Minimum sensing cell measurement in network domain based on PIR sensor array

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Abstract: To reasearch on the infrared target perception by pyroelectric infrared (PIR) sensor in network domain measurement, a closed sensing network domain composed of eight-PIR-sensor array is proposed for the minimum sensing cell measurement in network domain and to realize the moving target perception and trajectory prediction. Moreover, the feasibility and accuracy of the proposed method are verified through experiments. The experimental results demonstrate that the maximum error between the real trajectory and the predicted trajectory of the minimum sensing cell measurement method is 0.64 m, which can achieve infrared target perception and moving trajectory prediction.

Key words: pyroelectric infrared (PIR) sensor; minimum sensing cell; trajectory prediction

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0 Introduction

Robot technology has achieved rapid development in recent years. The application fields of robot have continuously expanded from automatic production lines to exploration of ocean resources and even spacewalk. However, with regard to the existing robot technology, the ability of an individual robot to obtain, process and control information is limited, because it is much insufficient for complex task and changeable working environment. Therefore, it is considered that the coordination and cooperation of multiple robots can accomplish the work which cannot or hardly be accomplished by an individual robot[1-3].

In this paper, a sensor array is used to form a sensing network domain for robot groups[4-6]. The task of network domain perception is accomplished by the cooperation of various robots, which accords with the concept of group. Pyroelectric infrared (PIR) sensor array group with weak PIR is replaced with powerful image equipment, which not only reduces the cost, but also has the advantages of stronger parallelism and robustness[7-8].

The perception ability of robot group network domain based on low-cost PIR sensor array has been enhanced with the increase of the number of sensors in the domain sensing system, and correspondingly the data to be processed by robot group network domain sensing system, including region, time and space information, are sharply increased. Therefore, the data processing becomes very important for the autonomous sensing of robot group network domain.

In the last ten years, many scholars have carried out a lot of preliminary research on robot group network domain sensing based on low-cost PIR sensor array. For example, Xu, et al. studied the target detection method by a single PIR sensor array[9]. Dr. Xian replaced the traditional Fresnel lens with infrared lens[10]. Sun, et al. proposed the dynamic use of PIR sensors to realize two-dimensional sensing[11]. Wang, et al. studied the dynamic target tracking based on PIR particle swarm optimization[12]. Zhao, et al. calculated the target trajectory through dynamic and static sensors array[13]. Hou, et al. further studied the dynamic and static target trajectory prediction technology, which laid a foundation for autonomous perception of robot group network domain.

1 Minimum sensing cell in network domain

All-weather warning applied to a specific area aims at accurately identifying the target passing through

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the sensing area and measuring the position and trajectory. The minimum sensing cell composed of four sensing platforms is not only the most basic part of network domain, but also the most efficient cell to realize spatial sensing. The minimum sensing cell is responsible for flexible perception of battlefield situation information according to geographical environment, information collection, information transmission, and information fusion through high-speed dynamic network. Therefore, the minimum sensing cell technology is an key part for cooperative sensing.

1.1 Theory base

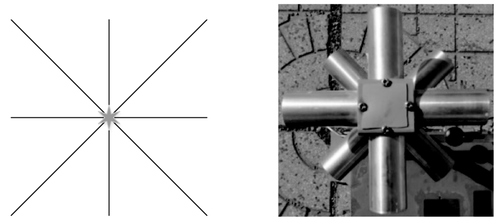
The minimum sensing cell technology is an important part of network domain sensing technology. By studying the layout and quantity of a sensing platform, the sensor array on the sensing platform is used to construct the minimum sensing cell of network domain for perception of the intrusion target and prediction of its moving trajectory.

A minimum sensing cell is a dynamic sensing platform with information processing module, which can perform primary fusion processing on the information collected by composite sensor array. These dynamic sensing platforms have a specific layout and number, a unified time-based standard and a global coordinate system. Using any platform as the "cluster head", the information at the decision level in the network domain is fused to predict the target positioning and trajectory, so that the optimal sensing effect for the situation of the designated area is achieved.

1.2 Composition

Although the dynamic use of PIR sensor not only solves the contradiction between the detection distance and the detection angle, but also realizes 360° detection, it is likely to be affected by the environment and has poor anti-interference ability. In the experiment, it is found that some small change of environments will affect the accuracy of detection and increase the frequency of misinformation. Therefore, the perception mode of eight static PIR sensors is proposed, which can make up for the deficient perceptual ability of four PIR sensors and improve the stability of the system and reduce the sensor data. This is convenient for data analysis and more suitable for networks with a large number of sensors.

A single robot sensing platform in perceptual network domain is a star-shaped sensor array composed of eight PIR sensors and the infrared information perception "line" with the angle of 3° (3° conical region), as shown in Fig. 1.



(a) Structure schematic of detector (b) Physical detector

Fig. 1 Schematic diagram of a single robot perception platform

Although the single robot perception platform can perceive in eight directions, it cannot form a closed sensing region to realize the leakless perception of the intrusion target. Four single robot sensing platforms can construct the minimum sensing cell in rectangular domain as shown in Fig. 2, complete a 360° closed perceptual region and realize leakless perception.

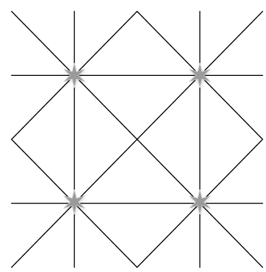


Fig. 2 Schematic diagram of minimum sensing cell in domain

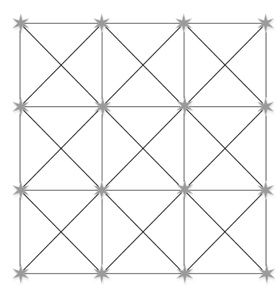


Fig. 3 Network domain sensing diagram

N minimum sensing cells in the domain can achieve situational sensing deployment in battlefield domain, as shown in Fig. 3. The closed perceptual domain covers the whole duty area. Any target passing through this domain is bound to be perceived, and the trajectory is predicted through the autonomous information fusion of the domain.

2 Measurement method for trajectory

The target is assumed to keep uniform linear motion from (x_0, y_0) in a short distance. The velocity is v; the intrusion angle is α; t_1, t_2, t_3, t_4 and t_5 are the intersection points of the sensors found for five times, as shown in Fig. 4.

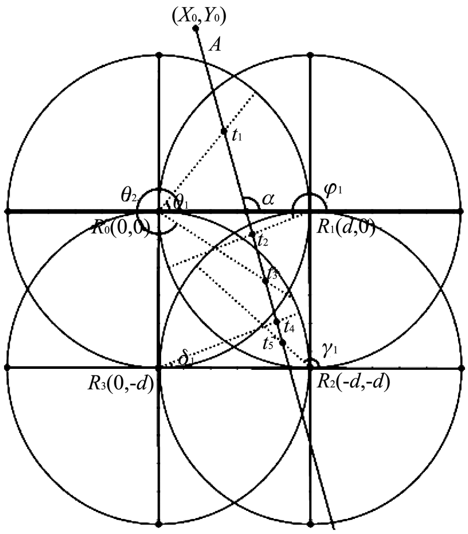


Fig. 4 Sensing platform collaboration localization

The linear equation of the target can be expressed as

$$x = x_0 + tv\cos\alpha, \tag{1}$$

$$y = y_0 + tv\sin\alpha. \tag{2}$$

Sensor node R_0 finds the target for the first time at t_1. The angle value θ_1 is given. The linear equation can be expressed as

$$y = \tan\theta_1. \tag{3}$$

The detection time t_1 is

$$t_1 = \frac{y_0 - x_0\tan\theta_1}{v\cos\alpha \cdot \tan\theta_1 - v\sin\alpha}. \tag{4}$$

Similarly, the times when the target is found for the second, third and fourth times are

$$t_2 = \frac{y_0 - (x_0 - d)\tan\varphi_1}{\tan\varphi_1 \cdot v\cos\alpha - v\sin\alpha}, \tag{5}$$

$$t_3 = \frac{y_0 - x_0\tan\theta_2}{v\cos\alpha \cdot \tan\theta_2 - v\sin\alpha}, \tag{6}$$

$$t_4 = \frac{(y_0 + d) - x_0\tan\delta_1}{\tan\delta_1 \cdot v\cos\alpha - v\sin\alpha}, \tag{7}$$

$$t_5 = \frac{(y_0 + d) - (x_0 - d)\tan\gamma_1}{v\cos\alpha \cdot \tan\gamma_1 - v\sin\alpha}. \tag{8}$$

The time difference Δt when the target is found for the fifth time is

$$\Delta t_1 = t_2 - t_1 = \frac{y_0 - (x_0 - d)\tan\varphi_1}{\tan\varphi_1 \cdot v\cos\alpha - v\sin\alpha} - \frac{y_0 - x_0\tan\theta_1}{v\cos\alpha \cdot \tan\theta_1 - v\sin\alpha}, \tag{9}$$

$$\Delta t_2 = t_3 - t_2 = \frac{y_0 - x_0\tan\theta_2}{v\cos\alpha \cdot \tan\theta_2 - v\sin\alpha} - \frac{y_0 - x_0\tan\theta_1}{v\cos\alpha \cdot \tan\theta_1 - v\sin\alpha}, \tag{10}$$

$$\Delta t_3 = t_4 - t_3 = \frac{(y_0 + d) - x_0\tan\delta_1}{\tan\delta_1 \cdot v\cos\alpha - v\sin\alpha} - \frac{y_0 - x_0\tan\theta_1}{v\cos\alpha \cdot \tan\theta_1 - v\sin\alpha}, \tag{11}$$

$$\Delta t_4 = t_5 - t_1 = \frac{(y_0 + d) - (x_0 - d)\tan\gamma_1}{v\cos\alpha \cdot \tan\gamma_1 - v\sin\alpha} - \frac{y_0 - x_0\tan\theta_1}{v\cos\alpha \cdot \tan\theta_1 - v\sin\alpha}. \tag{12}$$

The four variables (x_0, y_0), v and α can be obtained through the above equations to measure the moving trajectory of the target.

3 Target sensing experiment

In the experiment, by comparing the actual trajectory of the target passing through the minimum sensing cell with the measured trajectory, it can be determined whether the minimum sensing cell can accurately predict the target trajectory.

The remote control terminal written in C # language is used as the display platform. The collected sensor data are analyzed and processed to select the correct target information. The target trajectory is obtained and drawn by using the minimum sensing unit trajectory measurement method.

3.1 Experimental layout and method

The experiment adopts four rectangular minimum sensing cells with eight PIR sensors, as shown in Fig. 5. Nos. 1—4 in the left image represent the four sensing platforms, and the right image represents the distribution of 8-channel sensors on the single sensing platform.

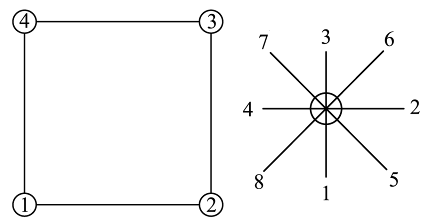


Fig. 5 Sensing platform layout and sensor distribution

In the experiment, human body is selected as the infrared target. The trajectory equations are $y=12$ and $y = 0.4x + 6$. The sensor information is collected, and the trajectory equation of the target mode is calculated. Compared with the real trajectory equation of the target, it can be verified that the minimum sensing cell measurement technology in network domain can accurately predict the trajectory equation of the target.

3.2 Experimental data and results

The data record of experimental acquisition mode 1 is shown in Table 1.

According to the infrared data collected in mode 1, the predicted trajectory can be calculated by using the minimum sensing cell measurement technology in the network domain.

It can be predicted that the target trajectory equation is $y=0.346x+6.346$.

Table 1 Data acquisition recording of mode 1

Sensor No.	Sensing platform No.	Time (ms)
4	1	11 827 590
4	1	11 831 381
3	1	11 841 848
8	4	11 856 216
5	3	11 860 303
5	3	11 864 110
1	3	11 876 605
8	3	11 882 081
2	3	11 891 878
2	3	11 900 817
8	3	11 907 509

The data record of experimental acquisition mode 2 is shown in Table 2.

According to the infrared data collected in mode 2, the predicted trajectory can be calculated by using the minimum sensing cell measurement technology in the network domain.

It can be predicted that the target trajectory equation is $y=0.024x+11.34$.

Table 2 Data acquisition recording of mode 2

Sensor No.	Sensing platform No.	Time (ms)
5	4	1 719 380
5	4	1 723 155
1	4	1 726 931
6	2	1 732 937
8	4	1 733 280
6	2	1 736 993
5	3	1 746 727
3	2	1 754 262
8	3	1 760 954
7	2	1 772 420
7	2	1 776 055

The real trajectory equations of the two modes are compared with the predicted trajectory equation, as shown in Fig. 6. It can be seen that the maximum error between real trajectory and predicted trajectory is 0.64 m. When the target passes through multiple minimum sensing cells in the domain, the error between the measurement target trajectory and the real trajectory can be corrected continuously, and more accurate target perception and trajectory prediction can be realized.

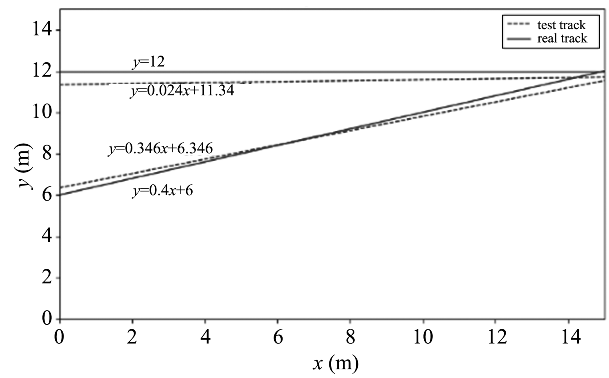


Fig. 6 Comparison between target test track and real track

4 Conclusion

In view of the network domain sensing of PIR sensors, the minimum sensing cell measurement technology in network domain was studied, and the measurement method based on PIR sensor array was designed. A closed sensing network domain composed of eight static PIR sensors arrays was proposed. Infrared target sensing and measurement using the minimum sensing unit measurement technology in network domain can not only guarantee the target sensing efficiency, but also solve the problem that dynamic use of PIR sensors which is vulnerable to small environmental changes. The experimental results demonstrate that the minimum sensing cell measurement technology can accurately perceive the infrared target and predict the trajectory of the target passing through the perceptual region at a uniform speed, and the maximum error between the real trajectory and the predicted trajectory is below 4.2%.

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基于 PIR 传感器阵列的网域最小感知单元测量技术

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摘　要： 为研究红外热释电(Pyroelectric infrared，PIR)传感器在网域测量中对红外目标感知问题，提出利用 8 路红外热释电传感器阵列组成封闭的感知网域，探究网域最小感知单元测量方法，完成对运动目标的感知和轨迹预测，并设计实验验证该测量方法的可行性和准确性。实验结果表明，网域最小感知单元测量方法的预测轨迹和真实轨迹间的最大误差为 0.64 m，可以完成红外目标感知及运动轨迹预测。

关键词： 红外热释电传感器；最小感知单元；轨迹预测

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