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Modeling abnormal walking of the elderly to predict risk of the falls using Kalman filter and motion estimation approach ☆

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ABSTRACT

It is estimated that in 2050, more than one fifth of the world's population will be over 65 years old and these people will face serious risks in their future life. In this paper, a new method is proposed which models the motion aggregation pattern by receiving video strings containing the walks of the elderly and tracking their motion to identify the position of the joints involved in movements. Then, drawing on biomechanical laws of motion and joint angle estimates, the skeletal framework is mapped on the image, which is eventually transferred to the 3D space. The data include a set of 322 video strings taken from CASIA and CAVIAR databases and a sample of the falls in the elderly taken from Sabzevar's Mother Nursing Home in Iran. The results show the effective performance of the algorithm in identifying the risk of falls associated with abnormal walking of the elderly.

1. Introduction

The method often used by clinicians and motion specialists for the analysis of movements and walks of individuals involves the use of markers or external signs mounted on the body, which are aligned with the bony parts attached to the joints. These markers may be attached to the body separately or in form of a cluster. Triple cameras are used to reconstruct the 3D motion of an individual. Each year, thousands of people suffer from damages and injuries caused by the loss of balance and falls including broken joints or fractures, which in severe cases may be even life threatening. According to World Health Organization (WHO), in developing countries, people over 60 are regarded as the elderly. They are further divided into three distinct groups: people aged 60–74 that are called young-old; people aged 75–90 that are called old, and people older than 90 that are called old-old [1]. The number of the elderly has tripled in the last 50 years and it is expected to maintain its current rate in the next 50 years [2]. To deal with the growing problems of the aging population in the society, appropriate technology and systems are needed to provide safety measures and to help improve the lives of this vulnerable segment of the society. According to the demographics published in 2010, it is estimated that in 2035, one third of the European population will be over 65 years old [3]. Amongst the greatest risks facing the elderly are the loss of balance or falls, which according to statistics, constitute more than 60% of the admission of the elderly to the hospitals [4]. Studies show

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that in general 25–47% of the elderly will at least once experience falls, and this figure is approximately 50% amongst the elderly living in the nursing homes [5]. The injuries caused by falls and loss of balance may negatively affect the performance and independence of the elderly. Thus, it is of paramount importance to identify the elderly who are at the risk of fall [6]. The first step to prevent this unexpected accident is to alleviate the side effects of falls. The consequences of such accidents will be devastating if the elderly fail to inform others of their condition in time [7].

Abnormal gait is a common complication in 8–19% of the elderly and it is especially prevalent in individuals aged 65 years and above and in 50% of people aged more than 85 years [8,9]. Gait abnormalities and the subsequent sensorimotor function complications that arise from the old age or diseases can affect the manner of walking in people, especially the elderly. Some research suggests that that there are marked differences between gait patterns of young people and the elderly [10,11], which are primarily due to senility, especially problems in the neuromusculoskeletal system.

Within the framework of wearable sensors, Sixsmith and Johnson proposed an intelligent sensor to detect falls in the elderly in 2004 [12]. Alexander et al. [13] proposed another system in which sensor network techniques were used for online monitoring and surveillance of the elderly.

In other techniques, a wireless sensor network and an alarm system is employed in which the elderly use a button to signal their situation when they fall. The main shortcoming of this system is that the elderly are required to wear bulky clothes without which they will be unable to declare their situation when they lose their balance. Further, this technique will be inoperable if they lose consciousness after a fall.

Moreover, there are other systems to detect falls in the elderly that are more efficient than sensor networks. Vibration analysis instruments, gyroscope, status belts and pressure gauge board are amongst the methods designed based on the manner of walking in individuals. Bourke et al. [14] created a secure threshold for fall detection algorithms that used a biaxial gyroscope. Other systems use accelerometers that can identify the range and acceleration direction of the elderly's movement to detect their motion. The simultaneous combination of the accelerometer system of the elderly's movement and the estimate of the movement's direction was also proposed by Nyan [15]. Vibration analysis system is also used to detect falls in the elderly or the disabled. Zigel also improved the device used for detecting the floor vibration by adding a sound sensor [16]. As to the video surveillance algorithms, Nascimento [17] proposed a method based on the analysis of Machine Vision for detecting changes in the position of individuals. Wann and Ju [18] detected the position of the elderly using video surveillance and Liao [19] detected slips and falls in the elderly using Bayesian networks.

Within the framework of movement modeling, some of the proposed solutions involve detecting the position of the joints in the video sequence using non-automatic shifting [20]. Unsupervised learning algorithms such as body organs design based on formal structure were proposed by Song et al. [21]. Cheung et al. were the first to derive 3D models from video frames [22], which were based on the systematic structure of motions in people. Accordingly, they extracted the skeleton of the human body by analyzing sample images. Pose estimation techniques, which are based on the body structure and motion equations, are the most recent strategies used by the researchers [23]. In motion modeling discussions, there may be some inaccuracies in the data related to the movement analysis, which are caused by shifts in the soft tissue of the feet. Low accuracy, low processing speed, lack of real-time response of the system and high positive error rate are among the weaknesses of these systems.

The remaining of this paper is organized as follows. In Section 2, the proposed method and its details for implementing walking model are presented. This section consists of HSV space conversion, Kalman filter, motion estimation, human walking modeling, Euler angles description and joint identification in the model. In Section 3, the results of the simulation are discussed. In this section, the implemented algorithm is evaluated and the results are compared to other similar systems. Finally, the conclusions are drawn in Section 4.

2. Proposed algorithm

2.1. HSV space

In many machine vision and image processing algorithms, the intensity of disproportionately high or low light shades in separating a special part of the image may cause errors. One of the efficient conversions of the color space caused by removing the unwanted effects of the light is HSV space [24]. The features of color space in HSV environment can reduce the complexities between the image surface and the intensity of unwanted light that produce errors. In calculation of H section, it is assumed that $M = \max(R,G,B)$, $m = \min(R,G,B)$ and $d = M - m$. The values of r, g and b are also calculated according to $r = (M - R)/d$, $g = (M - G)/d$ and $b = (M - B)/d$. The main advantage of converting frames from RGB into HSV space is minimizing the effect of a person's shadows in images, which is the major cause of errors in mode separation. RGB image is converted into HSV space diagram as shown in Fig. 1. In Fig. 2, a set of frames taken from a video sequence in Sabzevar's Mother Nursing Home in Iran is shown. HSV space demonstrates more efficient performance in eliminating reflection and shadows compared to other colored spaces. However, this is not always the case and this space may encounter problems when researchers aim to decompose foreground and background of video frames using algorithms such as Gaussian Mixture Model [25]. For instance, it would be problematic when there are reflections or large shadows in frames. The stability of sector V offers two main advantages in HSV transition: first, the background model remains unchanged and second, updating the background model only supports latest changes in the luminance since the difference in light conditions explains the