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Intrusion Detection Using Passive Infrared Sensor(PIR)

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Abstract: Pyroelectric Infrared (PIR) sensors are widely used as a simple presence trigger for alarmsand a reliable counter for people in security home and smart office. Most paper have focused on thedesign and application of such systems, however, few research has be done on the detecting of targetsin 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 frequencyand corresponding frequency amplitude as features, we successfully classify people, wheeled vehicleand tracked vehicle in the unattended wild ground environment. Our detecting and classifying resultsconfirm 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.

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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, PIRsensors are quite fit for detecting moving targets.PIR sensors are largely accepted in indoor security systems for its low-cost, low-power, reliableperformance and convenient operation. Beyond these characteristics, it provides accurate information for target presence and even the number of targets. Nowadays, many securitysystems have made PIR sensors to be a good alarm of intrusion [1] and a precise counter fortargets who are not only people [2] but also vehicles [3, 4] and so on. However, previous worksmostly 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 isconfined in several meters. They are used to detect targets more than 20 meters away in anunattended 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 areto be detected and classified by means of PIR nodes. Simulation results show that the accuracy issatisfied and thus proved that PIR nodes can be used in an outdoor environment such as stateborder and battlefield.The rest of the paper is organized as follows. In Section III, we introduce the structure of PIRdetectors and nodes. Our method for detecting, counting and classifying is presented in SectionIV and V. Finally, we give the experimental results and conclude the paper in Section VI and VII.

LITERATURE REVIEW

PIR detectors are widely used in people presence detecting systems. In [2], PIR detectors insteadof camera sensors are installed over the stairs in the building to count the passersby. By usingpattern recognition methods, the detecting accuracy of moving direction can be 99% and thenumber of passersby is 95%. Paper [1] describes a simple intruder detection system based on PIRsensors which are installed on the wall of a protected room. Entering into this monitored area willcause 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 awall of a hallway to extract people's movement features with 100% correct of directionrecognition 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, theauthor 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, theydeveloped a resident location-recognition algorithm using a Bayesian classifier to increase theaccuracy [7]. Similarly, four sensor modules, each consisted of five PIR detectors, are mountedon the ceiling of a monitor field to fix the position of a moving human target [8]. In

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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 andtracking system using wireless pyroelectric sensor networks. In recent years, more workconcerned with recognition and classification utilizing PIR sensors has been done. For example, awireless 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 withthe velocity and vertical distance of movements, they pointed out that a PIR system can be usedto monitor the occupancy pattern of elderly people. In [12], 40 infrared sensors are installed atdoors, 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 threegroups: 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 indoorenvironment 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 PIRdetector 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 outdoorenvironment 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 alsoother targets such as vehicles [3, 4]. Therefore it is natural to use PIR sensors to detect multitarget and classify them. For instance, they can be used to classify military vehicles instead ofacoustic sensors that are sensitive to wind noise [15].In this paper, a novel application is proposed that PIR detectors are utilized to classifyindividuals, wheeled vehicles and tracked vehicles more than 20 meters away in a wildenvironment. Through our analysis and experimental results, it is proved that targets such asvehicles can also be detected and counted. Besides, these three targets are able to be classified tosome extent.

METHODOLOGY

Pir Detectors and Nodes

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

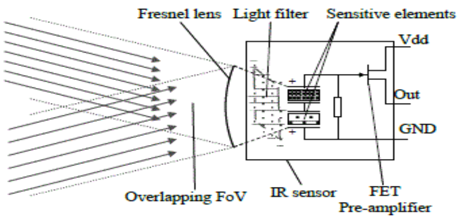

Figure 1: The structure of a PIR detector

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.

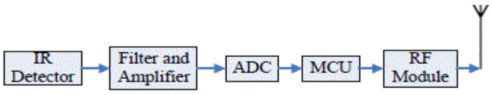

Figure 2. The block diagram of PIR nodes

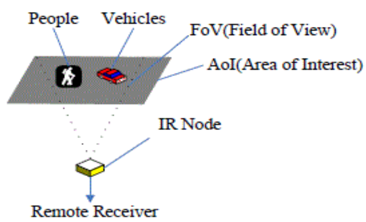

Figure 2 and 3: The block diagram of PIR nodes and Detecting system using IR nodes

Figure 2 gives out the block diagram of PIR nodes. As we can see, a PIR node is mainly madeup of a PIR detector, a signal processing unit and a communication unit. The PIR detectorbelongs to the class of passive sensor being low-power but reliable. The signal processing partconsisting of a filtering and amplifying module, an ADC module and a microcontroller module isthe 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 only1.2uA when in standby mode [17]. However, low-power microcontroller is often at the price oflow computational complexity and little memory space. Hence, it is not appropriate to use toocomplex algorithm on such processor. In later section we will present how to deal with the PIRsignal 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 amicroprocessor. Usually there is a compromise between signal processing and wireless communication because more signal processing such as aggregation and fusion will get a simpleresult which requires less communication burden, and vice versa. In our system most of thesignal analytic task is placed on the node locally as the wireless module needs relatively hightransmit power to support a far transmission distance to the remote receiver. Considering theexcellent performance of microcontroller, it is rational and worthwhile to make processor morehardworking.

Figure 3 demonstrates how we use IR nodes to detect an area of interest. PIR nodes are placedtens 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 directionand furthermore extract several target features. Then the controller sends targets' informationincluding 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. Ifnecessary, the results will report to the user to help make a decision. During this process, thedetecting algorithm and classifying ability are the most critical, as will be discussed next.

DETECTING ALGORITHM

A PIR detector with a single Fresnel lens and a sensor of two inverse sensitive elements producesan 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 entersinto the FoV, the dual sensitive elements with opposite polarity response the change one afteranother, thereby producing a positive peak and a negative peak. We can easily process such asignal 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 iscompletely located between the positive threshold AP and the negative threshold An while thelatter starts when one of the thresholds is crossed and ends when another threshold is crossedfollowed a stable period. This duration is called settle down time T that indicates the ending oflast target and enables the following detection. It is clearly stated in paper [14] that there is atradeoff between amplitude threshold and settle down time threshold. A high amplitude thresholdmay cause a potential distant target incapable of being detected. However, a low threshold bringsa 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 ourtests, by computing the mean value of noise, denoted as Am, we fix the threshold AP and an tobe Am ±400, respectively. Meanwhile, T is chosen to be 0.8 sec.

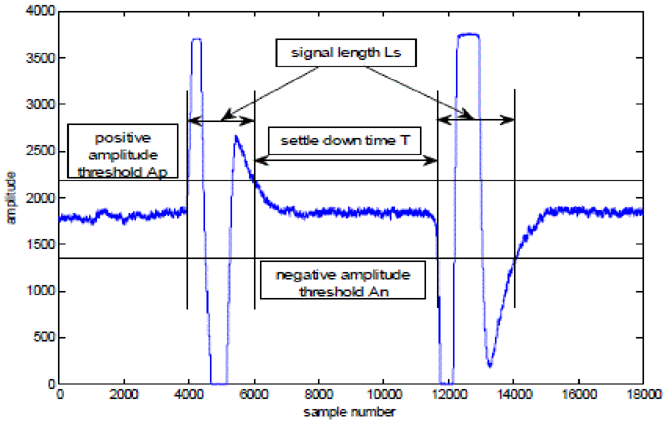

Figure 4: PIR output and detecting algorithm

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

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

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 thepresence and direction of moving targets but also reflects certain targets' attribute informationsuch as distance, category, velocity, etc. Previous works mostly concentrate on the former whilethis paper will discuss the latter thoroughly.Although literature [11, 14] has carefully examined the output characteristics of IR signal in thetime domain, it is just based on the empirical observation and test which lacks of strictlytheoretical 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 isdesigned to let other targets' IR radiation absorb. Once the Fresnel lens is determined, the opticalsystem is then fixed and has negligible influence on the output of different targets. Hence, thedistance and speed are the major factors to decide the output. Specifically, these two mainlychange the signal amplitude defined by the difference between positive and negative peaks andthe signal length being the time interval between entry point and end point (see Figure 4). Thus inpaper [14], the author chooses signal amplitude and length as features to distinguish differentdistances for a fixed speed target. However, it is incapable of classifying various types of target atdifferent speed within different distance. To solve this problem, we have to take frequencyinformation 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 therelation between velocity, focus and frequency:

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

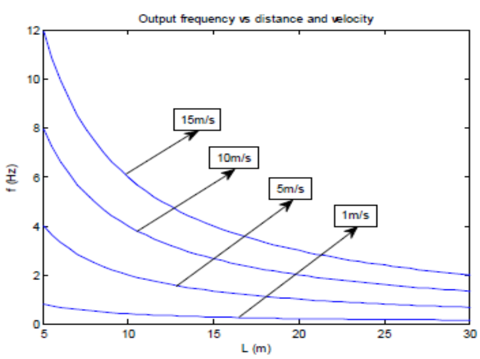

Figure 5. Output frequency as a function of distance L and velocity v_b

For a specific practical detecting system, b f and s are constants. Therefore, f is decided by b vand L . Figure 5 gives out an intuitive explanation for the relationship between output frequency,velocity and distance. Here we choose b f = 25mm and s = 1mm. It can be seen that the outputfrequency is a function of velocity and distance. Either of them is constant, the output is changingfollowed the other. As stated in last paragraph, target distance can be distinguished by timedomain features. Hence, from the point of principle, targets with different speed and differentdistance can be classified depending on the output frequency. However, in our application, thedetecting range is fixed once the detector is installed. Thus velocity difference of targets is a soleproof to recognize targets. If the output frequency differs from each other, then the velocityrepresenting different targets is also different.Figure 6 illustrates a map of output signal and the corresponding frequency. Figure 6(c) is thefrequency output of the signal in Figure 6(a) when a person being 20 meters away walks and runsacross the sensor at a speed of 1m/s and 2m/s, respectively. It indeed shows that fast movementsresult in high frequency output. At the same time, the signal length of walking is longer than thatof running as shown in Figure 6(a). This is because slower movements would bring longerexisting time in the fixed FoV of the sensor at a fixed distance. It can also be seen from Figure6(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 highestmain frequency component while people have the lowest main frequency component due todifferent 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, usingfrequency information to recognize targets with different speed is feasible.

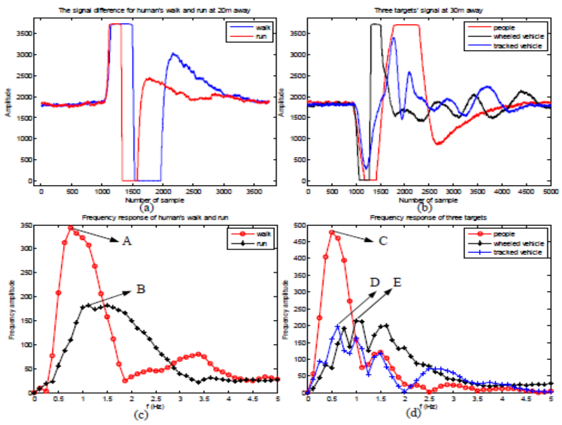

Figure 6. Output signal and frequency

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

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

Using this 4-D vector, it iscapable of recognizing different targets at different speeds. Next section will prove the feasibilityand success of our target classification method.

CONCLUSION

This paper proposes the possibility to use PIR nodes to classify targets. By making use of a singlePIR node, we can not only detect and count targets being several tens of meters away, but alsocan distinguish different targets by extracting features from both time domain and frequencydomain. 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 believedthat PIR detectors are not only qualified to detect, but also to classify. In addition, they are quiteappropriate to be largely employed in unattended ground sensor network (UGSN) systems whichare principally implemented in battlefield and state border. In the future, we will continue toimprove the classifying accuracy and try to recognize more kinds of target.

Resource Requirements

Computer/laptop with below mentioned configurations are required.

Hardware Requirements

Hard ware needed to connect the chip & system: programming Kit (IC chip burner to program microcontroller) AT commands to drive GSM modem.

Software Requirements

Compiler: KeilMicrovision software

Bootloader: Burning tool or Burning software

Protocol Design: C

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 onSolid 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 monitoringvehicular 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 fordetection of vehicular traffic using digital signal processing techniques". IEEE Transactions onVehicular Technology, Vol. 44, No. 3, 1995, pp. 683-689.
5. P. Zappi, E. Farella and L. Benini, "Enhancing the spatial resolution of presence detection ina PIR based wireless surveillance network". Proceedings of 6th IEEE Conference on AdvancedVideo 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-awaresystem 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 aBayesian classifier in the PIR sensor-based indoor location-aware system", IEEE Transactions onSystems, 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 pyroelectricinfrared 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 andpyroelectric sensory fusion system", Proceedings of 2010 IEEE/RSJ International Conference onIntelligent 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 pyroelectricsensors", Proceedings of 2010 IEEE International Conference on Multisensor Fusion andIntegration for Intelligent Systems (MFI 2010), Salt Lake City, UT, United States 5-7 September2010, pp. 168-173.
11. A. Kaushik and B. Celler, "Characterization of Passive Infrared Sensors For MonitoringOccupancy Pattern", Proceedings of 28th Annual International Conference of the IEEEEngineering 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 humanbehaviors with infrared sensor network", Proceedings of Fourth International Conference onNetworked 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 WithPyroelectric 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 TimeDomain 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 wirelesspyroelectric sensor networks”, International Journal on Smart Sensing and Intelligent Systems,Vol. 6, No. 4, 2013, pp. 1400-1418.