PIR Sensor Array for Hand Motion Recognition

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Abstract—In this paper we present our work towards a hand gesture recognition system realised with a passive thermal infrared sensor array. In contrast with the majority of recent research activities into gesture recognition, which focus on the complex analysis of video sequences, our approach shows that the functionality of a simple pyroelectric movement sensor can be expanded to detect differing hand gestures at short range. We show that blob detection from a hand waving over a 16 element passive infrared sensor array provides sufficient information to discriminate four directions of hand stroke. This sensor system is unique and lends itself to low cost, low profile and low power applications.

Keywords-touchless input device; dynamic hand gesture; infrared motion sensor; infrared sensor array; pyroelectricity;

I. INTRODUCTION

Non-contact operation of electrical appliances is becoming increasingly desirable. This is particularly the case in public areas where hygiene is important. Public washrooms increasingly have taps, cisterns, soap dispensers, hand dryers and doors activated by simple hand proximity/movement detectors. The advantages of removing physical contact from the activation and control of devices range from limiting the chance of infections transmitted through touch and better energy efficiency to simple convenience. In other environments such as medical facilities and food processing areas, strict hygiene rules are essential and direct hand contact with appliances is best avoided if at all possible [1]. These environments present a wide spectrum of opportunities for non-contact control, as reducing the number of touched surfaces positively suppresses risk of cross contamination and infection. There are often cases, where operators' hands may contaminate surfaces, e.g., in a kitchen or a workshop. Strict rules apply in operating rooms, where doctors' hands must remain sterile throughout a procedure [2]. There are other, rarer cases where a cultural or individual preference may be not to make physical contact with an appliance. In all these circumstances touch-free control is beneficial.

Existing non-contact hand proximity/motion switches provide the binary "on/off" operation. They are commonly based on single or dual cell pyroelectric infrared sensors with a simple lens system [3], although capacitive sensing can also be used [4]. Thus the degree of human control over the electrical appliance is severely limited.

In this paper details are given of a pyroelectric array device that detects simple hand movement gestures, thereby allowing greater non-contact control capability with little increase in size, cost or power consumption. This paper gives an overview of existing methods of gestures detection. Further, the problem of hand gesture recognition is discussed and our implementation is explained.

II. RELATED WORK

Gesture recognition systems can be categorized into three broad groups [5]: those that use a handheld pointing device, those that require wearable sensors and those with no user-held devices but operating using the analysis of 2D images (external sensing). For general application of gesture recognition sensors, it is important that the system requires no user held or worn devices.

Research into gesture feature extraction from image sequences is the most active. Most common implementation uses a video camera to capture a wide scene, from which hands are extracted and tracked, for example [6] and [7]. Such approach gives great flexibility in terms of detection distance and detection precision and scope. Commercially, systems operating on a video processing basis have been developed by GestureTek [8], EyeSight [9] and Edge 3 Technologies [10]. However, it is not practical to implement such systems ubiquitously, for example as switches, due to size, cost and, in many cases, energy consumption.

Byung-Woo Min et al. [11] classify hand gestures into static (hand posture) and dynamic (hand movement). Dynamic gestures are generally more intuitive for the user, as the direction of motion or its shape can reflect the resulting action, e.g., up/down hand stroke for increasing/decreasing brightness in a room. Moreover, it is easier to capture this type of gesture with a low resolution and low cost imager.

Sensor based touchless solutions become more popular after the recent success of touch screen interfaces. Mechaless [12] provide a hardware solution. They use an active near infrared (NIR) arrangement with multiple IR LEDs and a sensor that is used to calculate the distance of an object from each LED by timing pulse to reception interval. They propose use of their touchless interface in wall-mounted gesture switches (increase / decrease a control by up / down

hand movement) or in a remote control with a touchless 'joystick'.

One of many NIR proximity array systems is being developed by Dongseok et al. [13]. A 3-dimensional map of the scene is created by analyzing reflections of emitted near infrared light captured by an infrared array. Each pixel can read range, as with simple infrared range-finders. Interestingly, the research group develops a near-field touchless, free air touchpad-like device, where position of a finger in front of the sensor is tracked precisely and analysed.

An ultrasonic realization of a touchless pointing interface is proposed by Chiu et al. [14]. In this case an array of ultrasonic receivers creates an image-like output based on reflections received from a pointing object.

The related concept of interactive shop windows is introduced by Krumm [15]. Interactive or immersive advertising reacts to people passing by, trying to engage them by showing dynamic content accordingly.

Active arrangements, comprising an emitter and a receiver, usually have the advantage of providing absolute measurements of distance and position. However the presence of the emitter results in higher energy needs than for a passive measurement. For dynamic hand gestures such precision is not necessary and detection can be realised by passively sensing thermal infrared radiation change only.

We believe that our solution is very well suited to the task of near distance, dynamic hand gesture recognition application and provides an alternative to existing propositions, that is more cost and energy efficient due to reduction in number of components or their complexity.

III. PIR ARRAY BASED HAND MOTION RECOGNITION

The set of basic hand movements in front of a sensor is limited, e.g., horizontal, vertical and diagonal swipes across the field of view, circular motion and in and out movements. At this stage, only linear motion across the field of view is considered. Four directions of swipe were chosen as easy to describe and reproduce: up / down, left / right.

A. Design Principle - PIR Array

As identified in the introduction to this paper, a simple, low cost and low energy consumption device to extend the concept of a touchless interface is desirable in many environments.

A PIR Array is an interesting potential solution: the technology has been widely proven in settings such as burglar alarms and automatic light switches. However, only now has it become financially viable for ubiquitous application in the form of an array (previously mostly used a single or dual element occupancy sensor).

Passive detector does not require additional light sources for illumination of the scene, as the human body is naturally a good thermal infrared emitter [16]. Scenes at a temperature
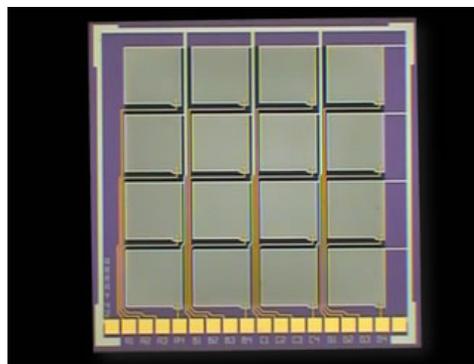

Figure 1.   4x4 PIR Sensor Array ([18], with permission).

above 0 K may be dark in visible spectrum, while still full of thermal energy [17].

A limitation common to all passive infrared detectors exists. The minimum detectable temperature difference creates a band of target temperature relative to the background temperature resulting in low signal to noise ratio. When the temperature of the detected object is higher than that of the background, the response of the infrared elements will be positive. While when temperature of the object is lower, the response is inverted. Increase in the temperature of the environment and hence that of the sensor can reduce responsivity of such passive device.

B. Research Questions

The primary aim of this study is to investigate whether it is feasible to use a passive infrared array for hand gesture recognition, and if so, under what conditions, and what range of gestures can be recognized. The secondary aim is to compare the cost effectiveness and power efficiency of the passive infrared system with existing solutions using active infrared or visible cameras.

IV. IMPLEMENTATION

We propose a system to realize the task of simple dynamic hand gesture recognition at short distances.

A. Prototype

The implementation described in this paper is a proof-of-concept prototype. Existing signal conditioning integrated circuit and PC interface board and software provided by the sensor manufacturer are used for signal capture. Signals are processed using the computer for ease of development. In future developments a migration to an embedded system is anticipated in order to provide a low footprint, low power solution.

B. Capture Device

A thin-film, passive infrared sensor, 4 pixel x 4 pixel array, pictured in Figure 1, is enclosed in a package with a broadband infrared filter.
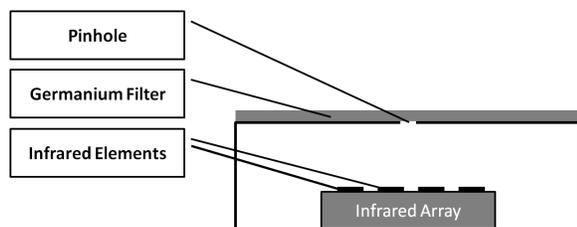
Figure 2.   Optical Arrangement.

This thin-film sensor is manufactured using standard, high throughput wafer processing techniques. The sensor die is a customisable MEMS structure with pixels patterned on a silicon membrane. Such approach provides an integrated, robust array with consistent physical properties.

Thin-film infrared elements have low thermal mass compared with bulk PZT elements. The result is higher optimal frequency of operation, well suited for tasks such as gesture recognition, where detected object moves quickly across the field of view.

An infrared-blocking film is mounted on the underside of the filter, with a pinhole centred above the array, as seen in Figure 2. This optical arrangement produces a low resolution infrared image of the scene in front of the sensor within a field of view of 60° up to 20 cm away from the sensor.

Electrical signals from the infrared array are amplified, low pass filtered and digitised. The images are captured using a dedicated interface board. The digitized frames are sent to a computer and pre-processed to provide a stable and uniform output. This involves per-pixel low pass filtering and normalisation of signals across the array.

C. PIR Sensor Array

The PZT infrared array sensing elements transform thermal radiation into electrical charge based on the pyroelectric principle.

The transducer operates in the same manner as standard security PIR motion detectors, where the change in incident flux arises from the motion of a thermal infrared source across the field of view. This has an advantage in that the background subtraction is inherent in the transducer itself: stationary infrared emitters do not cause a change in incident flux, and therefore are not detected. However, it also becomes a limitation in that an object that moves into the field of view and then becomes stationary will soon become invisible. This is not a problem in a system designed to recognize simple 'swipe' type gestures where motion, and the direction of the motion, are the dynamic features that are to be recognized.

In a fully passive arrangement, where there is no additional modulated illumination nor is the incoming infrared radiation modulated, effectively only active motion can be reliably detected.
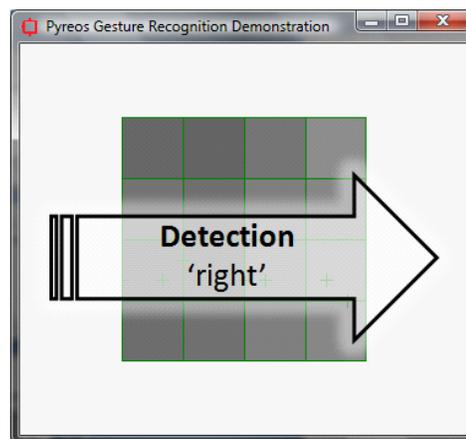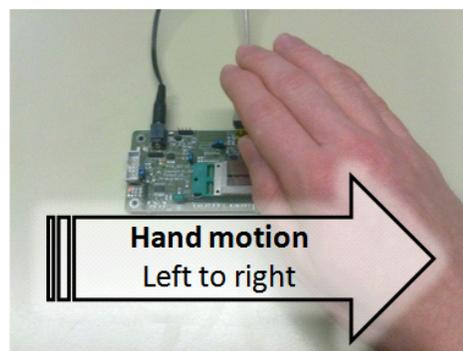

Figure 3.   Hand motion and tracker response [21].

D. Signal Processing

A tracking algorithm is applied to the frame sequence. Blob detection technique is derived from the Automatic Centroid Extractor [19], also used for people counting application [20]. Adaptation of the algorithm involved increased processing rate and adjustment for larger object size.

Hotspots are localized and tracked in the image. Analysis of the trail of a detected and tracked object allows the determination of direction of motion. The length of the track is used to determine if it was a valid detection, while the x and y difference between starting and finishing point is evaluated to provide direction information.

V. INITIAL EVALUATION

Functionality of the system was tested in four main directions of hand swipe across the sensor. Five participants were asked to perform a set of 100 hand movements each (25 per direction). Detection rate and accuracy of system response (correct direction detected) were recorded.

Figure 3 demonstrates the test arrangement and correct detection: a sample hand motion from left to right results in a correct 'right' detection.

Table I
INITIAL EVALUATION RESULTS

Direction	Detection Rate (%)	Accuracy (%)
Up	72.8	93.6
Down	86.4	93.6
Left	88.0	93.6
Right	78.4	89.6
Average	**81.4**	**92.6**

Detection in the distance range of up to 20 cm from the sensor was accurate 92.6% of time overall. 81.4% of gestures were detected at the first attempt. When considering only horizontal swipes (left to right and right to left), it can be seen that the detection rate (87.2%) and accuracy (93.6%) were higher than overall. This is attributed to the test arrangement, where it was more difficult to accurately present clean vertical swipes to the system then it was to produce horizontal ones.

VI. APPLICATION

As an example application of the system, the output of the prototype was used to emulate arrow key strokes on the host computer. This simple test demonstrates the suitability of the system for performing certain tasks on the computer. As an example, the gesture recognizer was used to change slides during a multimedia presentation.

VII. CONCLUSION AND FUTURE WORK

With our prototype system we have demonstrated that it is feasible to recognize hand motion direction with a pyroelectric passive thermal infrared array. Our approach shows that the functionality of a simple pyroelectric movement sensor can be expanded to detect differing hand gestures at short range. We show that blob detection from a hand waving over a 16 element passive infrared sensor array provides sufficient information to discriminate four directions of hand stroke.

Operation under different ambient conditions still needs to be determined: detection relies on there being a perceptible temperature difference between the hand and the background scene.

Future work on the software algorithms will focus on improving detection reliability, working towards an increase in angular resolution for more gestures to be recognised. Optimization towards embedded system application is required to achieve a low power system suitable for real application. With the development of a dedicated array for this type of recognition, further optimisation of the system is possible.

VIII. ACKNOWLEDGEMENT

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