www.s2is.org
International Journal on Smart Sensing and Intelligent Systems
ISSN 1178-5608

Target Classification Using Pyroelectric Infrared Sensors in Unattended Wild Ground Environment

Dongfeng Xie, Huawei Liu*, Baoqing Li, Qianwei Zhou and Xiaobing Yuan
Wireless Sensor Network Laboratory
Shanghai Institute of Microsystem and Information Technology
865 Chang Ning Road, Shanghai, 200050, China
Email: dfhsie@gmail.com

Submitted: Sep. 5, 2013 ***Accepted: Nov. 17, 2013*** ***Published: Dec. 16, 2013***

Abstract- Pyroelectric Infrared (PIR) sensors are widely used as a simple presence trigger for alarms and a reliable counter for people in security home and smart office. Most paper have focused on the design and application of such systems, however, few research has be done on the detecting of targets in an outdoor environment using PIR sensors. In this paper, we realize a detecting system by means of PIR nodes to monitor outdoor targets more than 20 meters away from the PIR detectors. Furthermore, because of velocity difference, by extracting time domain amplitude, signal length, maximum frequency and corresponding frequency amplitude as features, we successfully classify people, wheeled vehicle and tracked vehicle in the unattended wild ground environment. Our detecting and classifying results confirm the average accuracy is 85.67% and 82.67% when PIR detectors are deployed 20 meters and 30 meters away from the area of interest (AoI), respectively.

Index terms*:* Target Classification, Pyroelectric Infrared, Wheeled Vehicle, Tracked Vehicle, Support Vector Machine.

I. INTRODUCTION

Pyroelectric Infrared (PIR) sensors are made of pyroelectric materials which can produce an electric potential by means of a very small change in temperature. The heat variation of a human or animal from several feet away is enough to generate a difference in charge. Hence, PIR sensors are quite fit for detecting moving targets.

PIR sensors are largely accepted in indoor security systems for its low-cost, low-power, reliable performance and convenient operation. Beyond these characteristics, it provides accurate information for target presence and even the number of targets. Nowadays, many security systems have made PIR sensors to be a good alarm of intrusion [1] and a precise counter for targets who are not only people [2] but also vehicles [3, 4] and so on. However, previous works mostly concentrate on detecting while we use PIR sensors to classify targets after detecting. Moreover, our PIR nodes are not deployed in an indoor environment where the detecting range is confined in several meters. They are used to detect targets more than 20 meters away in an unattended wild ground environment.

In this paper, we design a detecting system to monitor a specific wild district using PIR sensors. Targets such as people, wheeled vehicle and tracked vehicle from more than 20 meters away are to be detected and classified by means of PIR nodes. Simulation results show that the accuracy is satisfied and thus proved that PIR nodes can be used in an outdoor environment such as state border and battlefield.

The rest of the paper is organized as follows. In Section III, we introduce the structure of PIR detectors and nodes. Our method for detecting, counting and classifying is presented in Section IV and V. Finally, we give the experimental results and conclude the paper in Section VI and VII.

II. RELATED WORKS

PIR detectors are widely used in people presence detecting systems. In [2], PIR detectors instead of camera sensors are installed over the stairs in the building to count the passersby. By using pattern recognition methods, the detecting accuracy of moving direction can be 99% and the number of passersby is 95%. Paper [1] describes a simple intruder detection system based on PIR sensors which are installed on the wall of a protected room. Entering into this monitored area will cause the processor to produce an alarm signal and send it to the control center. Zappi.etc in [5] proposed a novel configuration and use of PIR sensors. They use three detectors located along a wall of a hallway to extract people's movement features with 100% correct of direction recognition and 89% accuracy of people counter. As the research of PIR sensors goes deeply, more attentions are focused on target localization and tracking application. For example, the author in [6] proposed a smart system by deploying an array of PIR sensors on the ceiling of a room to locate a moving resident and at the same time record the trajectory. Furthermore, they developed a resident location-recognition algorithm using a Bayesian classifier to increase the accuracy [7]. Similarly, four sensor modules, each consisted of five PIR detectors, are mounted on the ceiling of a monitor field to fix the position of a moving human target [8]. In addition, Kalman filter is adopted to improve the tracking accuracy. To achieve higher accuracy, reference [9] combines PIR monitoring system with RF localization module to get the target position at a mean square error of less than 1m. Paper [20] proposes an infrared object localization and tracking system using wireless pyroelectric sensor netwroks. In recent years, more work concerned with recognition and classification utilizing PIR sensors has been done. For example, a wireless pyroelectric sensor system is presented to recognize different walkers' gait features [10]. Kaushik and Branko [11] have investigated the characteristics and spatial sensitivity of PIR detector through experiments. Finding that the detector output has an evident relationship with the velocity and vertical distance of movements, they pointed out that a PIR system can be used to monitor the occupancy pattern of elderly people. In [12], 40 infrared sensors are installed at doors, gateways of the laboratory to extract individual human behaviors from long-term data. Paper [13, 14] has developed a PIR system to classify target distance from sensors into three groups: close, middle and far by extracting signal output amplitude and duration as features. Classifiers including Naive Bayes, Support Vector Machines and k-Nearest Neighbor (k-NN) are applied on those features to achieve a correct ratio ranging from 83.49% to 95.35%.

These applications mentioned above [1, 2, 5-14] have illustrated how the research with regard to PIR goes deeply. However, all of these systems have placed PIR detector in an indoor environment less than 10m×10m. Thus it limits PIR sensors to be deployed at a hall or in a room where a certain security and smart system is constructed. But the detecting range of a PIR detector can be up to more than 20m, which makes it possible to be used at a highway intersection or a distant wild path. Hence, we creatively use PIR detectors in an outdoor environment to extend their scope. On the other hand, the literature demonstrates that PIR sensors are able to extract kinds of features and accordingly to distinguish people's behavior, gait, position, distance and etc. However, PIR sensors are not patent for human detection but also other targets such as vehicles [3, 4]. Therefore it is natural to use PIR sensors to detect multi-target and classify them. For instance, they can be used to classify military vehicles instead of acoustic sensors that are sensitive to wind noise [15].

In this paper, a novel application is proposed that PIR detectors are utilized to classify individuals, wheeled vehicles and tracked vehicles more than 20 meters away in a wild environment. Through our analysis and experimental results, it is proved that targets such as vehicles can also be detected and counted. Besides, these three targets are able to be classified to some extent.

III. PIR DETECTORS AND NODES

Pyroelectricity is the ability of certain materials to generate a temporary voltage when they are heated or cooled [16]. When a pyroelectric element senses an incident IR flux, it first converts the radiation flux change into a temperature change and then performs a thermal change to be a temporary voltage. Generally a window equipped with a light filter is set on the top of the pyroelectric sensor to filter infrared light of specific wavelength. Thus only human IR radiation is absorbed if the light filter constrains the passing wavelengths to be human body infrared wavelength region. This kind of sensor is specially designed to detect people presence.

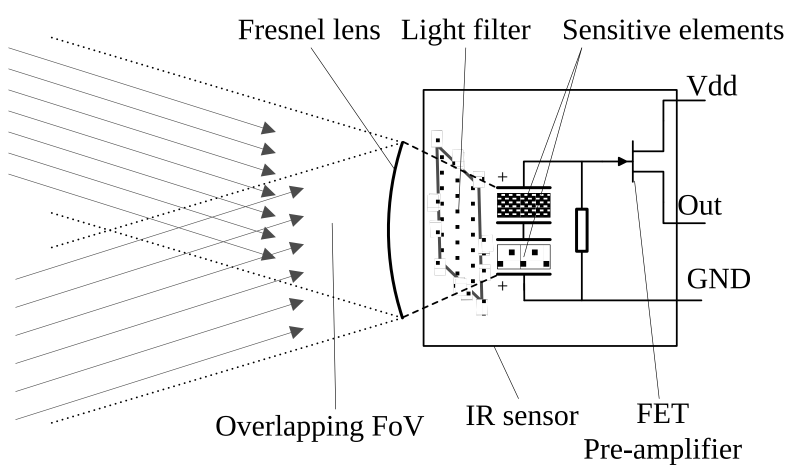

Figure 1. The structure of a PIR detector

In order to improve the sensitivity and detecting distance, a Fresnel lens is often equipped before the sensitive element. Fresnel lenses are able to enhance the energy amplitude by dividing the field of view (FoV) of PIR sensor into several sections which are blind zones and high-sensitive zones in turn. By using Fresnel lenses and amplifier, an incident change in IR radiation is able to be enlarged. Hence, a well-designed PIR detecting system can sense the movement of a person who is 20 meters away even 30 meters away.

A PIR detector is usually made up of Fresnel lenses and a PIR sensor as illustrated in Figure 1. When a person walks across the FoV, the detector will response the presence immediately and produce a mutative signal on Out. This tiny variation is plenty amplified to facilitate processing by a PIR node which is described in detail next. In our system, the PIR detector only uses a single Fresnel lens, thus making the output signal very easy to process.

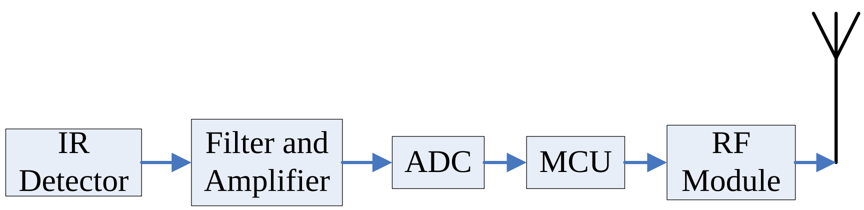

Figure 2. The block diagram of PIR nodes

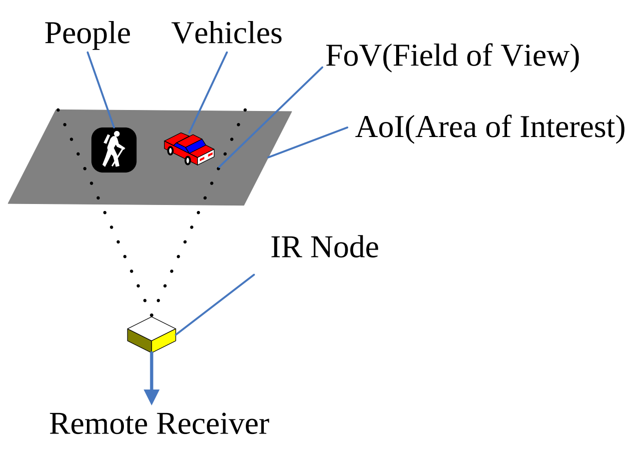

Figure 3. Detecting system using IR nodes

Figure 2 gives out the block diagram of PIR nodes. As we can see, a PIR node is mainly made up of a PIR detector, a signal processing unit and a communication unit. The PIR detector belongs to the class of passive sensor being low-power but reliable. The signal processing part consisting of a filtering and amplifying module, an ADC module and a microcontroller module is the most complicated. In order to reduce power consumption, we can choose low-power devices such as Texas Instruments' ultralow-power microcontroller MSP430 series whose current is only 1.2uA when in standby mode [17]. However, low-power microcontroller is often at the price of low computational complexity and little memory space. Hence, it is not appropriate to use too complex algorithm on such processor. In later section we will present how to deal with the PIR signal as simple as we can. The communication unit includes a RF module and an antenna. In most cases, wireless transmitting and receiving is rather energy-consuming compared to a microprocessor. Usually there is a compromise between signal processing and wireless communication because more signal processing such as aggregation and fusion will get a simple result which requires less communication burden, and vice versa. In our system most of the signal analytic task is placed on the node locally as the wireless module needs relatively high transmit power to support a far transmission distance to the remote receiver. Considering the excellent performance of microcontroller, it is rational and worthwhile to make processor more hardworking.

Figure 3 demonstrates how we use IR nodes to detect an area of interest. PIR nodes are placed tens of meters away from the AOI. When targets such as people and vehicles enter into the FoV of a specific PIR node, the microcontroller processes the detector output to judge the direction and furthermore extract several target features. Then the controller sends targets' information including direction, number and feature vector to the remote receiver through wireless module. The remote receiver will classify the targets respectively according to each feature vector. If necessary, the results will report to the user to help make a decision. During this process, the detecting algorithm and classifying ability are the most critical, as will be discussed next.

IV. DETECTING ALGORITHM

A PIR detector with a single Fresnel lens and a sensor of two inverse sensitive elements produces an output as shown in Figure 4 while a person moves through the detector and turns back. Generally speaking, this is a typical output signal for all kinds of targets. Since a target enters into the FoV, the dual sensitive elements with opposite polarity response the change one after another, thereby producing a positive peak and a negative peak. We can easily process such a signal only in the time domain and achieve a reliable detecting result. As described in Figure 4, the output is divided into noise and useful signal by two amplitude thresholds. The former is completely located between the positive threshold Ap and the negative threshold An while the latter starts when one of the thresholds is crossed and ends when another threshold is crossed followed a stable period. This duration is called settle down time T that indicates the ending of last target and enables the following detection. It is clearly stated in paper [14] that there is a tradeoff between amplitude threshold and settle down time threshold. A high amplitude threshold may cause a potential distant target incapable of being detected. However, a low threshold brings a longer settle down time which makes two close targets unable to be distinguished. Hence, proper thresholds and settle down time are always determined by concrete applications. In our tests, by computing the mean value of noise, denoted as Am, we fix the threshold Ap and An to be $Am \pm 400$, respectively. Meanwhile, T is chosen to be 0.8 sec.

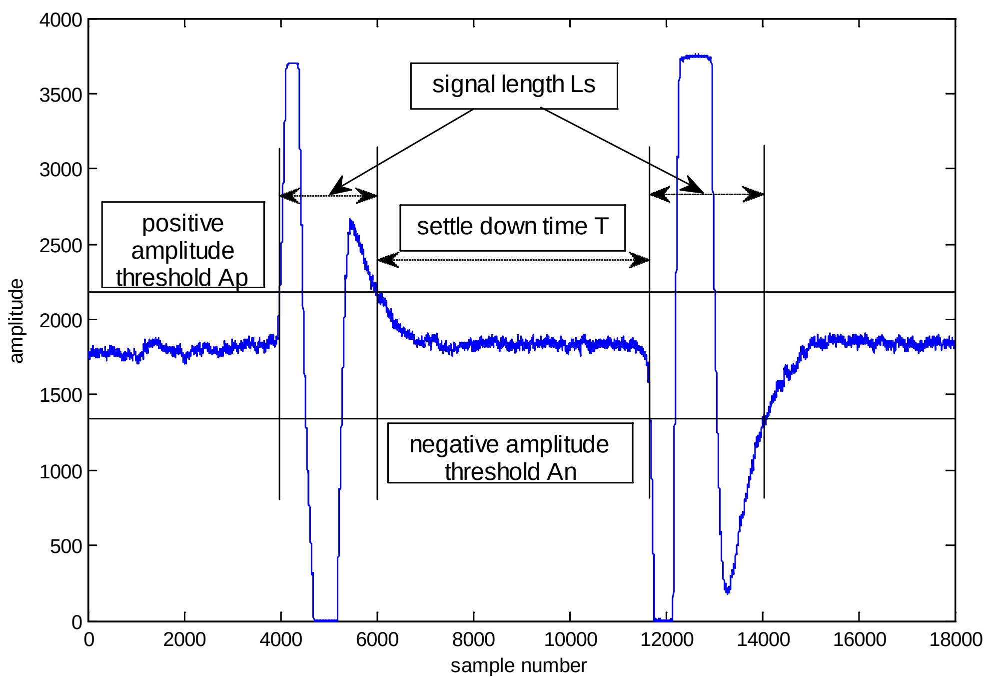

Figure 4. PIR output and detecting algorithm

It is easily discovered from Figure 4 that the two different peaks of a real signal represent the direction of a moving target. Reaching the positive threshold firstly indicates that the object is moving from one side to another. On the contrary, firstly grabbing the negative threshold means the object is moving in an opposite direction. This direction identification task is just a piece of cake for any microprocessor.

Based on our detecting algorithm as shown in Figure 4, two time domain features are extracted from a PIR signal. The first is the signal amplitude. Different targets have different temperature and radiation property, thus making the output amplitude variable. The second is the signal length. Due to different volumes and distances of targets, the output signals have different lengths of duration. In fact, paper [13, 14] has successfully chosen signal amplitude and length as features to classify targets' distance away from the sensor into three ranges. However, only these two features are not enough to classify different targets. In the next section, we will show how to classify different types of targets by combining the two time domain features with other frequency domain features.

V. TARGET CLASSIFICATION

In [11], it is found that the PIR detector output voltage is relational to the velocity of movements. These achievements reveal that the output of IR detectors does not only demonstrates the presence and direction of moving targets but also reflects certain targets' attribute information such as distance, category, velocity, etc. Previous works mostly concentrate on the former while this paper will discuss the latter thoroughly.

Although literature [11, 14] has carefully examined the output characteristics of IR signal in the time domain, it is just based on the empirical observation and test which lacks of strictly theoretical analysis. In fact, the IR output signal depends on such aspects [18]:

1) Distance of human body to the motion sensor
2) Walking speed of human body
3) Focal length and pattern design of the optical system

Here, we can replace human body with other targets if an appropriate light filter system is designed to let other targets' IR radiation absorb. Once the Fresnel lens is determined, the optical system is then fixed and has negligible influence on the output of different targets. Hence, the distance and speed are the major factors to decide the output. Specifically, these two mainly change the signal amplitude defined by the difference between positive and negative peaks and the signal length being the time interval between entry point and end point (see Figure 4). Thus in paper [14], the author chooses signal amplitude and length as features to distinguish different distances for a fixed speed target. However, it is incapable of classifying various types of target at different speed within different distance. To solve this problem, we have to take frequency information of IR output into consideration.

Paper [18] points out that a very good rule of thumb can be the use of the formula below for the relation between velocity, focus and frequency:

$$f = \frac{v_b * f_b}{2\pi * s * L} \tag{1}$$

where f_b equals focal length (mm) while f means frequency of output signal (Hz). The parameters v_b and s are the moving speed (m/s) and size of sensing element (mm), respectively. L denotes target distance from the sensor (m).

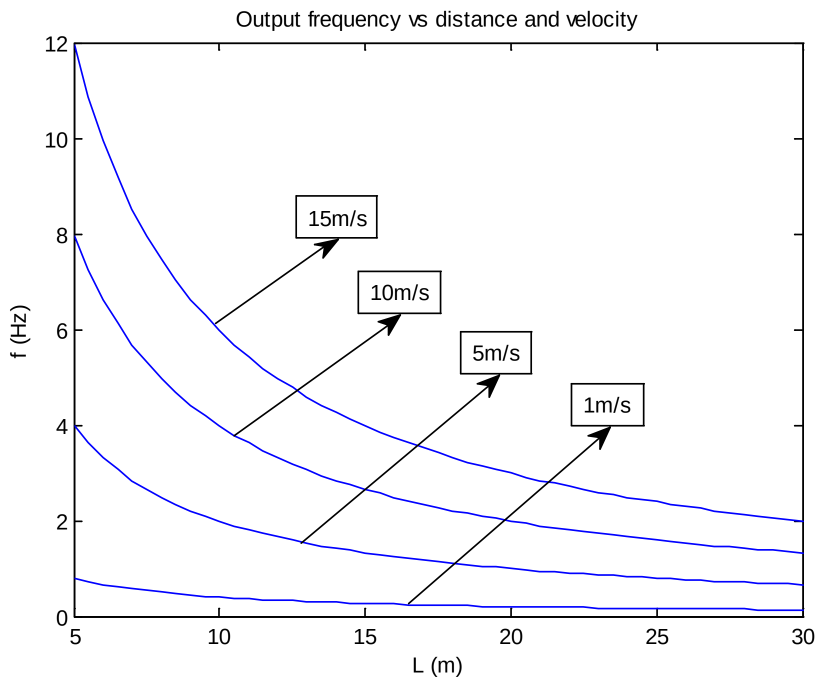

Figure 5. Output frequency as a function of distance L and velocity v_b

For a specific practical detecting system, f_b and s are constants. Therefore, f is decided by v_b and L. Figure 5 gives out an intuitive explanation for the relationship between output frequency, velocity and distance. Here we choose f_b = 25mm and s = 1mm. It can be seen that the output frequency is a function of velocity and distance. Either of them is constant, the output is changing followed the other. As stated in last paragraph, target distance can be distinguished by time domain features. Hence, from the point of principle, targets with different speed and different distance can be classified depending on the output frequency. However, in our application, the detecting range is fixed once the detector is installed. Thus velocity difference of targets is a sole proof to recognize targets. If the output frequency differs from each other, then the velocity representing different targets is also different.

Figure 6 illustrates a map of output signal and the corresponding frequency. Figure 6(c) is the frequency output of the signal in Figure 6(a) when a person being 20 meters away walks and runs across the sensor at a speed of 1m/s and 2m/s, respectively. It indeed shows that fast movements result in high frequency output. At the same time, the signal length of walking is longer than that of running as shown in Figure 6(a). This is because slower movements would bring longer existing time in the fixed FoV of the sensor at a fixed distance. It can also be seen from Figure 6(b) that different velocity leads to unequal signal duration. Figure 6(d) is the amplitude-spectrum of Figure 6(b). From this figure, we conclude that wheeled vehicles have the highest main frequency component while people have the lowest main frequency component due to different moving speed. In fact, we sampled the signal in Figure 6(b) at 30meters away at 1m/s, 8m/s and 10m/s for people, tracked vehicle and wheeled vehicle respectively. In general, using frequency information to recognize targets with different speed is feasible.

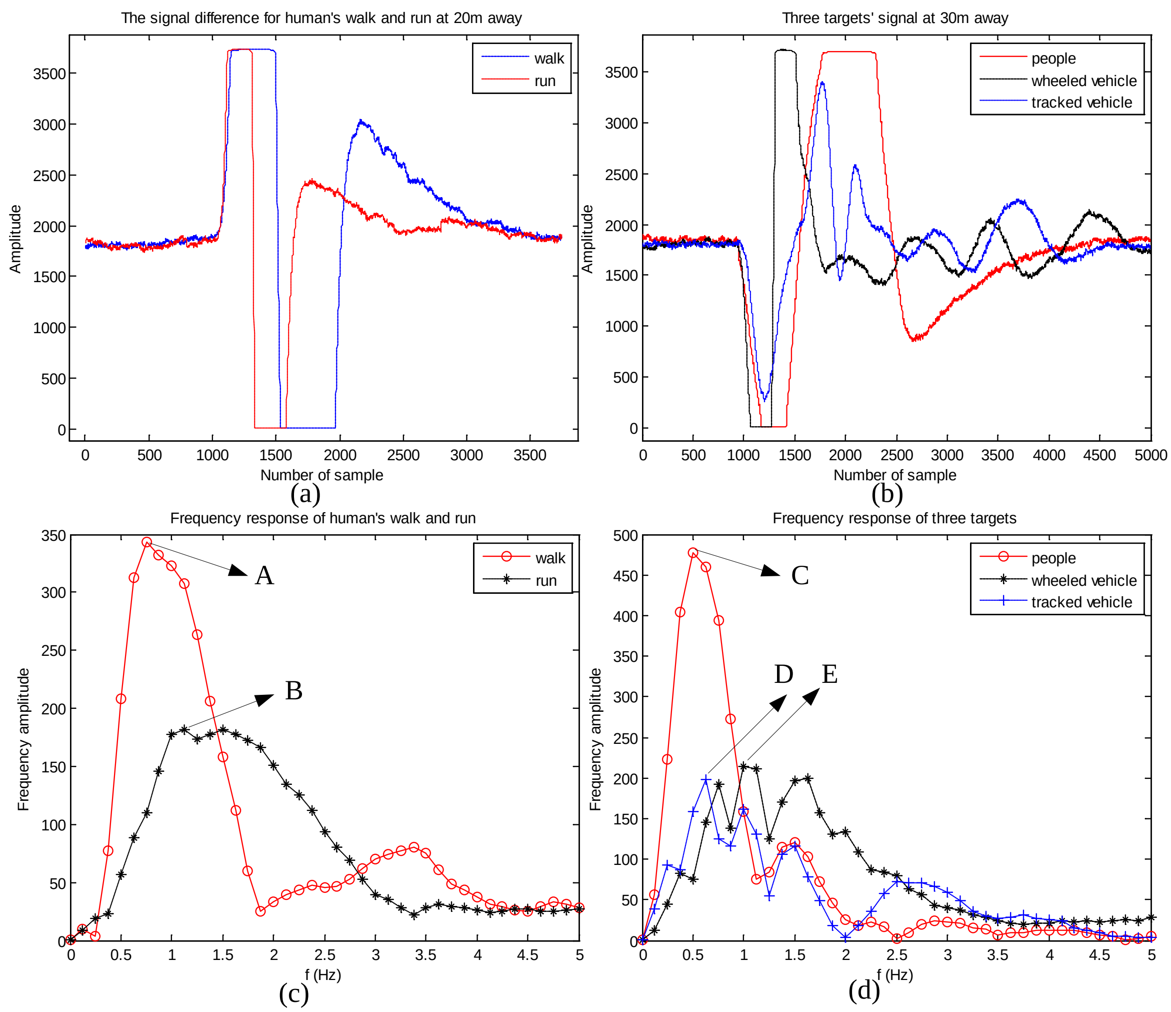

Figure 6. Output signal and frequency

Based on the above analysis, we extract two frequency domain features: main frequency component and its corresponding amplitude. As shown in Figure 3(c,d), A, B, C, D and E are the extracted feature points. In order to classify human and vehicles, time domain features have to be used to distinguish distances. In addition, frequency domain features must be extracted to recognize different moving speeds of human and vehicles. Therefore, frequency domain features and time domain features are combined to form a feature vector as follows:

$$V = \left[S_{amp} \quad L_s \quad F_{\max amp} \quad f \right] \tag{2}$$

where S_{amp} means signal output amplitude and L_s is signal length. $F_{\max amp}$ and f represent maximum amplitude of frequency and main frequency ingredient. Using this 4-D vector, it is capable of recognizing different targets at different speeds. Next section will prove the feasibility and success of our target classification method.

VI. TEST AND SIMULATION RESULTS

We have realized a PIR detecting system to verify our analysis. Figure 7(a) is the chosen dual element detector LHi 968(A product of PerkinElmer Optoelectronics). Figure 7(b) is the prototype of our PIR node. As previously mentioned, TI MSP430F5438A is used as our main microcontroller and processor. Apart from its extreme ability of saving power, it also has a 12-bit analog-to-digital converter, 256KB flash memory and 16KB ram which are all enough for our algorithm. In our experiment, we choose the sampling frequency to be 1kHz which may be a little high. However, it is worthwhile to get more accurate frequency information.

（a）　　　　　　（b）

Figure 7. PIR sensor and detector. The left (a) is LHI968, the right (b) is the prototype of our detector

To evaluate our approach, three kinds of target pass through the detector and get back for 100 times at 20 meters and 30 meters away respectively. At each distance, the corresponding speed of people, wheeled vehicle and tracked vehicle is 1m/s, 10m/s and 8m/s. The microcontroller processes every signal, checks its direction and extracts a 4-D feature vector. These results are transmitted to the remote receiver who further exports all the feature vectors to a PC (personal computer). In order to get a better result, we decide to apply a classifier on those data collected by the PC. The SVM (support vector machine) method is chosen because it delivers a global optimal solution and can yield good results for classification compared to other 16 classification methods [19] . We randomly choose half of the data to be train set and the other half to be test set. By using LIBSVM library in matlab, we directly get the classifying result.

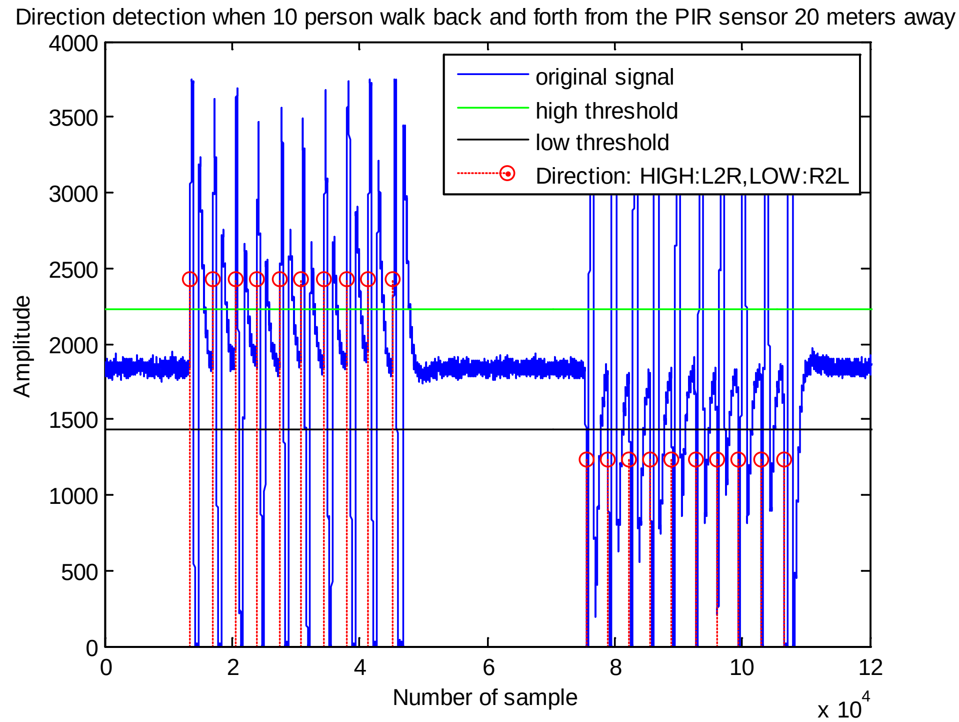

Figure 8. Direction detection when 10 people walk back and forth from the PIR sensor 20 meters away

Although the detecting algorithm is very easy, it is useful and reliable. We get 100% accuracy in detecting and direction judging. Figure 8 gives a visual simulation result on the collected signal when 10 people normally walk back and forth from the node 20 meters away.

Table 1 gives out the average features of 20 groups of data that we get from the experiments when sensors are deployed 30 meters away from the objected area. It is interesting to discovery that people's signal amplitude is the highest in three targets. This is concerned with the focal point of PIR detectors. As shown in Figure 9, targets must not only enter into the horizontal FoV but also the vertical FoV in order to capture the movements. Hence, the focal point which is the center point of the focal plane should be straightly faced with targets. However, when a sensor is focused on the chest of a human body, it is not exactly focused with vehicles such as truck and tank as they are much taller than human body. In earlier researches [4, 5, 13], this does not seem to be a problem as detecting targets are all people while we firstly use PIR sensors to simultaneously detecting heterogeneous targets. Although some information of the signal amplitude is lost due to the focal problem, the other three features are precisely extracted as shown in Table 1.

Table 1: Average extracting features of 20 groups of data at 30 meters

Targets \ Features	S_{amp}	L_s	$F_{\max amp}$	f
People	2507.6	3898	993.8697	1.9
Wheeled vehicle	1374	2718	686.4849	2.5
Tracked vehicle	1766.6	2792	364.3371	2.1

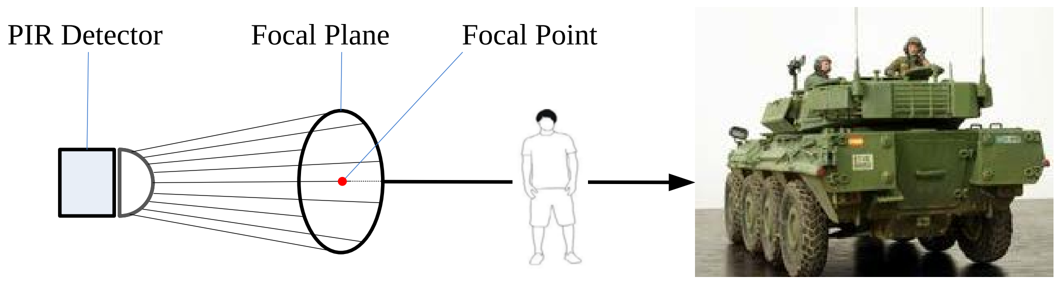

Figure 9. Focal plane and focal point of a PIR detector

Classifying results are presented in Table 2 and Table 3. Totally speaking, the average accuracy is 84.17%. Moreover, the average accuracy of 20 meters is 85.67%, better than 82.67% of 30 meters. This can be explained by Figure 5 that a closer distance makes a larger frequency difference and therefore a better classifying performance. However, it is venturous to deploy sensors too close to the objected area as they are easily to be discovered by enemies. Considering that, an installing distance of more than 20 meters is assumed to be safe and trusty. Besides, the recognizing ratio of people is higher than other two targets due to a larger speed difference. Since the speeds of tracked vehicle and wheeled vehicle are so close that they two are prone to confuse each other according to the misjudging probability.

Table 2: Classifying results at 30 meters

	Recognized as			**Accuracy**
	People	**Wheeled vehicle**	**Tracked vehicle**	

People	88	5	7	88%
Wheeled vehicle	2	78	20	78%
Tracked vehicle	3	15	82	82%

Table 3: Classifying results at 20 meters

	Recognized as			**Accuracy**
	People	**Wheeled vehicle**	**Tracked vehicle**	
People	91	3	6	91%
Wheeled vehicle	1	82	17	82%
Tracked vehicle	2	14	84	84%

Due to the focal problem, the signal amplitude is disturbed. On the other hand, the signal length is closely related to the signal detection technology while noise may corrupt the signal frequency. These aspects are all contributed to the failure of classification. In the future, we will try to solve these problems to improve the recognizing ratio. For instance, we can apply new signal detection technology or extract more accurate frequency information such as time-frequency analytical method. Furthermore, we can employ some other classify methods except SVM and investigate whether classification methods have influence on the categorization results. In a word, the classifying accuracy in our designed system is not so high, but it at least shows the feasibility of using PIR detector to recognize targets.

VII. CONCLUSION

This paper proposes the possibility to use PIR nodes to classify targets. By making use of a single PIR node, we can not only detect and count targets being several tens of meters away, but also can distinguish different targets by extracting features from both time domain and frequency domain. Simulation results show that the average accuracy can be up to 84.17%.

Our research has liberated PIR detector from applications of alarm and surveillance. It is believed that PIR detectors are not only qualified to detect, but also to classify. In addition, they are quite appropriate to be largely employed in unattended ground sensor network (UGSN) systems which are principally implemented in battlefield and state border. In the future, we will continue to improve the classifying accuracy and try to recognize more kinds of target.

REFERENCES

[1] M. Moghavvemi and L.C. Seng, "Pyroelectric infrared sensor for intruder detection", Proceedings of TENCON 2004: IEEE Region 10 Conference, Chiang Mai, Thailand 21-24 November 2004, pp. 656-659.

[2] K. Hashimoto, K. Morinaka, N. Yoshiike, C. Kawaguchi and S. Matsueda, "People count system using multi-sensing application", Proceedings of the 9th International Conference on Solid State Sensors and Actuators, Chicago, Illinois, USA, 16-19 June 1997, pp. 1291-1294.

[3] T.M. Hussain, T. Saadawi and S.A. Ahmed, "Overhead infrared sensor for monitoring vehicular traffic", IEEE Transactions on Vehicular Technology, Vol. 42, No. 4, 1993, pp. 477-483.

[4] T.M. Hussain, A. Baig, T.N. Saadawi and S.A. Ahmed, "Infrared pyroelectric sensor for detection of vehicular traffic using digital signal processing techniques". IEEE Transactions on Vehicular Technology, Vol. 44, No. 3, 1995, pp. 683-689.

[5] P. Zappi, E. Farella and L. Benini, "Enhancing the spatial resolution of presence detection in a PIR based wireless surveillance network". Proceedings of 6th IEEE Conference on Advanced Video and Signal Based Surveillance, London, UK, 5-7 September 2007, pp. 295-300.

[6] S. Lee, K.N. Ha and K.C. Lee, "A pyroelectric infrared sensor-based indoor location-aware system for the smart home", IEEE Transactions on Consumer Electronics, Vol. 52, No. 4, 2006, pp. 1311-1317.

[7] H.H. Kim, K.N. Ha, S. Lee and K.C. Lee, "Resident location-recognition algorithm using a Bayesian classifier in the PIR sensor-based indoor location-aware system", IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews, Vol. 39, No. 2, 2009, pp. 240-245.

[8] X. Luo, B. Shen, X. Guo, G. Luo and G. Wang, "Human tracking using ceiling pyroelectric infrared sensors", Proceedings of 7th IEEE International Conference on Control and Automation, Christchurch, New Zealand, 9-11 December 2009, pp. 1716-1721.

[9] R.C. Luo, O. Chen and C.W. Lin, "Indoor human monitoring system using wireless and pyroelectric sensory fusion system", Proceedings of 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2010), Taipei, Taiwan 18-22 October 2010, pp. 1507-1512.

[10] X. Zhou, Q. Hao and H. Fei, “1-bit walker recognition with distributed binary pyroelectric sensors”, Proceedings of 2010 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI 2010), Salt Lake City, UT, United States 5-7 September 2010, pp. 168-173.

[11] A. Kaushik and B. Celler, “Characterization of Passive Infrared Sensors For Monitoring Occupancy Pattern”, Proceedings of 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS), 31-Auguest to 3-September 2006, pp. 5257-5260.

[12] S. Honda, K.I. Fukui, K. Moriyama, S. Kurihara and M. Numao, “Extracting human behaviors with infrared sensor network”, Proceedings of Fourth International Conference on Networked Sensing Systems, Braunschweig, Germany, 6-8 June 2007, pp. 122-125.

[13] P. Zappi, E. Farella and L. Benini, “Pyroelectric infrared sensors based distance estimation”, Proceedings of IEEE Sensors 2008 Conference, Lecce, Italy, 26-29 October 2008, pp. 716-719.

[14] P. Zappi, E. Farella and L. Benini, “Tracking Motion Direction and Distance With Pyroelectric IR Sensors”, IEEE Sensors Journal, Vol. 10, No. 9, 2010, pp. 1486-1494.

[15] P.E. William and M.W. Hoffman, “Classification of Military Ground Vehicles Using Time Domain Harmonics' Amplitudes”, IEEE Transactions on Instrumentation and Measurement, Vol. 60, No. 11, 2011, pp. 3720-3731.

[16] Wikipedia Pyroelectricity. Available online: http://en.wikipedia.org/wiki/Pyroelectricity (accessed on 15-10-2011).

[17] T.I Datasheet,. Mixed Signal Microcontroller. Available online: http://www.ti.com/lit/ds/symlink/msp430f5438a.pdf

[18] Optoelectronics, P. Frequency Range for Pyroelectric Detectors. Available online: http://www.perkinelmer.com/

[19] D. Meyer, F. Leisch and K. Hornik, “The support vector machine under test”, Neurocomputing, Vol. 55, No. 1-2, 2003, pp. 169-186.

[20] B. Shen and G. Wang, “Distributed target localization and tracking with wireless pyroelectric sensor networks”, International Journal on Smart Sensing and Intelligent Systems, Vol. 6, No. 4, 2013, pp. 1400-1418.