Multi-Sensor Ambient Assisted Living System for Fall Detection

Ahmet Yazar[1], Fatih Erden[2] and A. Enis Cetin[1]
[1]*Dept. of Electrical and Electronics Eng., Bilkent University, Ankara, Turkey*
[2]*Dept. of Electrical and Electronics Eng., Hacettepe University, Ankara, Turkey*
{yazar,erden}@ee.bilkent.edu.tr, cetin@bilkent.edu.tr

Abstract

An important goal of Ambient Assisted Living (AAL) research is to contribute to the quality of life of the elderly and handicapped people and help them to maintain an independent lifestyle with the use of sensors, signal processing and the available telecommunications infrastructure. From this perspective, detection of unusual human activities such as falling person detection is of utmost importance. In this article, a low-cost AAL system using vibration and passive infrared (PIR) sensors is described for falling person detection, human footstep detection, human motion detection, and unusual inactivity detection. The proposed AAL system works in real-time on a standard computer or chipKIT Uno32 microprocessors. The resulting AAL system is a low-cost and privacy-friendly system thanks to the types of sensors used.

1. Introduction

Most European countries will face a large increase in the number of elderly people in the near future. It is reported that unexpected falling is a major problem and about one-third of people over 65 falls unexpectedly [1]. The development of intelligent homes will improve the quality of life of seniors and handicapped people. The use of wearable falling person detection systems has increased during the last five years. These systems are designed to call rescue units in an emergency situation like falling to floor or remaining motionless for a while.

Computer vision and sound sensor based systems can be also used for falling person detection [2]. However, most people find having a camera in their houses invasion of their privacy, even if the video and sound recordings are not transmitted elsewhere. The Kinect sensors can replace camera based systems for falling person detection [3], but they also require processing of depth video and they have to be installed in every room of the house. This means that it may not be possible to achieve a low-cost system in the near future due to the excessive computational cost of real-time processing of the multi-channel Kinect-video. Currently, commercially available fall detection systems are mostly body worn sensors [4], [5]. The main disadvantage of these systems is that wearing and/or carrying them all the time is not convenient and elderly people may simply forget to put on them.

Our system is different from the currently available fall-detection systems. We propose to install vibration and two pyroelectric infrared (PIR) sensors (Fig.1) to rooms of an intelligent home to realize a robust and practical system. The resulting AAL system is a low-cost and privacy-friendly system thanks to the types of sensors used. Both the vibration sensor and the PIR sensor produce 1-D signals of time.

In Sections 2 and 3, a brief technical description and implementation details of the new AAL system is described, respectively. A paper describing our AAL system was published in a special issue of the journal Pattern Recognition Letters [6]. The overall AAL system consisting of human activity analysis, flame detection and flooding detection is implemented at Bilkent University and described in detail in the first author's thesis [7] which is available in Internet. In Section 4, we describe a novel sensor fusion method which is not published elsewhere. Section 5 describes the demonstration set-up.

2. Brief Technical Description

We will demonstrate a fall-detection system consisting of a vibration sensor and two PIR sensors.

We employ the vibration sensor with the aim of sensing the vibrations on the floor. The vibration sensor converts vibrations into electrical signals depending on the intensity of the vibration waves in the axis of the vibration sensor. When a person walks on the floor or falls down he or she generates different waveforms. Feature vectors from the vibration waveforms are extracted using the complex wavelet transform (CWT) [8] and they are classified using a support vector machine (SVM) [6]. It is observed that most of the vibration sensor signal energy is concentrated in low-frequency bands. Hence, more emphasis is given to lower frequencies by assigning more sub-bands to them. The vibration sensor is also employed in human footstep detection and falling person detection.

Vibration sensor based systems [9],[10] may not be robust enough to distinguish human falls from door slams and other similar events. For example, microphones are used as an additional sensor in a recent US patent [9]. In our system, we use PIR sensors as additional sensors to detect the infrared radiation emitted by moving objects in the room. PIR sensors are also low-cost sensors and widely used for motion detection. Resulting multi-sensor system turns out to be a robust system with very low false-alarm rates.

3. Implementation

Fig. 2 illustrates the flowchart of the algorithm for the multi-sensor falling person detection system. Whenever the vibration sensor level exceeds an adaptive threshold, two different type falling person detection algorithms are run serially to make a final decision about falling. The first algorithm analyzes vibration sensor signal using CWT and SVM. The second algorithm analyzes the PIR sensor signals. Positions of two PIR sensors are adjusted in order to see upper and lower parts of a person separately. Essentially, if the lower PIR sensor detects a motion and the upper PIR sensor does not detect a motion for a while, the system decides that a fall took place in the room. Sensor signals are fused using the winner-take-all (WTA) based decision fusion algorithm.

Flowchart of the PIR sensor based unusual inactivity detection algorithm is presented in Fig. 3. Additionally, a measurement of the walking intensity of the person in a certain time period is calculated through the vibration sensor based human footstep detection system. Classification between the human-footstep sourced signals and the other signals is done by a Markov Model based system.

Figure 1. Images of the PIR sensor, the vibration sensor, and the Uno32 microprocessor, from left to right, respectively.

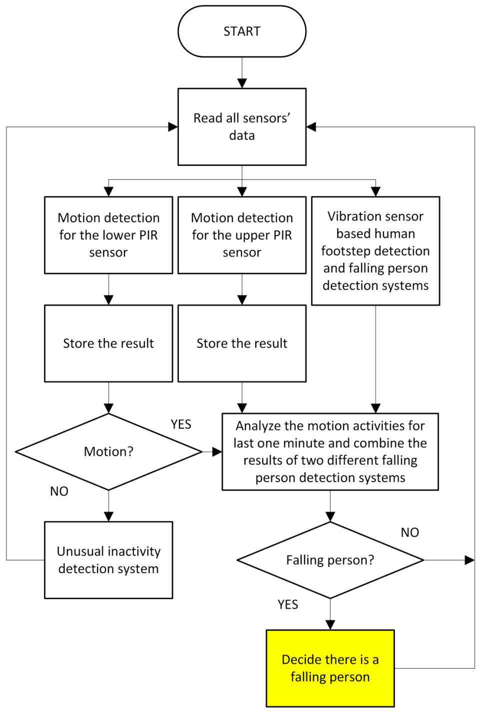

Figure 2. Flowchart of the multi-sensor based falling person and unusual inactivity detection system.

Data coming from the PIR and vibration sensors are fused to reach a final decision. The AAL system is implemented using chipKIT Uno32 microprocessor boards as a stand-alone system. A PIR sensor, a vibration sensor and a Uno32 board are shown in Fig.1.

4. Sensor Fusion Algorithm

In this section we describe a novel PIR sensor data fusion algorithm which is not published elsewhere.

In our system, wavelet based signal processing methods are used to extract features from PIR sensor signals. Wavelet domain analysis provides robustness to variations in the sensor signal caused by temperature changes in the environment. In order to keep the computational cost of the detection low, we use Lagrange wavelet filters which can be implemented in integer arithmetic. Let $x[n]$ be a sampled version of the signal produced by a PIR sensor with a sampling frequency of 100 Hz. Wavelet coefficients are obtained corresponding to [25 Hz, 50 Hz] frequency band information of the sensor signal $x[n]$. In this subband decomposition, output signal is filtered with an integer arithmetic high-pass filter corresponding to Lagrange wavelets [2,7] followed by decimation.

Sampled signals from each differential PIR sensor are divided into windows of length 100 and wavelet coefficient sequences of length 50 corresponding to each window are computed. Let $w_{r,n}[k]$ and $w_{l,n}[k]$ $(k=1,...,50)$ represent the wavelet coefficient sequences corresponding to a window of the PIR sensor signals of the upper and lower sensors, respectively, and $w_{s,n}[k] = w_{r,n}[k] + w_{l,n}[k]$. In the case that the energy of $w_{s,n}$ exceeds an adaptive threshold, it is concluded that there is motion in the viewing range of the PIR sensors. Afterwards the feature vectors of wavelet coefficients, which represent both of the PIR sensors at the same time is transformed into binary codes using WTA hash method as in [11]. WTA hashing provides a way to convert arbitrary feature vectors into compact binary codes. These codes are resilient to small perturbations in the feature vector. They preserve the rank correlation and can be easily calculated [11]. In our system, Jaccard distance between the binary codes is used as a similarity metric. In the classification process, the class affiliation of each data window is determined by computing the Jaccard distance between the binary code of the data window and the representative member of each action class. Jaccard distances between the WTA code of $w_{s,n}$ and the codes determined during training for each model are calculated and the model yielding the smallest distance is reported as the result of the analysis for the current data window.

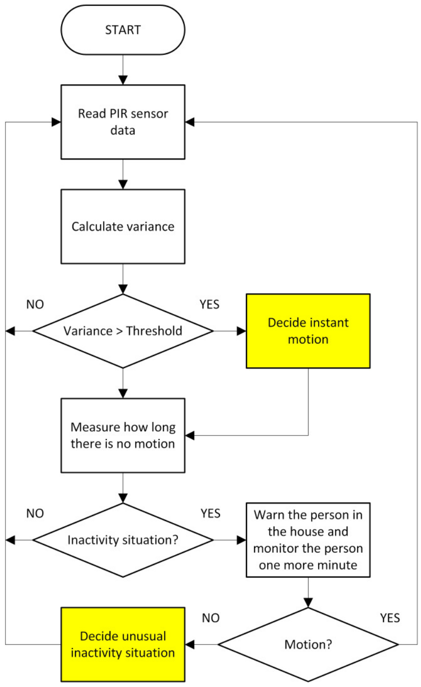

Figure 3. Flowchart of the PIR sensor based unusual inactivity detection algorithm.

5. Demonstration

Visitors can experience our human activity detection unit, which consists of falling person detection, human footstep detection, human motion detection, and unusual inactivity detection components implemented using a low-cost Uno-32 board. They can interact with the system in real-time. The system will not produce any alarms when people walk or sit on the floor but it will produce an alarm during an unexpected fall. Analog circuits connected to the sensors and the internal structures of the sensor systems can be examined by the visitors. The PIR sensor based uncontrolled flame detection system is also integrated to overall system.

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