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An Improved BCM Obstacle Avoidance Algorithm for Outdoor Patrol Robot

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***Abstract*—Security Patrol Robot was used to inspect the abnormal situation in the alert zone. To detect the hanging obstacles, a stereo sensing system was designed, which was composed of a full range of ultrasonic sensors with three-dimensional layout. Using obstacle distribution data acquired in this system, the improved BCM algorithm was proposed to guide robot to avoid obstacles. In the algorithm, the ranging information acquired by the three layers' sensors was mapped into the horizontal plane. And then with the constraints from the kinematics and dynamics of robot, overlapping simplified beams were constructed from the two dimensional distribution of obstacles. After the optimization beam searching, the corresponding angular velocity and the line speed were calculated and put out to control the robot to avoid vehicles and pedestrians on the road. Finally, in the experiments of campus environment, the effectiveness of the proposed algorithm was demonstrated.**

Keywords-Security Patrol Robot; Obstacle Avoidance; Beam curvature method

I. INTRODUCTION

Security patrol robot running on the road in senior residential areas, warehouses, factories and other high safety requirements environment, mainly fulfill the tasks of the mobile monitoring and intelligent anomaly detection. Autonomous patrol is the basis to accomplish these tasks and local obstacle avoidance is the reactive behavior as a guarantee of complete autonomous patrol. This paper mainly studies the problem of local obstacle avoidance for outdoor security patrol robot using low cost ultrasonic ranging sensor.

At present, in the normal mobile robot obstacle avoidance system, mainly based on the target plane cataract ranging the obstacle distribution information in the 2D plane acquired from ranging sensors and robot running direction, the angular velocity and linear velocity are calculated to drive the robot. The artificial potential field method [1] proposed by Khatib, is effective for processing obstacle avoidance in global path planning, but easy to fall into local optimum and make the robot in the trap. Borenstein et al proposed a vector field method (VFH) [2], by controlling the speed and direction, which has good effective of obstacle avoidance, but this method requires high detection precision and is not very easy to apply in practice. Velocity space method which takes the dynamic model of the robot into account , chooses the suitable linear velocity and angular velocity . The curvature velocity method (CVM) [3] describes the local obstacle avoidance problem as a constrained optimization problem in the velocity space, and selects optimized speed command to satisfy all the constraints by the objective function, which makes robot to avoid obstacles successfully, and run more smoothly and faster. Ko et al. based on CVM, presents a roadway curvature method (LCM) [4]. In this method the environment is divided into a plurality of road way, according to the distribution of obstacles and a wide channel is chose that provides more secure direction for CVM. The problem of LCM is difficult to detect the pathway that is represented as a sudden rotation in the experiment. Therefore, Fernandez [5] proposed a beam curvature method (BCM). BCM adopts a double-layer structure in which the environment is divided into several sectors and the linear and angular velocities are calculated by CVM according to the corresponding optimal sector. Compared with LCM, BCM can discover the new channel more easily while the disadvantage is the high computational complexity and the low real-time performance [6]. However, these algorithms are based on obstacle distribution detected in the two-dimensional plane, so that they can not deal with the hanging obstacles.

Figure 1. The security patrol robot

Security patrol robot running in the actual environment, may encounter hanging obstacles, such as: large vehicles that is higher than robot (part of the chassis suspension), branches of tree. If the ranging system is disposed in a single plane, the robot cannot complete the detection of obstacle avoidance on the road and hung above at the same time.

For the high cost of 3D laser scanner, using ultrasonic sensor system all-round layout, the patrol robot solves the security problems of obstacle avoidance, and keeps low cost.

In this system, the ranging information acquired by the three layers layout sensors was mapped into the horizontal plane. And then under the constraints from the kinematics and dynamics of robot, overlapping simplified beams were constructed from the two dimensional distribution of

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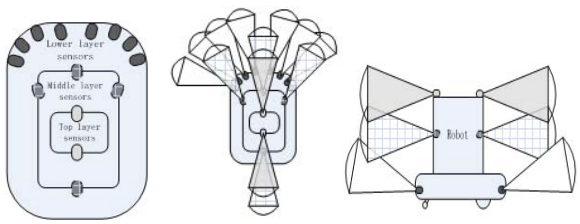
obstacles by the BCM algorithm. After the optimization beam searching, the corresponding angular velocity and the line speed were calculated and put out to control the robot to avoid vehicles and pedestrians on the road.

II. THE THREE-DIMENSIONAL DETECTION SYSTEM BASED ON ULTRASONIC SENSORS

In the autonomous road patrol task of security patrol robot, the main goal of obstacle avoidance is to prevent robots from entering below vehicles. Therefore, in consideration of the wide road, the low control precision and not high running speed, the system uses ultrasonic sensors to detect the full range of hanging obstacles and common obstacles.



(a) layout plan (b)overlooking (c) side looking

Figure 2. ultrasonic sensors layout in the patrol robot

In order to detect different height obstacles, from low to high, the ultrasonic sensors ware lay out into three layers: the lower, middle, upper. In the lower layout, 8 sensors ware installed at about 15 degrees, 30 degrees, 45 degrees, 75 degrees left and right In front of the robot. The measuring angle of sensor is 30 degrees, so the detection regions of middle sensors ware overlapped. The resolution angle in front decreased to15 degree, while 30 degrees in both sides (detection coverage shown in Figure 2 (b)). Because the robot moved in a straight line in most of cases, it can guarantee the machine running straight at high speed. The height of underlying sensors is set to 8cm, which ensure that the robot can detect the road shoulder and other obstacles that robots cannot cross. 4 sensors ware installed in the media layer, including one in the front , each at about 15 degrees at left and right and one in the back, which not very high hanging obstacles ware detected by. The top layer set up 2 sensors: front and rear, to deal with the obstacles at robot height. The overall layout and coverage are shown in figure 2.

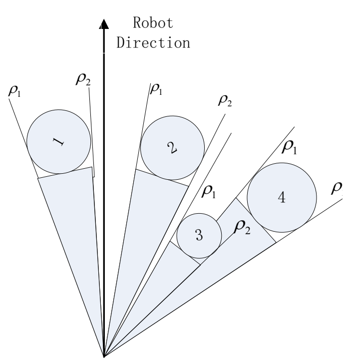


Figure 3. Fig. 3 Beam definition and overlapping

Because the local obstacle avoidance algorithm existing works based on the data in the obstacle distribution plane, using the three-dimensional distribution structure in this paper, the problem we first need to solve is that distribution of obstacles is mapped to the horizontal plane.

Considering obstacles in the upper and middle layer ware very few, feasible beam was defined afresh according to the concept of BCM and the mapping was completed.

According to the definition of the underlying sensors, $B(\rho_1,\rho_2,d)$ represents a viable beam, which ρ_1 is the starting angle, ρ_2 is the end angle and d is the distance.

For the two overlap beams, $B_1(\rho_{11},\rho_{12},d_1)$, $B_2(\rho_{21},\rho_{22},d_2)$, if $\rho_{11}<\rho_{21}<\rho_{12}<\rho_{22}$, the two beams are divided into three beams :

$$B_1(\rho_{11},\rho_{21},d_1)$$
$$B_2(\rho_{21},\rho_{12},\min(d_1,d_2))$$
$$B_3(\rho_{12},\rho_{22},d_2)$$

For the media sensors, beam is defined as $B(\rho_1,\rho_2,k_1*d)$, in which k_1 is the reduction coefficient and the value is 0.8.

For the lower sensors, beam is defined as $B(\rho_1,\rho_2,k_2*d)$, in which k_2 is the reduction coefficient and the value was 0.6.

The goal of setting k_1 and k_2 , was that when the hanging obstacles appear , the feasible beams are shortened quickly , the robot was forced to decelerate and avoid it after the BCM optimization.

III. THE IMPROVED BCM ALGORITHM

Fernandez proposed the beam curvature method (BCM) algorithm by combining with CVM and LCM algorithms [5] , in which instruction was put out by two steps . In the first step, local orientation and feasible distance of robot was determined by beams. At first, the beam was calculated that the parameters set $B(\rho_1,\rho_2,d)$ was defined for each obstacle, which ρ_1 and ρ_2 were the restricted angles to tangent line of an obstacle, d is the minimum safety distance of beam. Then, it was start to find the best beam. After the optimal beam was selected, the best way was found to guide the robot. In the second step, the guidance instructions ware put out by CVM method, considering dynamic constraints on the robot at the same time. At each sampling interval, the local target trajectory was real-time computed.

Suitable for the obstacle avoidance with the full range of ultrasonic sensors, the original BCM algorithm was improved. The detection area of Ultrasonic sensor was a tapered region and the projection on the plane was a sector with radius of maximum detection distance and 30 degrees angle from the middle of the installation position to both sides.

Based on this, the improvement of BCM algorithm was below:

(1) The beam selection and calculation ware simplified , and the process of overlap merging beam in original BCM algorithm was omitted, because the obstacle information itself was an estimate for the distribution of obstacles in one beam, and computing sector overlapping had been completed in the data preprocess .

(2) The anti collision conditions ware added to prevent the friction between obstacle and robot on the road and exclude beam overlapping influence with the beam selection accuracy.

(3)Feasible beam was calculated after the weighted maps of the upper sensor information to the horizontal plane, and processed by BCM algorithm together with other sectors to achieve the purpose of all-round obstacle avoidance.

Using the method above, the steps of improved BCM algorithm are as follows

Step1: Calculate each beam for every sensor. For the middle and upper sensor, weighted processing is needed.

Step2：Get the quasi feasible sector

Defined Beam Set as:

$Z = \{B_i(\rho_{i1}, \rho_{i2}, d_i) \mid i = 1, 2 \cdots n\}$

and made the following judgments:

(1) Minimum safety distance

If $d_i < d_{safe}$, B_i was unviable, in which d_{safe} was the minimum safety distance.

(2) chord length

The "chord length" condition was set to prevent robot entering to the narrow channels.

If $L_i < C_i$, B_i was unviable, in which $L_i = 2 * d_i * \sin(\rho_1 - \rho_2)$ was the chord length of beam, $C_i = \lambda_L D_L$ the width of channel , D_L the transverse diameter of the robot, and λ_L the amplification factor.

(3) Collision conditions

In order to guarantee the moving robot not to reach the barrier, beams shall meet the conditions of anti collision.

For each beam that meet the condition $d_i < d_{safe}$, two circles ware constructed with the center of starting point and end point of beam arc , the radius $C_i = \lambda_L D_L$. If the circles and the beam B_j ware overlapped, B_j was unviable.

(4) The feasible direction condition

The difference of the beam direction $\theta_i = (\rho_{i1} + \rho_{i2}) / 2$ and the given target direction θ_0 was calculated: $\Delta\theta = |\theta_i - \theta_0|$.

If $\Delta\theta > \pi / 3$, B_i was unviable

Step3: Get the optimal feasible beam

Excluding unviable beams, the remaining beams consists of the set of quasi feasible beams Z' .

Traverse each beam in Z' to get the optimized beam B_g that make the object function (1) to get the maximum value, in which α and β are the parameters of robot target tropism and rapidity.

$$f(i) = \alpha \frac{d_i}{d_{\max}} + \beta\left(1 - \left|\frac{\Delta\theta}{\pi / 3}\right|\right) \tag{1}$$

Step4: Get linear and angular velocities according to the kinematics equations of robot

Through the sector selection rules above, θ_g and d_g ware obtained and the computation by which the linear and angular velocities ware calculated.

The robot kinematics constraints ware that:

$$\begin{aligned} &rv > rv_{cur} - ra_{\max} * \Delta T \\ &rv < rv_{cur} + ra_{\max} * \Delta T \\ &tv < tv_{cur} + ta_{\max} * \Delta T \end{aligned} \tag{2}$$

In which rv_{cur} , tv_{cur} ware the current linear and angular velocities, $ra_{\max}$, $ta_{\max}$ ware the maximum acceleration of angular velocity and linear velocity, ΔT was the decision time.

At the same time, the linear velocity should also be guaranteed not to hit the barriers at the front of the beam, $tv < d_g / \Delta T$. Searching in the velocity space with above conditions, the linear velocity tv and angular velocity rv that made the objective function below arrive the minimum value, ware used to control the robot to avoid obstacles.

$$\begin{aligned} &f(rv) = \left|\theta_g - rv * \Delta T\right| \\ &f(tv) = d_g - tv * \Delta T \end{aligned} \tag{3}$$

However, in the case of intensive obstacle, after the operation Step2 in this algorithm, all beams may be excluded, when the robot system on task based hierarchical structure would call the upper path planning program and give the robot a temporary target to guide it to leave the trap.

IV. TEST RESULT

The software system was developed for the security patrol robot based on task hierarchical structure in which the robot can use behavior decision knowledge database to finish path planning and navigation and local obstacle avoidance control module was applied with this algorithm.

Figure 4. Road map in campus

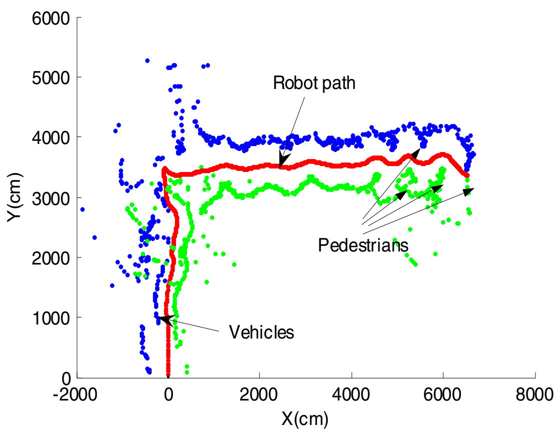


Figure 5. Robot path and obstacles distribution

Using this algorithm, we conducted a number of tests. In one of experiments, we let the robot move from the road node 2 to node 1, then to node 28 (as shown in Figure 4) and avoid the vehicles and pedestrians at the same time.

The section of road was concrete pavement with 8-15cm high shoulder and 20-80cm tall green bushes on both sides of the road. The section from Node 2 to node 1 was a road 28 meters long, 6 meters wide and the section from node 1 to node 28 was 86 meters long, 6.5 meters wide. They had flat surface on the ground with pedestrians, roadside parked minivan and static obstacles. The robot arrived node28 6 minutes after starting from node2 with the maximum speed of 0.5m/s. In the whole process of operation, the program automatically recorded all of the original perception information and the processed data. On off-line, the rendering path was shown in figure 5. From the figure, the robot successfully completed the autonomous obstacle avoidance. The trajectory is smooth and the speed meets the requirement of patrol.

V. CONCLUSIONS

In this paper, an obstacle stereo detection system which was a full range of three-dimensional layout ultrasonic sensors, was designed for the security Patrol Robot. Through the mapping of multi-layers sensors information, the simplification of beams and the velocity calculation with constraints from the kinematics and dynamics of robot, the BCM algorithm was improved to make robot avoid vehicles and pedestrians on the road.

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