# Chapter 5

# Conclusions and Discussions

In this study, we proposed novel designs for computational systems that use thermal biometrics to identify walking humans and successfully demonstrated the high accurate rate of this technology by selecting suitable sensor configurations and feature extraction/training algorithms.

## 5.1 Summary of Work

This thesis starts with the description of the main components of the proposed sensor system. In section 2.1, we introduced the working mechanism of the pyroelectric detectors and different types of detectors. We also characterized the detector used in our system. The sensor characterization involves measuring its band-pass step response and directional sensitivity over space. In order to estimate the heat exchange between humans and their environment (Section 2.2), the Stefan-Boltzmann's Law was used to describe the human heat emission model.

However, each detector element has a small detection area (2 $mm^2$), and the amount of the heat collected by the sensor is only a small fraction of the incident thermal radiation (Section 2.3). To overcome this drawback (Section 2.4), the Fresnel lens arrays were employed to improve both the collection efficiency and spatial resolution. In Section 2.5, we introduced another two important components, the Texas Instrument micro-controller (MSP430149) and RF transceiver (TRF6901) module that used in our sensor module. Finally, section 2.6 describes how a sensor module was fabricated for our identification system.

In chapter 3, we introduced a conceptual design of a novel human recognition system based on a pyroelectric infrared (PIR) sensor. A sensor module that contains a pyroelectric IR sensor and a Fresnel Lens array was mounted on a pillar to detect IR radiation from the target. Data was collected as individuals walked back and forth along a straight path perpendicular to the sensor. With heat flow, electric charge was built up on the sensing element by virtue of pyroelectricity. The resulting charge was then translated into a current which was further converted to a voltage signal by a current-to-voltage transductance amplifier. Finally, this signal was analyzed by spectral techniques to extract the individual motion features.

The experimental results show that the spectral distinctions among different humans walking at different speeds and the spectral features of objects at a specific speed can be collected repeatedly with small variances, given a fixed sensor configuration. By using the principal component regression method, those spectral features can be clustered around a set of points, along a unit circle in a 2-D label plane. From the training process, we can obtain a regression vector for each cluster, as well as the means and covariances of those clusters. Then, new data of objects walking at random speeds were tested against the pre-trained clusters to decide whether the target is registered, and which member of the registered group it is.

The optimal element number of the lens array for the identification system was also investigated to improve the identification capability. The experimental results suggest that the lens array with more elements can yield a better performance in terms of identification and false alarm rates. In addition, the other parameters of the system configuration such as the height of sensor location and sensor-to-object distance were studied to improve spectral distinctions among sensory data of human subjects.

After characterizing these parameters of the system, we implemented the real-time feature extraction and built a real-time identification system. This system has the features of low cost, low power consumption, and illumination independence. The procedure for real-time feature extraction and the improved multiple hypothesis testing were described in

Section 3.2. The extraction process consists of three parts: event detection, feature extraction and feature validation. As one event happens, its data will be retrieved at once. The length of the event data is checked first to reject trivial events. During the process, a fast Fourier transform was utilized to generate the feature data. This feature was then checked against the universal background model to make sure of its validity before being tested against all the hypotheses.

In the model training stage, the MLPCE method is employed to obtain the regression vector for each registered human subject. ROC curves were investigated to select a suitable threshold for maximizing subject recognition rate and minimizing rejection errors. The experimental results demonstrate the effectiveness of the proposed real-time pyroelectric sensor system in recognizing registered subjects and rejecting unknown subjects.

In chapter 4, we proposed the digital feature based system using a pyroelectric infrared (PIR) detector array and hidden Markov models (HMMs). This system can perform both the real-time path-dependent path-independent human identification. A PIR detector array with masked Fresnel lens arrays was used to sample the IR radiation from the human target. The binary event sequence was chosen as the digital human-motion feature, with an event defined as thermal flux collected by a pyroelectric detector exceeding a given threshold. Each event signal is associated with specific motions of human subjects, such as crossing one or more adjacent detection regions.

HMMs were trained to statistically model the motion features of individuals through an expectation-maximization (EM) learning process. Human subjects were recognized by evaluating a set of new feature data against the trained HMMs using the maximum-likelihood (ML) criterion. Different number of detectors and different sampling masks in the sensor module were also studied to improve identification rates. The identification performance can be improved by increasing the number of detectors and the spatial sampling frequency of the masks. Among all the tested sensor modules, the one containing 8 detector units and a high spatial frequency sampling mask demonstrated the best performance. Its average identification rates for 10 persons are 91% and 78.5%, in path-dependent and path-independent cases, respectively.

## 5. 2 Discussions

The advantages of the digital feature based system include its less rigid training process, decreased sensitivity to walking speeds, effectiveness in both the path-independent and path-independent identification modalities, and high data compression ratio for wireless data transmission. In the proposed identification system in chapter 3, the analog feature of a PIR sensor's temporal signal is used to represent the human motion features. This analog feature based system contains more detailed information about the thermal source. Although, this system is only suitable for path-dependent human identification, it is adequate for higher-security applications in human biometric verification and open-set identification.

In this study, both the analog feature and digital feature based human recognition system are based on the IR radiation from the human body. Among all the factors that affect the system performance, the cloth that walkers wear is the most important one. From the experiment results, the system recognition capability is invariant to the clothes with similar styles and fabric types. However, a person wearing clothes with different kinds of fabrics (e.g., a cotton garment for training and a polyester one for testing) will degrade the recognition rate. To alleviate this limitation, it may need the help of using multiple sensor nodes to get more information of subject from multiple perspectives or using multi-modal sensing technique after combining the conventional video devices with the pyroelectric sensors. Although IR/visible cameras with large numbers of pixels are also capable of advanced positioning and control, they are inevitably associated with high data-loads, computational costs, and much higher system costs. Therefore, the complexity and the cost of the system will be enhanced. It is a compromise between the recognition rate, complexity of the system and system costs. Besides, different weather situations (wind, rain snow, et al.) may influence the recognition rate. To find an effective way to offset those factors will be the aim of our future work. Our following work also includes simultaneous recognition of multiple people and performance improvement for a larger group of subjects, by using multiple sensor nodes.

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