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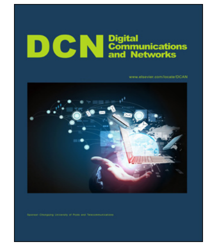

3D depth image analysis for indoor fall detection of elderly people

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Abstract
This paper presents a new fall detection method of elderly people in a room environment based on shape analysis of 3D depth images captured by a Kinect sensor. Depth images are pre-processed by a median filter both for background and target. The silhouette of moving individual in depth images is achieved by a subtraction method for background frames. The depth images are converted to disparity map, which is obtained by the horizontal and vertical projection histogram statistics. The initial floor plane information is obtained by V disparity map, and the floor plane equation is estimated by the least square method. Shape information of human subject in depth images is analyzed by a set of moment functions. Coefficients of ellipses are calculated to determine the direction of individual. The centroids of the human body are calculated and the angle between the human body and the floor plane is calculated. When both the distance from the centroids of the human body to the floor plane and the angle between the human body and the floor plane are lower than some thresholds, fall incident will be detected. Experiments with different falling direction are performed. Experimental results show that the proposed method can detect fall incidents effectively.

1. Introduction

It is estimated that 17% of the population in China will be over 60 by 2020. The health care of the elderly people living alone is becoming an important problem. One of the risks that the elderly people living alone face is falling down. For instance, there are more than 1.6 million elderly people who suffer fall-related injuries each year [1]. The fall is caused by the fragile bodies of the elderly people and the

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potential surrounding fall hazards (slippery floors, poor lighting, unstable furniture, obstructed ways, etc.) in home environments. If falls can be noticed in time, fall injuries and the associated costs can be reduced dramatically [2].

Most existing fall detection and alarm systems can be classified into three categories: wearable sensor-based, ambient sensor-based, and computer vision-based methods. Wearable sensor-based methods usually rely on accelerometer sensors that are attached to the subject's body, which has high level of obtrusiveness [3]. Ambient sensor-based fall detection systems use external sensors embedded in the environment, including the pressure sensor, acoustic sensors, electromyography sensors and so on [4,6]. With the development of computer vision in recent years, image and video-based methods have become popular in fall detection systems [7,8]. This kind of method is non-obtrusive, and convenient for elders.

In the visual fall detection systems, the status of the scene of the elders can be delivered to an appropriate destination if a fall is detected and alarm signals are triggered. Fall detection systems usually focus on a single elder in practice. If the situation contains two or more people, segmentation and marking module will be used to separate each person and detect and track them individually [9]. However, the fall can be delivered to the destination by the other person. So our work deals with the fall detection of the single elderly person in the home environments.

Since 2D grey or colour images are the projection of 3D targets, the problem of appearance deformation may occur in the fall detection [10]. In order to deal with the problem, this paper presents a new fall detection method based on analyzing the shape in depth images captured by the Kinect sensor. It can be described as follows: 1) depth images are pre-processed by a median filter for both target images and background images; 2) the silhouette of the moving individual in depth images is achieved by the subtraction method of background frames; 3) the floor plane equation is estimated by the least square method and a disparity map converted from the depth image; 4) shape information of the human body in depth images is analyzed by a set of moment functions, and the coefficients of ellipses are calculated to determine the direction and position of the individual. The centroids of the human body and the angle between the human body and the floor plane are further calculated for fall incident detection. When both exceed some thresholds, fall incident will be detected.

The rest of this paper is organized as follows. Section 2 reviews the relative works in the area of fall detection of the elderly people. Section 3 describes the proposed fall detection method in detail. Experimental results are presented in Section 4 to show the feasibility and performance of the proposed method. Finally, a brief conclusion is drawn in Section 5.

2. State-of-the-art

This section reviews three categories of sensors adopted in fall detection and two classes of fall detection methods. Applications of depth image and moment function in fall detection are also discussed.

2.1. Sensors adopted in fall detection

Fall detection systems have been designed by using either external sensors or wearable sensors. External sensors are deployed in the vicinity of the body in concern, and wearable sensors are connected to the subject of interest (SOI). Most existing fall detection systems can be divided into three categories: wearable sensor-based, ambient sensor-based, and computer vision-based systems [2,11].

Accelerometers are the most common wearable sensor used today. They are small, cheap and can easily be placed on any part of the body [12], which are an alternative to external sensing [2]. The wearable sensor-based approach relies on embedded sensors to detect the movement and position of the subject [11]. Accelerometers are a type of wearable sensors and they are widely used in fall detection systems [13]. There are several main wearable sensors-based methods in the current research, including accelerometer [11], fusion of accelerometer and posture sensors [14], inactivity with accelerometer [15], tri-axial accelerometer [11] and posture-based method [16]. The advantage of wearable sensors is they are generally less expensive than external sensors. However, the main drawback of wearable sensors is high drift.

Ambient sensor-based fall detection methods focus on how to embed sensors into the environment, and how to track the elderly person's movements. Usual features for fall detection and fall tracking are pressure, vibration, sound, infrared array, and so on [2,10]. Zigel et al. proposed a fall detection system based on ground vibration and sound sensors [4]. Infrared arrays can improve the accuracy and efficiency in fall detection [17]. Pressure sensors are commonly used because of their low cost and non-obtrusiveness, which is based on sensor pressure changes. The main disadvantage is the low detection precision of these sensors (below 90%) [2]. Since the pressure is sensed all around the object, they may generate false alarms. In addition, the distance has a direct impact on the accuracy of detection. Even though the sensor is very sensitive, the accuracy will decline if the fall occurred 5 m away [16] In order to obtain higher accuracy, the room should contain more sensors.

In the past 10 years, there have been great advances in computer vision and video cameras. It opens up a new branch of methods for fall detection. In general, fall accidents happen in less than a second of time, usually between 0.45 and 0.85 s [2,18], during which the falling people greatly change in posture and shape. These sudden changes are crucial to determine whether the fall is happening. Compared with other methods, vision-based methods are more robust and are less intrusive [10]. At the same time, more and more cameras are used in a family's daily life. This creates favourable conditions for the application of vision-based methods. Vision-based fall detection systems monitor the position and shape of the subjects which benefit from techniques of pattern recognition and image processing methods.

Vision-based fall detection methods can be broadly divided into three kinds: methods using a single RGB camera, 3D-based methods using multiple cameras, and 3D-based methods that use depth cameras [8,10,18]. Fall