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A novel low-cost and small-size human tracking system with pyroelectric infrared sensor mesh network

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HIGHLIGHTS

- A low-cost and small-size human tracking system is proposed based on PIRs and WSN.
- We propose a human location method based on detecting angle bisectors of PIRs.
- Human localization relies on the layout of PIRs and sensor nodes.
- Distributed computing in a wireless mesh sensor network is designed.
- Simulation and experiment have yielded promising results for human tracking.

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ABSTRACT

This paper presents a low-cost and small-size human tracking system based on pyroelectric infrared (PIR) sensor mesh network. A wireless pyroelectric sensor network is developed using PIRs and PIR cone optics. The layout of PIRs and sensor nodes are well investigated and the real detection range of PIR is analyzed. A simple and effective PIR signal processing method is designed to get the event signal, and an innovative location method based on detecting angle bisectors of PIRs and data fusion is proposed. An improved Kalman filter and a particle filter are used for human tracking respectively. Simulation and Experimental results have shown that the human tracking system can effectively recognize, locate and track a human target with promising accuracy.

1. Introduction

Wireless Sensor Network (WSN) is widely applied in target location and target tracking due to its large scale, small size, low cost, high density and strong network dynamic performance [1,2]. Pyroelectric infrared (PIR) technology is capable of detecting the human motion by sensing their thermal radiation, therefore, infrared sensor is very suitable for an untagged human tracking system. A human tracking system based on WSN and infrared technology has attracted much attention and could be a low-cost, low-data-throughput alternative to the expensive infrared video sensors in surveillance applications.

The information extracted from infrared detectors was limited, so it was difficult to locate the target precisely. It was once considered that infrared sensors could not be used for human target tracking.

Some literatures have demonstrated the application of infrared sensor network for target detection and intrusion detection. Zappi et al. introduced a novel approach to detect direction of movement and number of people passing in a hallway or through a gate using three PIR detectors [3], and they investigated the relationship between signal strength and target distance [4]. They achieved 100% correct detection of motion direction and 83.49–95.35% correct detection of distance intervals. Even there were some research on human recognition through a smart deployment of PIR sensors [5,6].

The current methods for target location mainly include the region partition and coding. Their location accuracy greatly depends on the distribution density of sensors. Byunghun et al. tested an indoor human location system [7]. Since its region partition is rough, the location accuracy is not high. They deployed 10 sensor nodes in a 9 m × 14.5 m room with the locating error between 0.27 m and 4.5 m in simulation, and the maximum error of experiment reached to 5.25 m.

Location accuracy affected by limited information of infrared sensors can be improved through a proper tracking algorithm. Considering limited storage and computation ability, and large and irregular noise of the infrared sensor caused by localization, a Kalman filter was used for target tracking by Hao et al. [8]. Yang et al. proposed a particle optimization algorithm for passive target

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tracking [9]. Current research on infrared sensor network for human tracking mainly focus on the simulation.

Human tracking can be extensively applied in surveillance, robotics, intelligent home and gait biometrics. This paper proposes a novel low-cost and small-size human tracking system based on a pyroelectric infrared sensor mesh network. It is organized as follows. Section 2 provides PIR sensor and its signal processing. Section 3 presents the hardware design of PIR sensor wireless network system. In Section 4, we propose a target localization method based on detecting angle bisectors of PIRs and data fusion, and deployment analysis of sensor nodes for human localization is presented. Section 5 provides the simulation results of human tracking with some modified tracking algorithm. The experiment results are described in Section 6. Section 7 contains some conclusions.

2. PIR sensor and its signal processing

2.1. PIR sensor and its cone optic

An infrared detector is mainly composed of a sensitive element and a filter glass made of pyroelectric materials with high thermoelectric coefficients. An novel infrared detector is used in our system. We select PIR C172 and PIR Cone Optics TR230 by KUBE as shown in Fig. 1(a). The Cone Optics TR230 is compact with a window opening of 11.5 mm × 4 mm and much smaller than conventional Fresnel lens design. Fig. 1(b) shows front view and top view of TR230 (left) and conventional Fresnel lens lets (right).

TR230 is about a quarter of the size of an usual Fresnel lens. Its price is low but slightly higher than the an usual Fresnel lens. But compared with the special designed PIR detector [8], the size and cost of TR230 are competitive.

2.2. Detecting characteristics of PIR sensor

KUBE integrated optics provides 90° field of view (FOV) and up to 12 m of detection zone (Fig. 2(a)), which will be determined by the sensitivity of target and environment. It performs like much larger Fresnel lenses, but its detection region has different spatial shape. The small and flat front opening does allow for an unobtrusive and vandal proof design. Also, environmental effects like air draft or lights are largely compensated. The detection region of an infrared sensor is divided into 12 dark and bright sectors, which is called boom, by TR230. The ideal output of single human target passing through the infrared sensor detection area is shown in Fig. 2(b). For comparison, the detection zone of a Fresnel lens is shown in Fig. 2(c) and can be viewed as part of a sphere. Therefore, the PIR sensor with TR230 is more easier to deploy on the ground.

2.3. Signal processing method of PIR sensor

Pyroelectric material is particularly sensitive to temperature. Besides the temperature, the signal amplitude of infrared sensors is still related to the target thermal radiation and the target distance, etc. The signal processing method in time domain is simple but its accuracy is low, while the piecewise processing in frequency domain has good accuracy but consumes computation resources. Hao et al. presents three signal processing methods for his special designed PIR detector with Fresnel lens: Kalman Filtering, Windows FFT and Bandpass Sine Filtering [8]. Since we use cone optics TR230 instead of Fresnel Lens, the signal features are

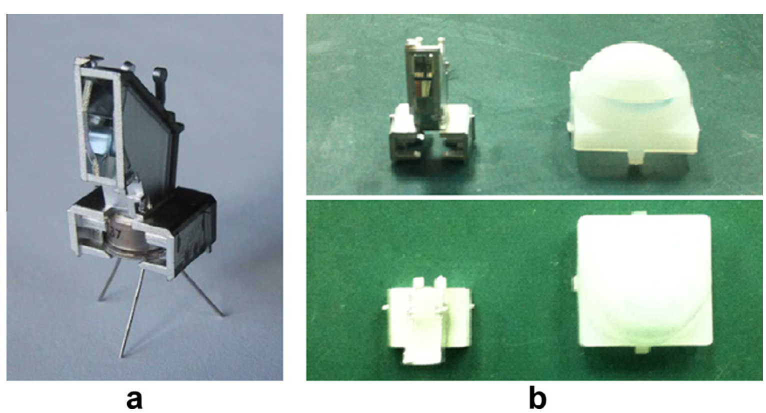

Fig. 1. (a) Infrared detector. (b) Comparison of TR230 cone optics and usual Fresnel lens.

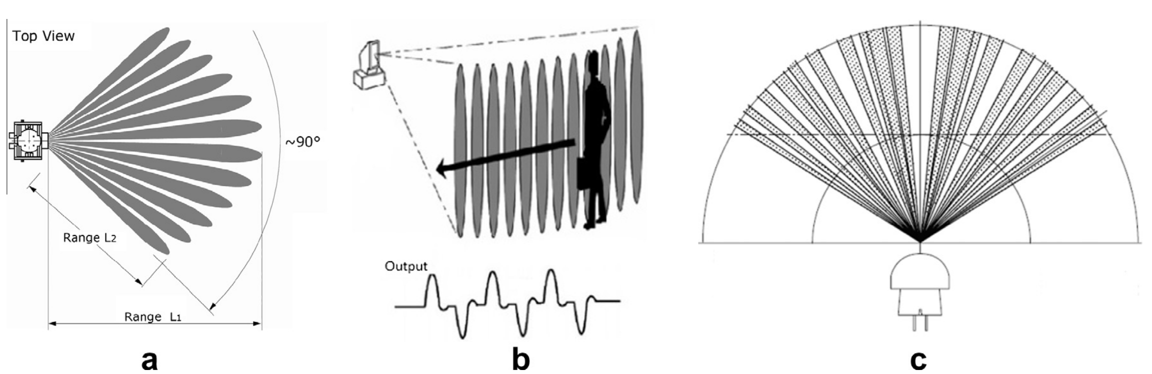

Fig. 2. (a) Detection zone of our infrared detector. (b) Human motion detection of our PIR detector. (c) Detection zone of an usual Fresnel lens.