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Improving fall detection by the use of depth sensor and accelerometer

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ABSTRACT

Since falls are a major cause of harm to older people, there is considerable demand for low-cost fall detection systems. To meet demands of the end-users we propose a new architecture for low cost and reliable fall detection, where an accelerometer is used to indicate a potential fall and the Kinect sensor is used to authenticate the eventual fall alert. In consequence, the depth maps are not processed frame-by-frame, but instead we download from a circular buffer a sequence of depth maps acquired prior to the fall and then process them to authenticate fall event. We determine features both in the depth maps and point clouds to extract discriminative fall descriptors. Since people typically follow typical motion patterns related to specific locations in home or typical daily activities, we propose to utilize k-nn classifier to implement an exemplar-based fall detector. We show that such a classifier is competitive on our publicly available URFD dataset in terms of sensitivity and specificity while being much more simple to implement on an embedded platform.

1. Introduction

People are living longer, and many forecasts make it clear that elderly people will have to live independently in their own homes for as long as possible. One of the highest risks of loss of independence for elderly persons living alone or spending much time alone is falling down [1]. Moreover, the risk of falls increases markedly with age, slower reaction and balance, and reduced muscle strength. Thus, approximately one out of every three seniors falls in any given year, and these sudden falls are the most common cause of injury and hospital admissions among this age group.

To extend the possibilities for independent living of the seniors, several smart home technologies [2] and smart cameras [3] have been proposed until now. In context of prolonged independent living, fall detection is an important task [1]. Medical alert systems with fall detection include simple push-button devices and accelerometer-based wearable systems. However, their applicability is restricted to limited markets like nursing homes rather than the broader aged communities. In context of independent living, currently available wearable systems are not acceptable by primary end-users, especially those who are not impaired. One of the most common reasons for disallowance of accelerometer-based assistive devices is their high false alarm ratio. This means that some daily activities are wrongly reported as falls, which in turn leads to frustration of the users.

A recent survey [4] demonstrates that the Kinect sensor can be very useful in detecting falls. However, the available algorithms for fall detection are not robust and do not exhibit both high sensitivity and specificity. Moreover, since such systems process, frame-by-frame, the depth maps acquired by the Kinect, they typically require a considerable processing power, and thus they usually need a PC or notebook computer. In order to keep low the number of false alarms as well as to reduce the computational burden we propose a novel architecture for fall detection, see Fig. 1. In our approach, the depth maps are stored in a circular buffer for an authentication of the fall if needed, whereas a threshold-based accelerometer module releases a depth map-based verification of the hypothesis about a potential fall. In contrast to the existing approaches [4], we extract the features not only in depth maps but we also process point clouds to extract very discriminative fall descriptor. Since people typically follow individual and distinctive at the same time motion patterns, related to specific locations in home or typical daily activities, we propose to utilize k-nn classifier to implement an exemplar-based fall detector.

The rest of the paper is organized as follows. In Section 2 we discuss related work that was accomplished in the area of fall detection. Section 3 is devoted to presentation of our embedded system for fall detection. In Section 4 we detail real-time and energy efficient data processing. The descriptors for distinguishing between fall and daily activities are discussed in Section 5. In Section 6 we present our URFD dataset as well as we discuss the classifier for distinguishing between daily activities and falls. The experimental results are discussed Section 7. Section 8 provides some concluding remarks.

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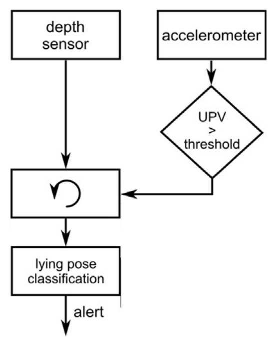

Fig. 1. Proposed architecture for reliable fall detection.

2. Relevant work

A range of body-attached sensors including goniometers, accelerometers, gyroscopes, pedometers, and actometers have been used to capture and analyze human movement [1]. Accelerometers offer a number of advantages in monitoring of physical human movements. Advantages of such sensors include a high accuracy even in noisy measurements as well as acceleration measurement down to 0 Hz. Rapid development in Micro-Electro-Mechanical Systems (MEMS) resulted in miniaturized and low cost accelerometers. These features have made possible development of small, lightweight, portable smart devices that can be worn without hindering physical activity. The smartphones and smartwatches are examples of mobile devices, which are equipped with accelerometers and which can be used to perform unobtrusive fall detection.

Majority of the accelerometer-based fall detection systems that were developed in the past investigates the use of a body-worn tri-axial accelerometer with a threshold algorithm [5]. A recent study [6] conducted by an international team of researchers evaluated the effectiveness of these algorithms to detect fall events within a database of real falls. The database contains accelerometer measures that capture the movements of participants, each for a period of two days. In all, it stores data from 29 real falls. Thirteen different algorithms were investigated to see if they were able to identify the real falls. Unfortunately, none of the investigated algorithms scored sufficiently high in both sensitivity (the ability to properly recognize falls that in reality occurred) and specificity (the capability to correctly identify a movement as a non-fall). Two algorithms achieved good scores on both of these measures, but each would create too many false alarms if employed as an automated fall detector. One of the main reasons for high false ratio of accelerometer-based systems is the lack of adaptability together with insufficient capabilities of context understanding. In consequence, they have difficulties in distinguishing fall events from typical daily activities, for example, lying down on the couch to relax, bending down to play with a pet, bending to pick up an object from the floor, or even just lying down to sleep.

Video monitoring systems use cameras that attempt to detect a fall acting on image-processing algorithms, which are designed to identify unusual activities. The main advantage of such systems is that the person does not need to wear any special device. However, this type of fall-monitoring is both the most expensive and most intrusive form of fall detection due to the fear of intrusion of privacy. Although many solutions for preserving privacy have been developed, people in monitored rooms still experience the feeling of being-watched, thus making the ordinary CCD cameras unacceptable in most cases, and especially in the bedroom and the bathroom. Moreover, while CCD-camera based techniques might work well in controlled environments, in order to be practically applied they ought to be adapted to non-controlled environments in which neither the lighting nor the resident tracking is fully controlled. Thus, such devices cannot work in nightlight or low light conditions. Additionally, the lack of depth information might lead to lots of false alarms. Nevertheless, due to recent developments in smart camera [3] and smart home [7] technology, the CCD camera-based solutions have some potential to be utilized in smart fall detectors.

As demonstrated several years ago, the cameras delivering in real-time the depth information can be very helpful in detecting and tracking faces and heads [8]. The head trajectory is a very useful source of information for behavior recognition and can be greatly advantageous for video surveillance applications, especially for fall detection [9]. Another promising research direction in this domain is the use of multiple omnidirectional cameras to observe and to track the inhabitants of a room [10]. Overall, the omnidirectional cameras are very useful in areas where large visual field coverage is needed, whereas stereo-pairs deliver very advantageous 3D information. Thermal imaging cameras, also called infrared cameras, which detect the heat given off by an object or human can also deliver very valuable source of information for detecting falls [11].

Recently, Kinect's depth camera has been proposed to be utilized in fall detection [12,13]. As demonstrated in the discussed work, depth information is sufficient to detect person undergoing monitoring. Since Kinect uses infrared light sensors to illuminate the objects in front of it and an infrared camera to observe them in invisible light, the fall detection can be done any time. In contrast to the discussed work, the algorithms presented in [14,15] rely on the 3D skeleton, which is automatically extracted by Kinect for Windows SDK/OpenNI-NITE framework. However, given that a person can be in any pose prior to a fall, it is very likely that the skeleton extraction may fail to acquire the skeletal model, or be unreliable in the period of the fall motion [16]. In [17] a network of multiple Kinect sensors is installed in different areas of a house monitoring the individual. However, it is unclear how a collaboration between the cameras under the communication and latency constraints, which is an important problem in camera networks [3], has been solved in the discussed work.

One way to improve the reliability of detection of emergency situations is to combine video/depth and accelerometer signals, as proposed recently [13,18,19]. Recent work [20,21] demonstrates that combining the depth with inertial sensors improves the human activity recognition. In this work, we demonstrate that the thresholded accelerometer signal can be used to reduce the computational overheads, whereas the combined data from the accelerometer and the depth sensor allows us to obtain lower false alarm ratio. We also propose a very discriminative fall descriptor and show that a k-nn classifier achieves very good results on our publicly available URFD dataset.[1] The system has been designed to consume least amount energy to achieve reliable fall detection.

3. The system

Having on regard that the system for fall detection should be inexpensive, we developed an energy-efficient data processing architecture, see Fig. 1, and implemented the algorithms on a low-cost PandaBoard ES, which is a development platform for mobile applications. It features a dual-core 1 GHz ARM Cortex-A9 MPcore processor with Symmetric Multiprocessing (SMP) and a programmable C64x DSP. The board contains 1 GB of DDR2 SDRAM, dual USB 2.0 ports as well as wired 10/100 Ethernet along with wireless Ethernet and Bluetooth connectivity. It supports various Linux-based operating systems such as Android, Chrome and Linux Ubuntu, which can be bootloaded from a SD memory card.

[1] http://fenix.univ.rzeszow.pl/~mkepski/ds/uf.html.