robot and its path planning in dynamic environment is a hot and difficult topic in the field of mobile robot research. Path planning algorithm and environmental awareness method are two important research issues. Commonly used path planning technology includes Template Matching algorithms, map construction planning technology and artificial intelligence method [1, 2]. The template matching method is compared the current state of the robot with past experience to make decisions. So, the method is much more dependent on the past experience of the robot. Map building path planning method is divided into road mark and grid method. The disadvantage of this method is a poor real-time. Artificial intelligence path planning method applies the advanced artificial intelligence technology to mobile robot path planning, including artificial neural network, evolutionary algorithms, fuzzy logic and the information fusion and so on. But artificial intelligence path planning exists learning sample difficult to obtain and learning lag problem. Traditional artificial potential field path planning method regards the movement robot in the environment as a kind of motion in virtual artificial stress field, existing defects of local minimum point and target unreachable problem [3-5]. In this paper, method based on improved artificial potential field is used and employ genetic trust region algorithm to solve the problem of the sub-goal point of improved artificial potential field, made up of multiple minimum global optimal path, to realize the real-time optimal path planning.

Ravari, with his partner, studied the mobile robot path planning and navigation based on video camera [6], but this method need to convert 2D video image to 3D model with large amount of calculation and the error is bigger too. Navigation of mobile robot localization based on wireless sensor network technology combine the wireless sensor network with mobile robot bringing about expanding its range of perception, providing localization and path planning, expanding the ability of the robot navigation [7-10]. But Kinect is a kind of 3D body feeling camera with the core technology of image identification, capturing RGB images 30 times per second, and also detecting image depth, combined with the 2D plane image photography and 3D depth image photography technology, possessing the functions of real-time dynamic capture, image recognition, 3D measurement, color recognition and so on. Microsoft provides a

Received May 14, 2014; Revised June 26, 2014; Accepted July 16, 2014

Windows platform SDK aiming at the device body sensor, the extension of the using VC++ programming tools which can easily extent the big power of Kinect, providing a good technical for that mobile robot system based on Kinect create real-time 3D terrain model. Benavidez, with his partner, studied the navigation and target tracking system of mobile robot based on Kinect and verified that the reliability of the system was validated by experiment [11]. Smisek with his partner, did researches about the methods of real-time 3D modeling and the target object orientation method and do the quantitative analysis for the modeling and positioning accuracy [12]. Csaba with his partner, studied the obstacle avoidance of mobile robot based on Kinect sensor and fuzzy logic [13].

In this paper, obtaining 3D depth imaging and RGB image information of dynamic environment by employing Kinect body sensor device, doing real-time detection and collecting local environment information for mobile robot, to improve the environment awareness of sensing ability of the system. Robot re-plans and adjusts the path according to the change of real-time environmental information, to make the effective use of local planning, to conclude a more optimized path, to timely process the information of encountered random obstacles, so as to improve the overall path planning of mobile robot performance. Among them, the improved artificial potential field based on the algorithm of genetic trust region is adopted, can effectively improve the efficiency of path planning for mobile robot.

2. Kinematic Modeling of the Robot

In the first place, motion model of mobile robot is established, as shown in Figure 1. Robot position vector is represented by a 3D vector X=$[x\ y\ \theta]^T$.（x, y）is the location coordinate of the robot in the two-dimensional space. θ is the orientation of the robot relative to the X axis, that is, the angle between speed direction and X axis. It mainly has two parameters controlling the mobile robot: speed v and orientation angle ω.

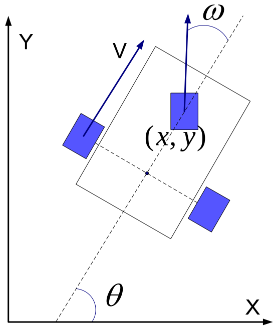

Figure 1. Robot Kinematic Model

The kinematics equation can be established by the robot kinematics model:

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \cos\theta \\ \sin\theta \\ 0 \end{pmatrix} V + \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \dot{\omega} \quad (1)$$

Liner velocity V and orientation angle ω are the control variables of the mobile robot, $\dot{\omega}$ is the velocity of the orientation angle.

3. Path Planning with Kinect sensor

In order to achieve the security of mobile robot in unknown dynamic environment, the following tasks need to be completed: the detection of terrain, obstacle recognition, definition of movable area, path planning and navigation, etc. Kinect body sensor device can generate the depth field image flow at the speed of 30 frames per second, recreate the real-time 3D environment nearby, complete the detection of terrain, map building, recognition of the obstacles and target and pass this information to the computer, so as to lay the foundation for path planning of mobile robot.

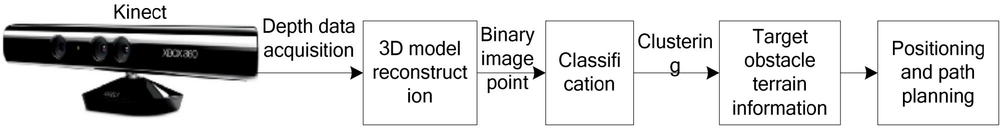

Figure 2. Path Planning with Kinect

According to the built maps and obstacle location information, the computer calculates the coordinates of the mobile robot, target and obstacle space point. According to the results of the coordinates, the potential field model of objectives and obstacles is set up, using genetic trust region algorithm for solving the sub-goal point, with multiple sub-goal point eventually make up global optimal path.

4. Path Planning Algorithm of Mobile Robot

4.1. The Improvement Measures of Improved Artificial Potential Field Method

In order to overcome the defects of the traditional artificial potential field path planning method, make the following improvements:

(1) The target's attraction for the robot and obstacles's repelling force for the robot can be transferred into a kind of potential field strength and the method of computing strength of potential field can be adopted to replace the traditional vector control.

(2) Coefficient item $\left\| \boldsymbol{X} - \boldsymbol{X}_{\mathrm{g}} \right\|_2$ is added in the repulsion vector, so that the repulsion vector is decreased until reaching the target at the same time when the robot get close to the target point and the attraction get decreased, with the repulsion vector getting decreased to 0 meanwhile. Thus the problem of target unreachable due to the reason that the obstacle and target point are too close is solved.

(3) For "dead lock" problem caused by local minimum point, the introduction of "bridging potential field" to guide the robot out of the local minimum points, namely an additional potential field U_{add} is increased in the local minimum point.

4.2. Model of Improved Artificial Potential Field

According to the above measures, model of artificial potential field is established:

(1) Model of the attractive potential of the target for the omni-directional mobile bodywork is shown in Formula (2).

$$U_{\mathrm{att}}(\boldsymbol{X}) = \tfrac{1}{2} k \rho^2 (\boldsymbol{X}, \boldsymbol{X}_{\mathrm{g}}) \tag{2}$$

Where:

$\rho(\boldsymbol{X}, \boldsymbol{X}_{\mathrm{g}})$——the distance between the current position and the target point of the center point of the mobile robot's body.

k——the coefficient of the proportional position gain.

$\boldsymbol{X}$——the location of the robot's center point in the movement space $[x\ y]^{\mathrm{T}}$.

$\boldsymbol{X}_{\mathrm{g}}$——position of the target points $[x_{\mathrm{g}}\ y_{\mathrm{g}}]^{\mathrm{T}}$.

(2) The model of the repulsion potential of the *i* th static obstacle for the omni-directional mobile car body is shown in the formula (3).

$$U_{\mathrm{reps}}(\boldsymbol{X}_i)=\begin{cases}0.5\eta\left(\dfrac{1}{\rho(\boldsymbol{X},\boldsymbol{X}_i)}-\dfrac{1}{\rho_0}\right)^2\left\|\boldsymbol{X}-\boldsymbol{X}_{\mathrm{g}}\right\|_2\\ \text{if}\quad \rho(\boldsymbol{X},\boldsymbol{X}_i)\le\rho_0\\ 0\\ \text{if}\quad \rho(\boldsymbol{X},\boldsymbol{X}_i)>\rho_0\end{cases}\tag{3}$$

Where:

$i\in(1,2,\ldots,n)$, n is the total number of static obstacles;

$\rho(\boldsymbol{X},\boldsymbol{X}_i)$——The shortest distance between the current position and the *i* th obstacle of the center of the mobile car body;

ρ_0——the effective influence distance of obstacles;

η——the coefficient of the proportional position gain.

(3) The position of the dynamic obstacle and the orientation of the motion can be obtained with the depth field image flow at the speed of 30 frames per second by using the sensory ability of the mobile environment of the Kinect. The environment information can't be fully reflected only considering the position, as dynamic obstacles are in motion. When the relative speed between the dynamic obstacle and the robot is inducted into the function of potential field, the model of the repulsion potential of the *r* th dynamic obstacle for the omni-directional mobile car body is set up and as shown in Formula (4).

$$U_{\mathrm{repm}}(\boldsymbol{X}_r)=\begin{cases}0.5\eta\left(\dfrac{1}{\rho(\boldsymbol{X},\boldsymbol{X}_r)}-\dfrac{1}{\rho_0}\right)^2\begin{pmatrix}\left\|\boldsymbol{X}-\boldsymbol{X}_{\mathrm{g}}\right\|_2+\\ \zeta\left|V-V_r\sin(\varphi-\phi)\right|\end{pmatrix}\\ \text{if}\quad \rho(\boldsymbol{X},\boldsymbol{X}_r)\le\rho_0\\ 0\\ \text{if}\quad \rho(\boldsymbol{X},\boldsymbol{X}_r)>\rho_0\end{cases}\tag{4}$$

Where:

$r\in(1,2,\ldots,m)$, m is the total number of the mobile obstacles

ζ——proportional coefficient;

V——the current motion speed of the mobile car body, $V\in(2V_{\max}/3,V_{\max})$

V_r——the current motion speed of the *r* th dynamic obstacle;

ϕ——the motion orientation of the mobile car body

φ——the current motion orientation of the *r* th dynamic obstacle;

(4) When the robot is in a local minimum point, the paved over potential is introduced to solve the problem of local minimum point, the model of the paved over potential is shown as in Formula (5).

$$U_{\mathrm{add}}(\boldsymbol{X})=\begin{cases}s\rho^2(\boldsymbol{X},\boldsymbol{X}_{\mathrm{g}}) & \rho(\boldsymbol{X},\boldsymbol{X}_{\mathrm{g}})>\rho_{\mathrm{a}}\\ 0 & \rho(\boldsymbol{X},\boldsymbol{X}_{\mathrm{g}})\le\rho_{\mathrm{a}}\end{cases}\tag{5}$$

Where:

ρ_{a}——the judging distance whether the mobile car body has reached the target point.

s——the proportional coefficient.

So the overall strength of potential field of the omni-directional mobile car body is shown as Formula (6).The strength of the overall potential field that the Formula (6) add the paved over potential when the robot is at the local minimum point.

$$U = U_{\mathrm{att}}(\boldsymbol{X}) + \sum_{i=1}^{n} U_{\mathrm{reps}}(\boldsymbol{X}_i) + \sum_{r=1}^{m} U_{\mathrm{repm}}(\boldsymbol{X}_r) \tag{6}$$

$$U = U_{\mathrm{att}}(\boldsymbol{X}) + \sum_{i=1}^{n} U_{\mathrm{reps}}(\boldsymbol{X}_i) + \sum_{r=1}^{m} U_{\mathrm{repm}}(\boldsymbol{X}_r) + U_{\mathrm{add}}(\boldsymbol{X}) \tag{7}$$

Based on the above model, in the process of the robot's movement the minimum of the sum of the strength of the potential field that can be reached is seen as the sub-goal point by each sampling period and multiple sub-goal point form the global optimization path. The sum of the strength of the potential field is shown as Formula (6). In order to avoid the shocks when the sub-goal point is nearby the local minimum point, the method of vector synthesis is adopted to make the judgment whether the robot situates in the local minimum point. if so, the strength of the potential field contains the paved over potential, shown as in formula (7). If set the robot's maximum speed be $V_{\max}$ and sampling period be t_0 , the range that the robot can reach in each sampling period is a circle with the current location to be its center and $V_{\max}t_0$ to be its radius. In order to ensure the motion stability and execution efficiency, the speed of the robot's movement can't be too small or too large, so that the sub-goal point can be selected In the annular region $R \in \left(2V_{\max}t_0/3, V_{\max}t_0\right)$, $\theta \in (0, 2\pi)$. As shown in Figure 3, the annular shaded part in the figure is the area of the sub-goal point can be selected. The point of the shaded part in the figure can be described as $x' = x + R\cos\theta$, $y' = y + R\sin\theta$. Thus, formula (6) and formula (7) is the function between variables R and θ, $R \in \left(2V_{\max}t_0/3, V_{\max}t_0\right)$, $\theta \in (0, 2\pi)$. Set $z_1 = x + R\cos\theta, z_2 = y + R\sin\theta$, $\boldsymbol{z} = (z_1, z_2)$. From Formula (5) and Formula (6), it can be concluded that when Using genetic trust region algorithm for solving the objective function of the sub-goal point shown as Formula (8) , that is, solving a class of linear constrained optimization problems and using vector synthesis method judge out that the robot locate in a local minimum point, Formula (8) added with paved over potential is used as objective function.

$$\min U(\boldsymbol{z}) = U_{\mathrm{att}}(\boldsymbol{z}) + \sum_{i=1}^{n} U_{\mathrm{reps}}(\boldsymbol{z}_i) + \sum_{r=1}^{m} U_{\mathrm{repm}}(\boldsymbol{z}_r) \tag{8}$$

Using the quadratic approximation, construct sub-problem of constraints trust region.

$$\begin{aligned} &\min q_k(\boldsymbol{d}) = \boldsymbol{g}_k^{\mathrm{T}}\boldsymbol{d} + 0.5\boldsymbol{d}^{\mathrm{T}}\boldsymbol{G}_k\boldsymbol{d} \\ &s.t. \quad \|\boldsymbol{d}\|_2 \le \Delta_k, \ \boldsymbol{z}_k + \boldsymbol{d}_k \in \Omega \end{aligned} \tag{9}$$

Where, $\boldsymbol{g}_k = \nabla U(\boldsymbol{z}_k)$, Δ_k is the radius of the trust region, $\boldsymbol{G}_k = \nabla^2 U(\boldsymbol{z}_k)$, it is very complex to solve $\boldsymbol{G}_k$ so that Quasi-newton method is used to construct Hession matrix B for representing $\boldsymbol{G}_k$ approximately. $\boldsymbol{d}_k$ is the following test step. Ω is the value range of R and θ.

The symbol instruction the algorithm involved: $\boldsymbol{z} \in R^2$, $\boldsymbol{z}_k = (z_{k1}, z_{k2})$, $\boldsymbol{z}_{k+1} = (z_{(k+1)1}, z_{(k+1)2})$, $\boldsymbol{z}_{k+1}^{e} = (z_{(k+1)1}^{e}, z_{(k+1)2}^{e})$, $\boldsymbol{y}_k = \boldsymbol{g}_{k+1} - \boldsymbol{g}_k$,:= represent assignment, $\boldsymbol{B}_{k+1}^{\mathrm{BFGS}} = \boldsymbol{B}_k + \boldsymbol{y}_k\boldsymbol{y}_k^{\mathrm{T}} / \boldsymbol{y}_k^{\mathrm{T}}\boldsymbol{d}_k - \boldsymbol{B}_k\boldsymbol{d}_k\boldsymbol{d}_k^{\mathrm{T}}\boldsymbol{B}_k / \boldsymbol{d}_k^{\mathrm{T}}\boldsymbol{B}_k\boldsymbol{d}_k$, the ratio of actual decrease amount and the forecast decrease amount is:

$$r_k = \Delta U_k / \Delta q_k = \frac{U(\boldsymbol{z}_k) - U(\boldsymbol{z}_k + \boldsymbol{d}_k)}{q_k(0) - q_k(\boldsymbol{d}_k)} \tag{10}$$

Among them, when resolving $\min U(\boldsymbol{z}_{k+1}^{e})$, Using genetic algorithm for quick solving $\min U(\boldsymbol{z}_{k+1}^{e})$ obtains the iteration point Superior to the current point and thus result in the final sub-goal point receiving the variables R and θ. The final linear velocity V and orientation angle ω of the mobile robot is calculated out using variables R and θ, thus the path planning of the mobile robot is obtained.

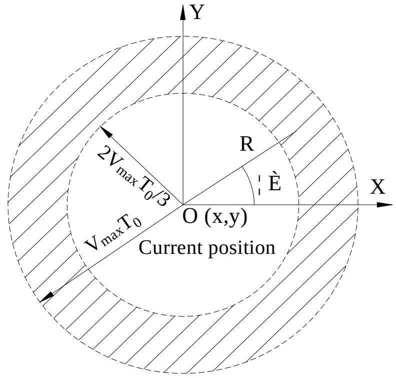

Figure 3. Selected Range of Sub-goal Point

5. Experiment and Analysis

5.1. The System Structure of the Mobile Robot Path Planning Based on Kinect

The structure of the control system of the mobile robot is mainly made up of Kinect body sensor device, computer, mobile robot. The system structure of the path planning is as shown in Figure 4:

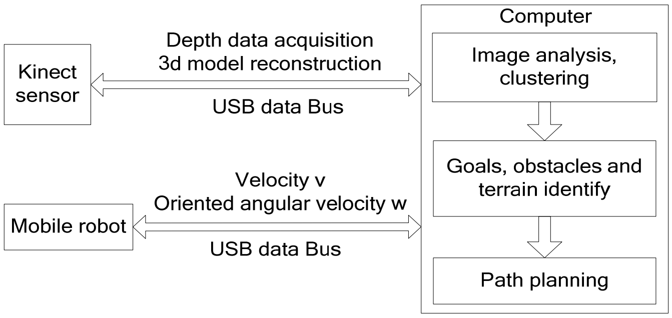

Figure 4. Control Framework of the Mobile Robot Based on Kinect

The perception of obstacles and terrain in the dynamic environment is realized by using the rgb image and 3D image generated by the body sensor device of Kinect, make the real-time detection and receive the surrounding dynamic environment. The computer analyze and process the original data stream of the 3D depth image, distance sensors and rgb image to realize the identification and positioning for the goal and obstacle. The characteristics of the surrounding dynamic environment of the mobile robot are supplied by the rgb image and 3D depth image, including the characteristics of the size, distance and color. The self orientation and target positioning of the robot in unknown environment is realized by using SLAM algorithm or VFH/VFH+ algorithm. The coordinate of the goal, obstacle and robot is obtained, the improved artificial potential field is constructed, sub-goal point is calculated with the algorithm of the genetic trust region, the global optimal path is formed with multiple sub-goal point by the positioning of the goal and the robot itself. The movement speed V and orientation angle velocity ω of the variables of the motion control is obtained from the computer by the mobile robot to adjust its movement state and movement motion and realize the free-collision motion.

5.2. Experiment

In order to verify the effectivity of the system construct, the existing conditions should be made use of: robot、body sensor device of the Microsoft Kinect、computer、dynamic obstacles、static obstacles. The effective experiment system is constructed and the experiment of the path planning is designed. The experimental scene is shown as in Figure 5.

Figure 5. Experimental Scene

The initial parameters of the algorithm is selected as:

$\Delta_0 = 0.05 \square U(z_0) \square$, $\varepsilon_1 = 0.1$, $\varepsilon_2 = 0.03$, $\varepsilon_3 = 0.05$, $a = b = 0.5$, $M = 1.5$, $\eta_1 = 0.15$, $\eta_2 = 0.3$, $\boldsymbol{B}_0 = \boldsymbol{I}_{2\times2}$, $\beta_1 = 0.35$, $\beta_2 = 0.75$, $\beta_3 = 1.25$, N=20, $P_c = 0.99$, $P_m = 0.05$, $T_{\max} = 100$, $\kappa = 0.1$, length of the code l =32, $V_{\max}$ =0.3m/s, t_0 =3s, $z_0 = (5V_{\max}t_0/6, 0)$, k =1, η =2, ζ =0.1, n =2, m =2, s =0.3, φ =π/2, ρ_0 =1m, ρ_a = 0.15m, the original point of the robot (1.00,0.25), the goal point (1.35,3.65), the unit is m. According to the established coordinate system, multiple typical points in the process of the mobile robot’s motion is recorded by the computer. The fitting path curve of the multiple points is shown as Figure 6. The potential field strength and the algorithm’s execute time of the typical point in the motion trajectory is shown as Table 1.

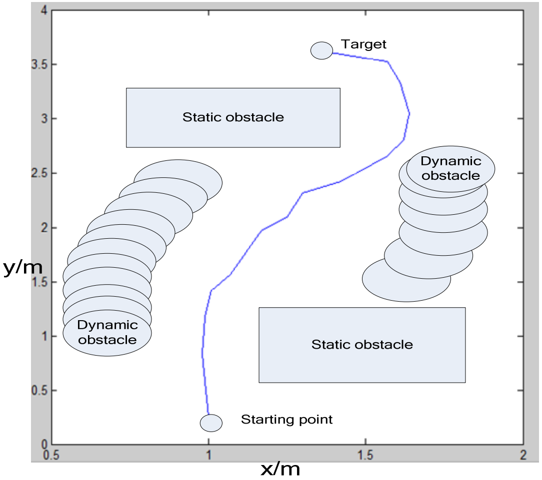

Figure 6. The Motion Trajectory of the Mobile Robot

Table 1. The Typical Point's Execute Time and the Potential Field Strength in the Trajectory

points	x/m	y/m	time/ms	field strength
1	1.00	0.25	17	43.635
2	0.98	0.83	19	41.729
3	0.99	1.17	20	40.109
4	1.01	1.42	16	38.987
5	1.07	1.57	15	35.679
6	1.17	1.97	17	30.250
7	1.25	2.09	10	27.629
8	1.30	2.31	21	24.873
9	1.42	2.42	14	20.298
10	1.57	2.65	19	19.234
11	1.62	2.80	22	16.378
12	1.64	3.05	16	12.394
13	1.61	3.33	19	9.234
14	1.57	3.52	9	4.983
15	1.35	3.63	12	0.002

From the analysis of the mobile robot's trajectory, the experiment shows that the behavior of the mobile robot has good stability, consistency, and continuity. The defect of the method of traditional artificial potential field can be overcome by the integration of the model of improved artificial potential field and genetic algorithm and it has a faster converged speed when the sub-goal point is solved. It can be seen from the experiment the mobile robot can quickly avoid the static and dynamic obstacles and reach the target location quickly without collision. This architecture can better achieve the path planning task of the mobile robot in the dynamic environment.

6. Conclusion

This paper proposes the path planning method of the mobile robot in the dynamic environment based on the Kinect body sensor device with the latest vision sensing technology. Obtaining the real-time current 3D terrain information by using the body sensor device of Kinect can perceive the dynamic environment information of the robot's surroundings effectively and using the method of improved artificial potential field based on the genetic trust region can overcome the defect of the traditional artificial potential field method and realize the optimization of the path planning. The system of the mobile robot based on the Kinect and the method of improved artificial potential field has been verified that it has a better Stability and practicability, can better meet the demand of the real-time control, realize the path planning task of the mobile robot in the dynamic environment and supply a new approach for the path planning of the mobile robot.

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