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The implementation of an intelligent and video-based fall detection system using a neural network

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ABSTRACT

This paper presents the development of a smart fall detector to minimise accidental falls which occur among elderly people, especially for indoor situations. A video-based detection system was utilised, as this can preserve privacy and monitor the physical activities of elderly people. In order to identify the correct situation among a set of predetermined situations, which consisted of praying, sitting, standing, bending, kneeling and lying down, a neural network system was incorporated in the fall detection computation algorithm. The neural network analysed the binary map image of the person and then identified which plausible situation the person was in at any particular instant in time. The fall detector's performance in successfully detecting falls was then evaluated using two statistical metrics: specificity and sensitivity. The performance of this fall detection system in identifying falls was also evaluated during two non-normal gait movements, stumbling and limping, so as to mimic the motions of a good proportion of the elderly people having these types of walking gait movements. It was shown that the implemented video-based fall detection system could be a promising solution for detecting indoor falls among senior citizens.

1. Introduction

Felder and Alwan [1] posited that the percentage of elderly people as a proportion of the population has increased rapidly over the last two decades, and that, therefore, there is a need for proper care to be administered to them so that they can live happily and as independently as possible [2]. Unfortunately, accidental falls that occur among elderly people can cause serious physical complications or death [3]. For this reason, it was crucial to investigate and develop a smart and reliable fall detector to alleviate this issue. An efficient fall detection system can restore confidence and enable senior citizens to carry on with their normal active lifestyles [4].

The current methods commonly used to detect falls are portable sensors which need to be worn or embedded on various parts of the human body [3,5] in order for them to be able to detect falling events experienced by the person. If the wearer of these portable devices falls down, a signal is sent to a response centre for analysis and subsequent resolution [6]. For instance, some researchers have attempted to detect falls using different types of sensors, ranging from accelerometers to microphones or gyroscopes, or a combination of all these [7,8]. However, the majority of senior citizens are not comfortable wearing these devices wherever they go, and to make matters worse, the standard portable sensors do not generate easily interpretable information, making the detection of falls difficult or unreliable and hence putting the lives of elderly people at risk [8,9].

Another emerging method in fall detection is the use of video-based sensors. A video-based sensor uses a video surveillance mechanism as well as digital image processing applied to the real-time video-recorded images in order to detect whether or not a falling event has taken place [10]. An efficient and reliable surveillance video system needs to be robust in order to tackle image processing issues. Therefore, the correct choice of camera, the position of the camera and an appropriate video compression method, so that artefacts can be reduced [11], are important factors to take into consideration in the implementation of a video surveillance system. Londei et al. [12] found that in a group of 30 senior citizens who experienced sudden falls, about 87% of them were in favour of this type of intelligent video-monitoring system. The advantages of the video surveillance system are that they provide a secure and quick intervention for senior citizens, and that video-taped images before the fall occurrences can supply important information enabling better understanding of the origins of falls. By so doing, both the security and interventions for fall events can be improved. As stated by Rougier et al. [11], the video surveillance system seems to be a promising fall detection system to help elderly

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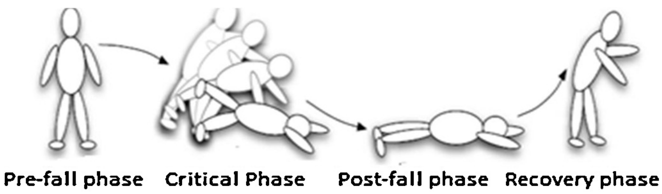

Fig. 1. The different phases of a fall event [12].

people overcome their fear of falling. However, some of them are concerned about the safety and privacy of the transmission of the video-taped images.

Furthermore, current research should also improve on the accuracy of the video-based detector, as, for instance, studies conducted by Willems et al. [13] showed that detection rates up to 85% (by recording video images from the side view of the person in motion) and 78% (by recording the images from the frontal view of the moving person) can be achieved using a video-based fall detection system. Therefore, this paper presents a video-based sensor approach to detecting falls, employing an intelligent neural network system algorithm to detect falls while simultaneously preserving the privacy of the recorded person.

1.1. Different phases of a fall event

The main issue for any fall detection problem is to differentiate a fall from all the daily life activities, such as crouching, sitting down or praying activities that bear similar characteristics to falls. Noury et al. [14] posited that a fall event can be separated into four specific phases, which are shown in Fig. 1.

As shown in Fig. 1, the pre-fall phase represents the normal daily activities, which include sudden movements towards the ground or floor, such as sitting down, crouching or praying. These activities should not induce any alarm from the fall detection system. Secondly, the critical phase, which normally lasts for just a brief period, represents the movement of the body towards the ground or the shock of the body's impact with the ground. Thirdly, the post-fall phase is normally characterised by a person remaining motionless on the ground just after the falling event has occurred. This post-fall phase can be represented by a lying down position or the absence of significant motion. Finally, the recovery phase is the period where the person is actually able to stand up unassisted or with the help of another person.

1.2. Importance of neural network in real-time applications

Recently, artificial neural networks can solve complex problems in industry and academia. They can solve many engineering problems and intelligent systems currently play crucial roles in the advancement and innovation of products worldwide [15]. In the medical field, they are used to monitor the patients' daily health in hospitals Debard et al. [16] and in all areas of life. In the engineering field, the neural networks are used to classify patterns; to develop nonlinear filters which are adaptable to any situations and they are utilised in system identification as well. Nowadays, the neural network is considered an important available artificial intelligence tool to humankind [17].

These artificial systems perform much better than linear system in resolving complicated computations. In addition, when one component or element of the artificial neural system fails to work, the artificial neural system still continues to function without an overall system failure because the neural system has the characteristic property of working in parallel. Normally, the learning process of a neural network relies on the desired outputs and the inputs. Moreover, the neural network does not require any re-construction as the structure can be used to build on or include new elements or components. The neural network requires simple arithmetic tasks such as additions and multiplications. However, the neural network needs to be trained properly so that it can function well or to the desired response. And also it is worth to know that as the neural network structure increases, this result in a lengthy processing time [18].

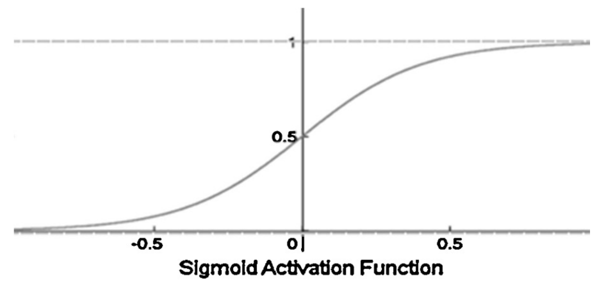

Fig. 2. The sigmoid activation function for decision making.

1.2.1. The working principle of neural network systems

A neural network is a structure which can receive inputs, process these inputs to produce the output where the input data can be of any dimensional value. For instance, an image which is used in this research is two dimensional. There is an error created at the output layer when the input data is presented to the neural network system. This error data represents the difference in value between the real system output and the desired response value. Afterwards, this error is fed back into the neural network system to adjust its weights through the use of a learning rule.

The basic building block of a neural network is the neuron, which consists of a black box with weighted inputs and an output. The black box section of the neuron consists of an activation function $\Phi(X)$; in this case, it is $\Phi(W\text{–}T)$, where W is the weighted sum of the inputs and T is a threshold or bias value. The weights are initialised to some small random values, and during the training process, these weights are updated. The weighted sum (W) is given below from inputs 1, 2, 3,. . . to n and associated weights:

$$W = \sum_{i=1}^{n} weight_i \times input_i \tag{1}$$

1.2.2. Neural network activation function

The activation function ensures that the output of the neuron in a neural network is between certain values (usually 0 and 1 or −1 and 1). Various functions can be used for the activation function Φ. The most common ones include the step function and the sigmoid function. In this paper, the sigmoid function is used in the back propagation neural network, as it is the classical activation function. The sigmoid function $\sigma(x)$ is defined as:

$$\sigma(x) = \frac{1}{1+e^{-x}} \tag{2}$$

The sigmoid function has the graph which is shown in Fig. 2.

The following section describes the methods and materials used for the implementation of a smart fall detector using a neural network algorithm.

2. Materials and methods

A sample of 20 healthy participants took part in this study; 10 participants performed normal walking gait motions, which were then followed by actions of praying, sitting, falling and lying down (see Fig. A1, Appendix A), while the other 10 participants performed non-normal walking gait motions (stumbling and limping), which