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Research on the Strategy of Obstacles Avoidance of Outdoor Mobile Robot

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Abstract: **In this paper, we propose two types of strategies for obstacle avoidance of outdoor mobile robot. One is Safety Channel Estimation Algorithm (SCEA) ,it is a simple and direct algorithm of obstacle avoidance by computing the largest Safety-channel and then adjusting the steering angle command ,this algorithm is essentially Safety-First algorithm. The estimation of Safety-channel ensures the vehicle to select at least one path to track while there are many obstacles. The other algorithm is the Most Dangerous Obstacle Estimation Algorithm (MDOEA), it is much more complicated than SCEA, however it has obvious purpose, and ensures the vehicle to avoid the current most dangerous obstacle. Therefore this algorithm shows higher artificial intelligence, it is essentially Danger-First algorithm which is obviously inverse against the Safety-First algorithm. It also shows a better effect of the globe path tracking under globe environment.**

Keyword: **obstacle avoidance, mobile robot, obstacle density, rough set**

I. Introduction

Tsinghua Mobile Robot (THMR-V) is designed as an outdoor mobile robot with the function of both autonomous navigation and remote operation, and is shown in figure 1. Now the emphasis of studying includes smooth and stable path tracking under no obstacles, and intelligent decision of obstacles avoidance while obstacles exist. In this paper, we describe the research on the strategies of obstacles avoidance in navigation using THMR-V as a test-bed. Two typical strategies, one is called Safety Channel Estimation Algorithm (SCEA) and another is called the Most Dangerous Obstacle Estimation Algorithm (MDOEA), will be discussed.

II. The System Structure of THMR-V

The system structure frame of the autonomous navigation of THMR-V is shown in Figure 2, the position sub-system makes a fusion of the information from Differential Globe Position System(DGPS)、Optical-coding Machine and Electronical Compass，then generates the comprehensive posture feedback information of the vehicle and is transferred to the monitor system via 10M ether LAN. Meanwhile, the Laser Measurement Sub-system(LMS) treats the primary scanning radar information as a continuous fan-chart(See figure 5) and also transfers it to the monitor center through the LAN. Based on the circumstance information, the monitor center system makes decision to take one of the following Algorithm: PID control Algorithm in straight ling tracking, Artificial Potential Field Algorithm in curve path tracking and obstacles avoidance Algorithm in the emergence of obstacles. The decision information is transferred to the control computer system and drive the direction control

Figure 1. THMR-V:
outdoor mobile robot of the fifth generation

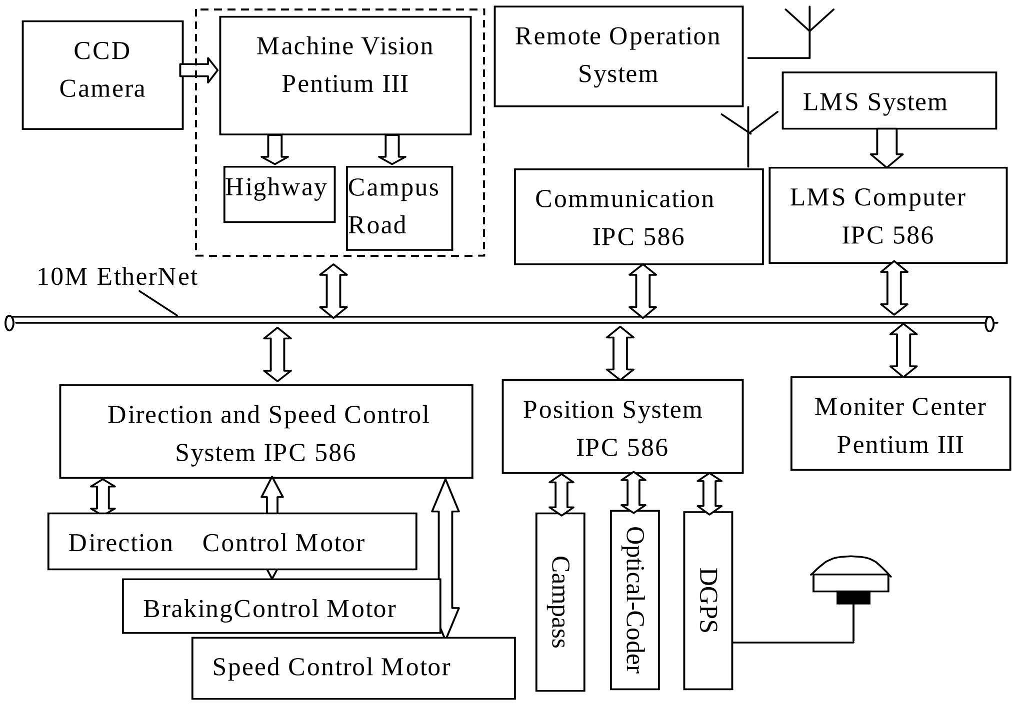

Figure 2. the system structure frame of THMR-V

motor, speed control motor and braking control motor separately. (See Figure 2)

III. Data from Laser Measurement System

The Laser Measurement System(LMS) used in THMR-V has the longest scanning distance of 50 meters, the primary raw data is calculated by the pre-treatment computer and then transferred to monitor center as an array RadarData(i),which stands for the obstacle distance in the ith scanning angle of the LMS, The starting scanning angle is assumed to be zero degree, and the end angle 180 degree, the interval angle is 1 degree. Therefore the ith element of the array is the very obstacle distance of I degree rightwards, the total array may then be plotted as a semi-circle figure(See Figure 3)

IV. Safety Channel Estimation Algorithm

The following is the psudo-code of obstacle avoidance during the general control loop of THMR-V:

```
while(TRUE){ //control loop
     ;
  calculate bArrival  with accordance to road
  state;
  if(!bArrival){
  //not arrive at the next planned point
```

```
swith(CURRENT_ROAD_STATE){
  case STRAIGHT_LANE:
    if(OBSTACLE_AVOIDANCE_IS_NEEDED)
        Algorithm for obstacle avoidance;
```

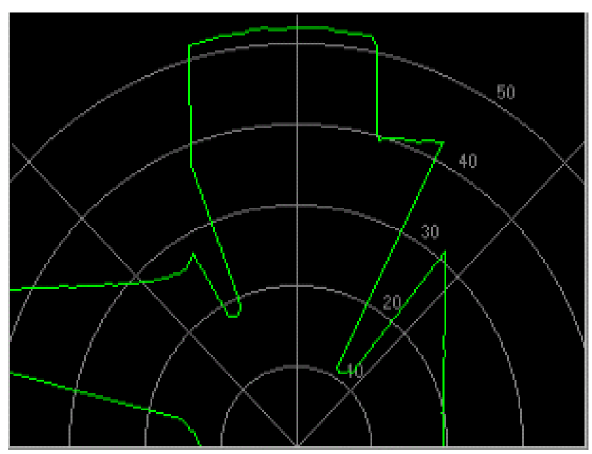

Figure 3 the Scanning Figure of LMS

```
    else PID STRAIGHT_LANE TRACKING;
    break;
  case CURVE_LANE:
Artificial-Potential-Field Algorithm; break;
case CROSSROAD: ARC_TRACKING Algorithm; break;
}
```

```
Update the control command(STEERING_ANGLE,
SPEED, BRAKING);
}
else{  //Arrive at the next point
            ;}
}//while
```

4.1 OBSTACLE DENSITY FUNCTION

The obstacle density function BlockDeg represents the normalized number of obstacles in front of the robot, it has the domain of [0,1],and the bigger the value, the more obstacles in the front of the robot:

$$BlockDeg = \left(\sum_{i=StartIdx}^{EndIdx} \frac{RDanger}{RadarData[i]} \right) \Big/ (EndIdx - StartIdx + 1) \quad (1)$$

Where RadarData(i) is the scanning data array afore mentioned, Rdanger is the obstacle avoidance distance threshold, StartIdx and EndIdx are the starting scanning angle and end scanning angle separately. The threshold value of obstacle avoidance is a constant according to the human driving experience.

We may get the distance of every obstacle from 0 degree to 180 degree in front of the robot according to the laser scanning data array. If RadarData(i) is less than the threshold value, we mark the angle (i) as a local obstacle belt, otherwise as a Safety belt. While we get serious consecutive Safety belts, we call it as a local Safety area. The widest local Safety area from 0 degree to 180 degree is the best local navigation channel. The center angle of this channel is then taken as the current best expected driving angle (but it's still not the steering angle).

Table 1 shows an instance including the scanning data array ranging from 0° to 9° ,where

Angle [i]	0	1	2	3	4	5	6	7	8	9
RadarData[i]	1	2	3	5	4	2	2	1	3	4

Table 1 scanning data array from 0 to 9 degree

[0，1]、[5，7] are local obstacle area, and[2，4]、[8，9] are local Safety area, and [2，4] is the widest local Safety area, then The center angle of this channel is 3°.

If the current best expected driving angle is α,we have: (See Figure 3):

$$\cos\alpha = \frac{OA}{OO_1} = \frac{RDager/2}{R} = \frac{RDanger}{2R} \quad (2)$$

$$\Rightarrow R = \frac{RDanger}{2\cos\alpha}$$

where R is the local turning radius, $\alpha=\angle BOC$, $RDanger=OC$, $R=OO_1$.

For $\tan\theta = \frac{L}{R}$, where L *is* distance between the front wheel and rear wheel of the vehicle. Hence, the steering angle θ is obtained by the following:

$$\theta = \arctan\left(\frac{L}{R}\right) = \arctan\left(\frac{L}{RDanger/2\cos\alpha}\right) = \arctan\left(\frac{2\cos\alpha \cdot L}{RDanger}\right) \quad (3)$$

The proposed Safety Channel Estimation Algorithm is described in the following. :

Step 1) set the initial condition of navigation such as obstacle avoidance threshold distance *Rdange;* the maximum speed V_{max} and the planned object point.

Step 2) compute the obstacle density function *BlockDeg* by (1);

Step 3) Estimate the best local navigation channel as the Safety channel of navigation, and computer the center angle of this channel as the current best expected driving angle α.

Step 4) computer the current steering angle command by (3);

Step 5) computer the current speed command by the following :

$$V=V_{max}\cdot(1-BlockDeg) \quad (4)$$

Following this procedure, the commands of steering angle and speed are obtained in the process.

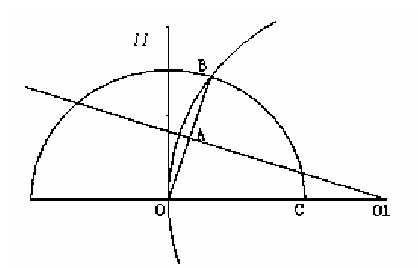

Figure 4 Steering Angle Computation While Avoiding Obstacle

4.2 EXPERIMENT 1

The presented algorithm has been tested in an outdoor environment with the obstacle-avoidance threshold as 5 meters, Figure 5 shows the trace curve while continuous obstacle-avoidance is taken, where A and B are two continuous obstacles.

V. THE-MOST-DANGEROUS OBSTACLE ESTIMATION ALGORITHM(MDOEA)

5.1 Obstacle Clustering

In this algorithm, the obstacle density function BlockDeg in (1) is still treated as the criterion of obstacle-avoidance. However, in prior of estimating the most dangerous obstacle, the data array representing the obstacle distribution between 0 to 180 degree should be clustered first, the most dangerous obstacle is then computed out of the clustered obstacles. Constrained by the real-time control ,the clustering algorithm should not be too complicated. therefore the Euclid distance clustering algorithm is taken, in the algorithm(i1,i2) representing the Euclid distance between two point P1 and P2 of the corresponding scanning angle i1 and i2 separately, and T(i) representing the ith clustering result. (See figure 6)

∀i1,i2∈[0,180], d(i1,i2)<dth⇔T(i1)=T(i2)，dth is the clustering threshold value;

5.2 Attribute value of the clustered obstacle

Danger estimation about the clustered obstacles is processed according to the attribute value, Suppose Ob is a clustered obstacle and Ob={P0,P1,…,Pn-1}， where Pi=Pi(xi,yi),the attribute value of Ob is(See Figure 6):

$$\begin{cases} x_{\min} = \min\{x_i \mid i = 0,1,\dots,n-1\} \\ x_{\max} = \max\{x_i \mid i = 0,1,\dots,n-1\} \\ y = \min\{y_i \mid i = 0,1,\dots,n-1\} \\ \theta_{\min} = \min\{\theta_i \mid i = 0,1,\dots n-1\} \\ \theta_{\max} = \max\{\theta_i \mid i = 0,1,\dots n-1\} \end{cases} \quad (5)$$

where (x,y) representing the position information and θmin，θmax representing the starting angle and end angle of the cluster separately. The most dangerous obstacle is estimated by the following criterion:

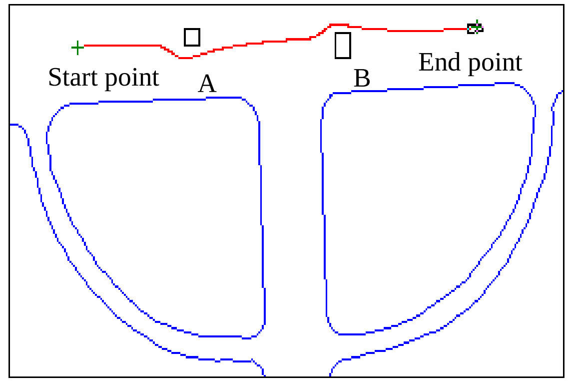

Figure 5 Safety Channel Estimation Algorithm

$$\begin{cases} criterion\ 1: \\ \quad y_k = Min_{j=1}^{cluster\ number}(y_j)\ ; \\ criterion\ 2: \\ \quad x_{\min}(k) * x_{\max}(k) < 0, \\ \quad or\ Min(|x_{\min}(k)|,|x_{\max}(k)|) \\ \quad\quad < \frac{b}{2} + D_{safty}\ ,if\ x_{\min}(k) * x_{\max}(k) > 0; \end{cases}$$

(6)

where b representing the width of vehicle(i.e. b =1.8 meter for THMR-V) and D_{safty} representing the design Safety constant.(typically $D_{safty} = 1\ meter$).

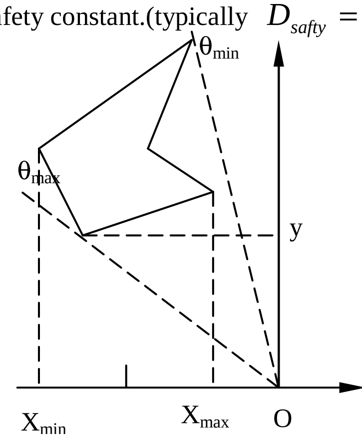

Figure6 attribute value of cluster

5.3 Strategy of Obstacle-Avoidance concerning the Most Dangerous Obstacle

In view of the most dangerous obstacle, the fuzzy logic rules obtained by machine learning using a data analysis tool of rough set are taken to navigate the vehicle, This strategy of obstacle avoidance is on the experience of human driving. The LMS samples the real time data about the obstacle distribution, the cluster algorithm aggregates every continuous obstacle, then the most dangerous obstacle and its attribute value are obtained by the estimation algorithm .At the same time, the real steering angle of human driving is simultaneously sampled, therefore the database implying human driving knowledge will be easily obtained. (See table 2)

Table 2 Obstacle-Avoidance Database of *THMR-V on 2003-4-26 , vehicle width=1.8meter*

n	Heading	θ min	θ max	Xmin	Xmax	Y	Steering angle	Description
1	-178. 0	96	99	-0. 92	-0. 61	5. 73	-1	Turn right for the first time of obstacle avoidance
2	-179. 1	99	104	-1. 17	-0. 76	4. 56	-4	
3	179. 4	107	112	-1. 40	-1. 10	3. 45	-5	
4	177. 5	118	124	-1. 66	-1. 37	2. 43	-5	
5	175. 6	137	146	-1. 90	-1. 59	1. 27	-4	
6	173. 9	168	175	-2. 00	-1. 73	0. 17	-2	
7	-175. 6	80	83	0. 76	1. 08	6. 06	2	Turn left for the second time of obstacle avoidance
8	-173. 9	75	79	1. 02	9. 38	4. 68	3	
9	-172. 2	67	72	1. 18	1. 52	3. 53	4	
10	-171. 2	53	59	1. 42	1. 75	2. 27	3	
……	……	……	……	……	……	……	……	

Based on rough set theory, firstly, the continuous value is turned to discrete into limited intervals, then attribute reduction is processed, and control rule under different precision is obtained. The obstacle-avoidance rules are divided into two hierarchal parts, the first group of rules are used for judgment about whether or not the obstacle-avoidance action should be taken, the second layer of rules play important role of navigation after the vehicle has begun to take obstacle-avoidance action.

5.4 Experiment 2

The Most Dangerous Obstacle Estimation Algorithm (MDOEA) and avoidance algorithm based on rough rules has been tested in an outdoor environment, Figure 7 shows the trace curve while obstacle avoidance action is taken.

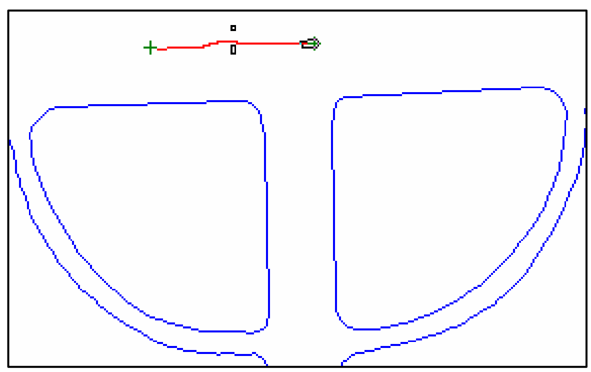

Figure 7 the-Most-Dangerous Obstacle Estimation Algorithm (MDOEA)

6 RESULTS

Safety Channel Estimation Algorithm (SCEA) is a simple and direct algorithm of obstacle avoidance by computing the largest Safety-channel and then adjusting the steering angle command. Hence, this algorithm is essentially Safety-First algorithm. The estimation of Safety-channel ensures the vehicle to select at least one path to track while there are many obstacles. However the obstacle density function BlockDeg is just a local information, the effect of this algorithms is sometimes not so good.

The Most Dangerous Obstacle Estimation Algorithm (MDOEA) is much more complicated than SCEA, however it has obvious purpose, and ensures the vehicle to avoid the current most dangerous obstacle. Therefore this algorithm shows higher artificial intelligence, it is essentially Danger-First algorithm which is obviously inverse against the Safety-First algorithm. It also shows a better effect of the globe path tracking under globe environments.

7 CONCLUSIONS

In this paper, we propose two types of strategies for obstacle avoidance of outdoor mobile robot .Both of the algorithms succeed in obstacle avoidance .In future, we will extend these algorithms in dynamic environment and under the existence of multi-obstacles and moving obstacles,and also will research the automated generation of rules based on rough set theory.

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