Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.12785/amis/090546

A new Pyroelectric Sensor System for Target Detection and Recognition

Sun Qiao[1,2,*], *Yang Wei*[1,2] *and Zhang WenDong*[1,2]

[1] Science and Technology on Electronic Test, Measurement Laboratory, North University of China, Taiyuan, China
[2] Key Laboratory of instrumentation Science, Dynamic Measurement, North University of China, Taiyuan, China

Received: 13 Feb. 2015, Revised: 15 May 2015, Accepted: 16 May 2015
Published online: 1 Sep. 2015

Abstract: In this paper, a novel method using a dynamic pyroelectric infrared (PIR) sensor to detect and identification the moving target is presented. The sensor equipped with an infrared lens acts as an optical setup for this system, which is driven by a uniformly rotating device, a single detector can collect into infrared signals within a range of 360°. The method solves the problems that improving the (PIR) sensor's detection range will inevitably reduce the detection distance and increasing the detection distance will inevitably decrease the detection range. Experimental results show that (PIR) detector in regular running state can monitor a wide range of regions, and accurately determine the target orientation without decreasing the detection range. Using frame differential method can extract target information and using principal component analysis achieved the identification of target expand the use of pyroelectric sensor field.

Keywords: PIR sensor, dynamic, high sensitive, signal processing

1 Introduction

The average human frame radiates about 100W/m2 of power, peaking at 9.55um. The PIR sensor has a high detection capability for IR radiation and has been used for a wide range of applications [1] [2] [3]. The PIR detector used for this work is low cost, has low power consumption, and is sensitive in a range of 5-14um. The study about human tracking and identification using PIR sensor is still few, and the target detection range is less than 20 meters.

The research group of Duck university using PIR infrared detector and Fresnel lens group realized human identification and target tracking [4] [5] [6]. Yang Jing implemented an experimental system for monitoring the human walking and jumping actions [7]. A wavelet entropy of double-density dual-tree complex wavelet transform method for human identification was proposed by Wang Lin Hong *et al* of Chongqing University [8]. Optimization algorithm [9] [10] and mathematical models [11] [12] [13] are used for target tracking and trajectory planning. But their search coverage only a few meters and there are few reports on human tracking and human identification based on a wide range of areas.

With the breakthrough of the traditional way to use PIR sensor, the paper puts forward the method that dynamic use of PIR sensor is taken for target detection and target identification method. This method is to make the PIR sensor move with uniform motion under the drive of the turntable, collect signals by dynamic use of PIR sensor , use frame differential method to extract the target signals, and then use the principal component analysis (PCA) for different target signal analysis [14] [15]. This method can not only solve the contradiction of detection between the distance and the angle using PIR sensor (according to the characteristics of the optical devices, expanding the detection range will reduce the detection angle, and vice versa) but also achieve the goal of simple identification to the target.

2 Principle of dynamic PIR sensor detection and identification

2.1 the working principle of dynamic PIR sensor

Whatever exists in the nature of the objects will be infrared radiation but different object due to its different

* Corresponding author e-mail: josun1985@163.com

materials have different infrared wavelengths. Human bodies are very good IR sources. There is a constant heat exchange between the body and the environment due to the difference in their temperatures. Dual-element PIR detector produces the output only to the changes of infrared radiation. Thus in a stationary condition, there is no output for PIR sensor without an objective movement in its field of view (FOV) using PIR sensor. When PIR sensors are in a state of movement, the surrounding environment is constantly changing relatively, where thermal radiation produced by different objects will irradiate to the source element of the sensor in succession, as a result, the sensor will keep output electric signals. So normally PIR cannot be used under the dynamic state, however, through research and experimental verification, the background signals collected by dual PIR sensor under the condition of pictured motion can also be described. Under the same conditions, with periodicity movement of the PIR, its signal changes periodically. So if moving objects are into the sensor detection area in the above conditions, target signals can be extracted from the background signal. The research proves that PIR sensor can be used in regular dynamic conditions.

2.2 target recognition principle

Principal component analysis (PCA) is widely used technique for data analysis and dimension reduction with numerous applications in science and engineering. In essence, PCA aims at finding a few linear combinations of the original variables, called principal components (PCs), which point in orthogonal directions capturing as much of the variance of the variables as possible. Analysts can therefore visualize the original high-dimensional observations on a lower-dimensional picture from the most informative viewpoint.

$$\begin{cases} Y_1 = R_{11}x_1 + R_{12}x_2 + \ldots + R_{1k}x_k \\ Y_2 = R_{21}x_1 + R_{22}x_2 + \ldots + R_{2k}x_k \\ \quad \ldots \\ Y_n = R_{n1}x_1 + R_{n2}x_2 + \ldots + R_{nk}x_k \end{cases} \tag{1}$$

The aim of PCA is to find a new set of variables, say $Y_1, Y_2, \ldots, Y_n$ in a form of a linear combination of $x's$ which is $Y = R^T X$. Here, $Y = (Y_1, Y_2, \ldots, Y_n)$ is a vector of principal components and R^T is a matrix of coefficients R_{ij} for $i, j = 1, 2, \ldots, k$ is then given by:

$$\begin{cases} Y_1 = R_{11}x_1 + R_{12}x_2 + \ldots + R_{1k}x_k \\ Y_2 = R_{21}x_1 + R_{22}x_2 + \ldots + R_{2k}x_k \\ \quad \ldots \\ Y_n = R_{n1}x_1 + R_{n2}x_2 + \ldots + R_{nk}x_k \end{cases} \tag{2}$$

Usually we take the first k principal components accounted for 85% because they already represent most of the information.

3 Experiment system setup

3.1 overall design

Experiment system is composed of optic module, sensor module, power module, signals acquisition module and signal processing module as shown in figure 1. Here we use murata manufacturing's IRA-E900 PIR sensor and use infrared lens as it's optical equipment. The module of data processing is used for amplifying the original gathered signal and dealing with noise then send to signal processing module for next step analysis after AD transform. One base station has 4 PIR sensors driven by a oscillating step motor which is oscillating in the range of $0° - 90°$. as shown in figure 2.

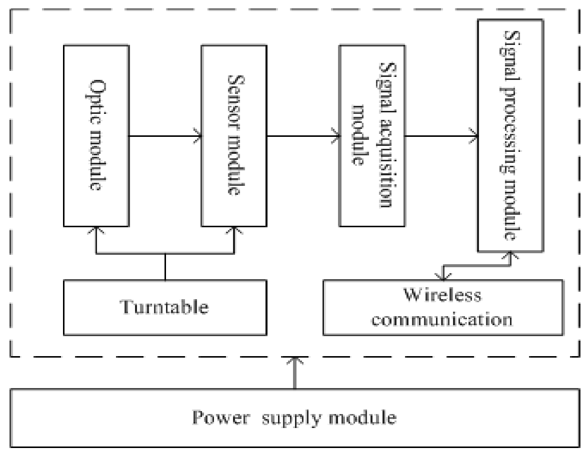

Fig. 1: Dynamic PIR sensor data acquisition system diagam.

3.2 optical system

The most common optical device used with PIR sensor is Fresnel lens which mainly had two aspects functions: on the one hand is increasing the detection range through with focused the infrared radiation energy on the PIR sensor, on the other hand is to modulate the visibility. But it's detection distance is less than 20 meters.

In this work, we used infrared germanium lens as the optical device, germanium is an excellent material for near-IR which average transmittance of the infrared is over 99%. The detection distance can be more than 50 meters when use infrared lens as the optical device and it can make different sizes for indoor different requirement and it mounts very convenience.

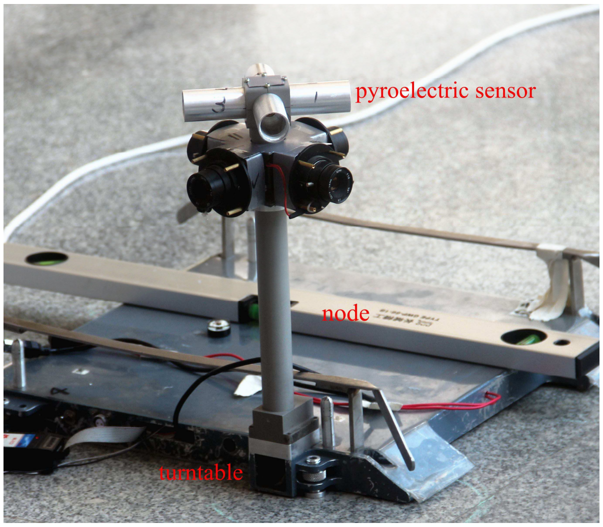

Fig. 2: The diagram of physical experiment system diagram.

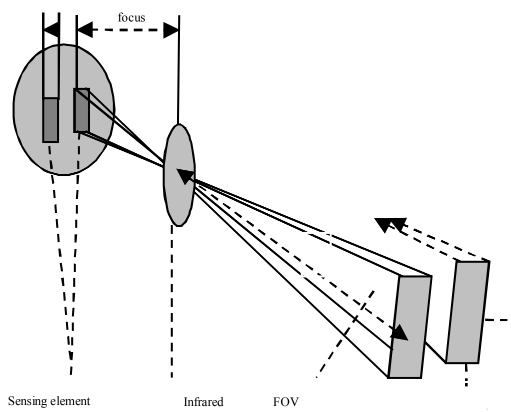

Fig. 3: Focusing principle diagram of infrared lens.

The infrared lens with a 40mm focal length we used in this work as shown in figure 3, so we can calculate the detection region of the PIR sensor.

The focal length is 40mm, so the width of the detection region is:

$$W = \frac{D}{f} = \frac{D}{40} \tag{3}$$

So the height H of the detection region is:

$$W = \frac{2D}{f} = \frac{D}{20} \tag{4}$$

And the area S of the detection region denoted as:

$$S = H * W = \frac{D^2}{800} \tag{5}$$

4 Experimental

The experimental verification of the theoretical model was examined by the fabrication of a prototype device whose photograph is presented in Fig.2. The dynamic PIR signal was collected that the infrared energy of background is homogeneous in different area. The figure 4(a) shows the signal without target and figure 4(b) shows the signal with a target in it. The result shows that the output of the dynamic PIR sensor is nearly a straight line when the infrared energy of background is homogeneous in different area. The waveform of the dynamic PIR sensor signal changes when the target walked through the detection area. Use the PIR sensor dynamically greatly increase the sensitivity of the PIR sensor that even the static target in the detection area can be detected accurately.

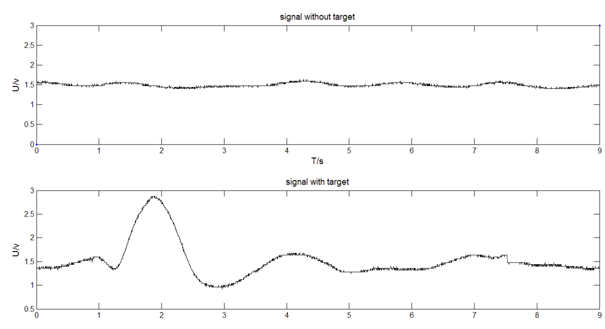

Fig. 4: PIR signal without background (a) signal without target (b) signal with target.

The figure 5 shows the dynamic PIR signal that the infrared energy of background is inhomogeneous. The figure 5(a) shows the signal of the background and figure 5(b) shows the signal of the background with a target in it. The result shows that when PIR sensors are in a state of movement, the surrounding environment is constantly changing relatively, where thermal radiation produced by different objects will irradiate to the source element of the sensor in succession, as a result, the sensor will keep output electric signals. But the wave form is periodically repeating with periodicity movement of PIR sensor and this rule will be break when the target walked through the detection area which caused the change of infrared energy.

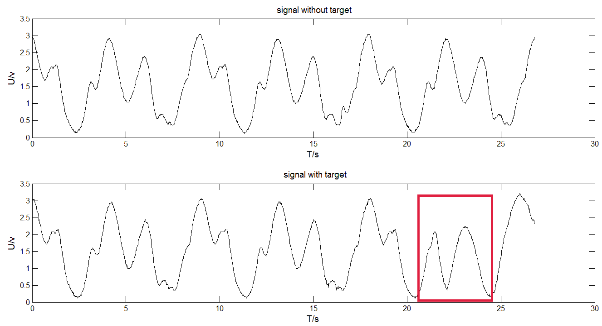

Fig. 5: PIR signal waveform with complicated background (a) signal without target (b) signal with target.

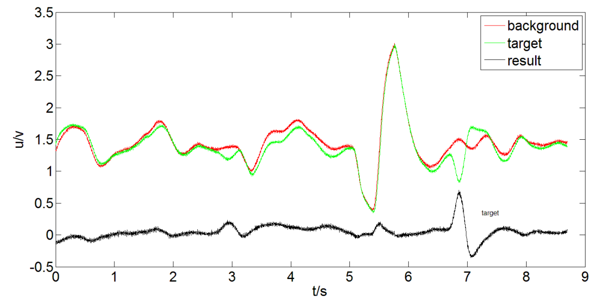

Fig. 7: Area Chart of the difference result with target in detection regions.

The most simple and effective method to process the signal of dynamic PIR sensor is the frame difference method which commonly used in image processing. Frame difference method is the most direct method to examine movement information form video sequences, which calculates difference between former frame and back frame by comparing point-by-point grey value. The signal of one cycle PIR sensor movement can be seen as a frame image and calculate amplitude of two contiguous periods. The infrared energy of background is relative stable in the short time and appears no signification changes between two contiguous periods so that the amplitudes is always less than the threshold when two signals are subtracted. Some clear differences will show between two contiguous periods when the target through the detection area and the target signal can obtained by the information of the subtraction of two consecutive signals.

Fig. 8: The experimental scene.

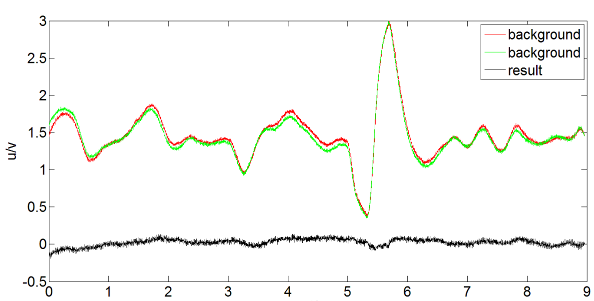

Fig. 6: Area chart of the difference result without target in detection regions.

As shown in figure 6 and figure 7, the red line and the green line represent the signals of two contiguous periods. The black line shows the result of subtraction of two consecutive signals. As seen in figure 6, the result of difference of consecutive signals is nearly zero when no target entered the detection area shows that processing the signal of dynamic PIR sensor by using frame differential method can eliminate disturbing background. The solution of PIR sensor can't be used under dynamic is given out by this method. The result in figure 7 shows that the target can be obtained after difference of consecutive signals and the direction of target can also be obtained through the location of target waveform.

The relative speed of target and PIR sensor is an important impact factor for signal collected of dynamic PIR sensor so studying the relative speed has important practical significance for further practical application of dynamic PIR sensor.

Figure 8 shows the experimental scene. The sensory data is collect when the target walked back and forth along a prescribed straight path, different meters away from and perpendicular to the static PIR sensor. And we also collected the data of the target (male, 172cm in height and 66kg in weight) on the 45°line, 10m, 20m, 30m, 40m away from the dynamic sensor which was oscillated with the speed of $5^\circ/s$, $10^\circ/s$, $15^\circ/s$, $20^\circ/s$, $25^\circ/s$. As show in figure 9, the X-axis is the target distance form PIR sensor, the Y-axis is the amplitude of waveform and the Z-axis represent the speed of the dynamic PIR sensor.

The detection distance can be more than 50 meters when the PIR sensor is used static and the detection distance is reduced to 40m when the PIR sensor oscillated with the speed of $10^\circ/s$. This value will reduced to less than 20m when the PIR sensor oscillated with the speed of $25^\circ/s$.

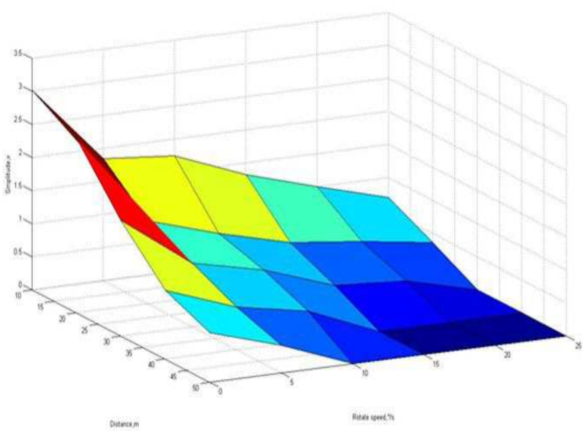

Fig. 9: the relationship between detection range and revolving speed.

by PIR sensor so the target will be missing. So, the speed of sensor need to selected according to the actual requirement.

For the path-dependent recognition problem, the sensory data is collect while three different persons walked back and forth along a prescribed straight path, 15m ways from and perpendicular to the sensor. The identification procedure consists of two parts: extracting and analysis. During extracting, we used frame difference method extracting the target signal from all 90 data clustered. Then the main target signals can get by reducing its dimensions through matrix component analyzed. The result is shown in fig.9, the three principal components explained more than 90% of the total variance. The load points of first three principal components distribution map is drawn which can showed the relationship between them intuitively. Figure 11 shows the data distribution in the system, composed of principal component. As can be seen from the graph, using principal component analysis can separated different target signals which collected by using dynamic PIR sensor.

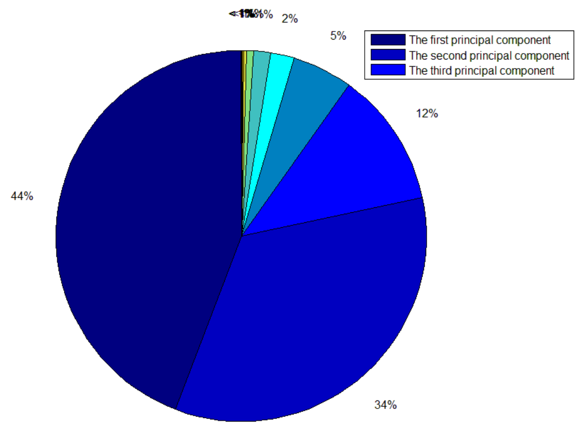

Fig. 10: Principal component distribution scale map.

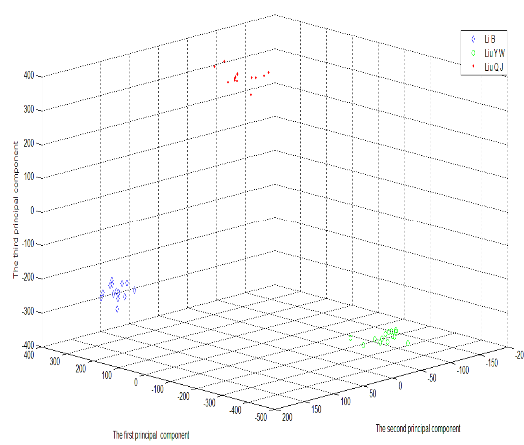

Fig. 11: 3D data plot in the coordinate space formed from first three principal components.

5 Conclusion

In this paper, we present real-time, low cost, low power consumption and large detecting area, PIR sensor systems for walker detection and recognition. Use the PIR sensor dynamic can not only solve the contradiction between the distance and the angle but also achieve the goal of simple identification. The result of experiment validate that using frame difference method can extracting the target signal from dynamic PIR sensor signal and using principal component analysis can achieve different personnel recognition.

Our future work will include better selection of features and algorithms for the open-set, less cloth sensitive human identification and simultaneous multiple people recognition by using dynamic PIR sensor.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (Grant N60871041o) and National High Technology Research and Development Program of China (863Program)(Grant No.011AA040404).

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Sun Qiao is currently working toward the Ph.D. degree at north university of China. Her research interests include wireless sensor systems for human tracking and identification.

Yang Wei received the B.E. degree from North university of China in 1982. He is a senior engineer working in north university of China. His research interests include wireless sensor systems and MEMS.

Zhang Wendong received the Ph.D. degree from Beijing institute of technology university in 1995 and his B.E. and M.E. degrees from North university of China in 1982 and 1986. He worked in the mobile postdoctoral stations in Tsinghua university from 1996 to 1998. His research interests include dynamic testing technology and MEMS. He is a senior member of IEEE.