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State of the Art: A Study on Fall Detection

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***Abstract*—**Unintentional falls are rife throughout the ages and have been the common factor of serious or critical injuries especially for the elderly society. Fortunately, owing to the recent rapid advancement in technology, fall detection system is made possible, enabling detection of falling events for the elderly, monitoring the patient and consequently provides emergency support in the event of falling. This paper presents a review of 3 main categories of fall detection techniques, ranging from year 2005 to year 2010. This paper will be focusing on discussing the techniques alongside with summary and conclusion for them.

***Keywords*—**State of the art, fall detection, wearable devices, ambient analyser, motion detection.

I. Introduction

FALLS for the elderly population or patient is a very serious issue. According to Centers for Disease Control and Prevention (CDC), one out of three adults age 65 and older falls each year.

In the event of a fall, a strong impact may be inflicted on their body, causing bruises, internal bleeding or even bone fractures. The injuries might be perilous and fatal. The elderly might not be able to stand much impact as compared to younger people. For centuries, many methods have been used to decrease the likeliness of falls. Traditional methods include instruments like walking stick, wheel chair and so on. Thanks to the advancement of technology, fall detection systems can be implemented at home and perform monitoring. The fall detection system is able to decrease the chances of mortality and therefore increasing the rate of survival in a falling event, giving the elderly to live on independently.The concept is simple, the system detects and identifies a fall and send an alert should a fall happens. With this system, help can be given efficiently to the elderly. A typical fall detection system comprises of camera, sensor, computer and network. Due to the complexity of the current systems, it gets harder to implement.

II. Fall Detection System

There has been a lot of fall detection techniques proposed since the early 1990s. It can be said that most fall detection systems runs on the same mechanism. Fig. 1 shows the general framework of a fall detection system [1].

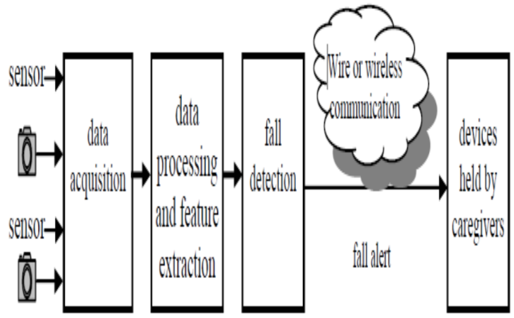

Fig. 1 General framework of a fall detection system

From the research made through the fall detection systems which consist of prototype system, approaches or proposals, it can be categorized into 3 main categories. First category of fall detection system involves wearable devices. The next classification is fall detection involving ambient analyser. The last category of fall detection involves motion detection. The details of the systems which include how the systems work as well as the pros and cons will be discussed in detail later on.

III. Fall Detection involving Wearable Devices

A. A New Washable Low-Cost Garment for Everyday Fall Detection

[2] introduced a new way of detecting falls using a garment. The whole fall detection system consists of a washable pullover with integrated acceleration sensors, evaluation and control electronics. The idea came in as elderly people may often forget to carry sensor devices along.

The system is usable in daily life. Fig. 2 shows the system's parts and interfaces.

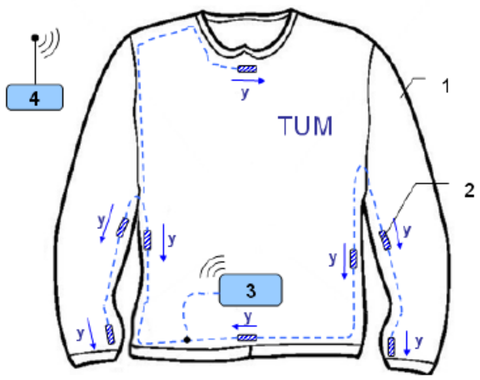

Fig. 2The system's components

The parts are labelled in numbers, which are garment (1), acceleration sensors (2), electronics unit (3) and base station (4). The y-axis is defined for each sensor as shown along the cable net. The garment's physical appearance does not differ much than that of a normal garment. Inside the garment, there

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are eight acceleration sensors to detect the motions of the torso and the upper body. The data is then read in the electronics unit and the fall occurrence is analysed. An alarm is sent to the base station if there is a fall. The whole system runs on rechargeable and removable battery. The algorithm of how the system works is shown in Fig.3.

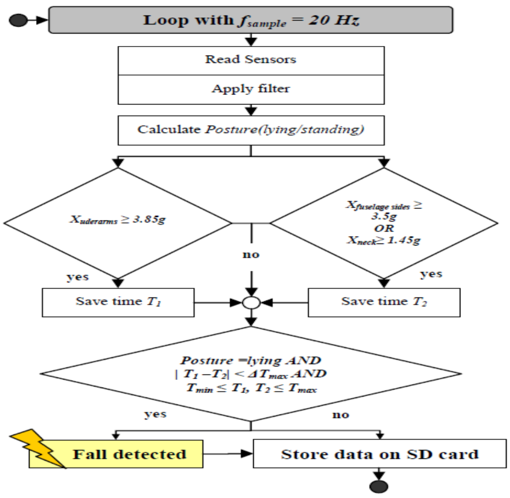

Fig. 3The algorithm of the system

To detect a fall, it is required to calculate the geometric mean value ($|\vec{a}|$) of all sensor axes for all sensors. The gravity is subtracted from this afterwards using (1).

$$X = |\vec{a}| - g = \sqrt{a_x{}^2 + a_y{}^2 + a_z{}^2} - g$$
$$\sqrt{a_x{}^2 + a_y{}^2 + a_z{}^2} \quad (in\ static\ state) \qquad (1)$$

If the resulting values exceed a certain threshold, a possible fall is detected. MATLAB is used to analyse the preliminary data. The calculation concluded that combination of sensors of the underarms provides the maximum of true-positive-rate and the minimum of false-positive-rate.

If a possible fall is detected, it is checked whether the posture of the person has changed from vertical to horizontal. One of the four torso sensors is used to calculate the posture of the person. A combination of the normalized y-axis of the sensors located on the left and right side of the torso is calculated using Formula 1.2 as information from a single sensor is insufficient. a_{norm}amounts to $1 \pm \varepsilon$ in the vertical posture and to $0 \pm \gamma$ in the horizontal posture, where ε and γ indicate a certain tolerance area and g is gravity.

$$a_{norm} = \frac{a_y}{g} \qquad (2)$$

The wrist and trunk thresholds would be exceeded at different times. Therefore the times T_1 (wrist) and T_2 (trunk), each exceeding are saved and compared later on. A maximum time interval $\Delta T_{max} = 500ms$, in which both indicators have to be set, was deduced empirically. To let the body come to rest after a fall, T_1 and T_2 are furthermore demanded to be a minimum of $T_{min} = 600ms$ in the past. On the other hand, both indicator times must not be older than$T_{max} = 1200ms$, which would indicate a too slow event. When all the conditions are fulfilled, a fall is confirmed.

Pros: low cost, fast, resource-saving algorithm, washable garment.
Cons: limited power supply.

B. Wearable Sensors for Reliable Fall Detection

[3] introduced the concept of using a wearable sensor for the monitored subject. The goal is simple, a system using an accelerometer (Analog Devices ADXL210E) which is small and light-weight, enabling the device to be worn by the person without interrupting his/her daily routines. It is recommended to wear the device at the waist for more success [4].

The device worn by the person consists of two dual-axis MEMS accelerometers mounted at right angles to each other, such that three orthogonal axes of acceleration can be computed to detect any falls. The design of the device is shown in Fig. 4.

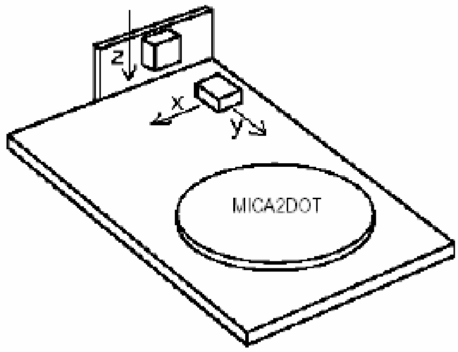

Fig. 4 Fall detection sensor board

In general, when an individual falls, he or she will go through a large change in position from before the fall to after. A good example is from standing upright to lying flat, an orientation change in the mote of 90 degrees. The actual change may vary, depending on the beginning and end position of the person. The fall detection algorithm is shown in Fig. 5 below.

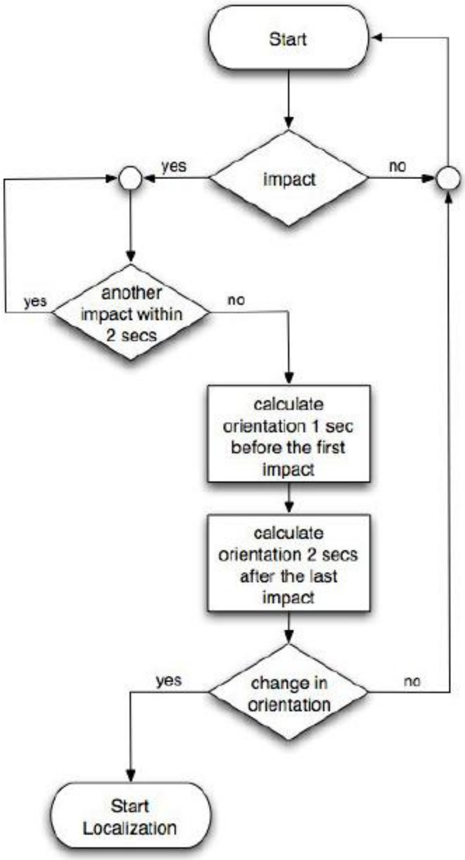

Fig. 5 Fall detection algorithm of the system

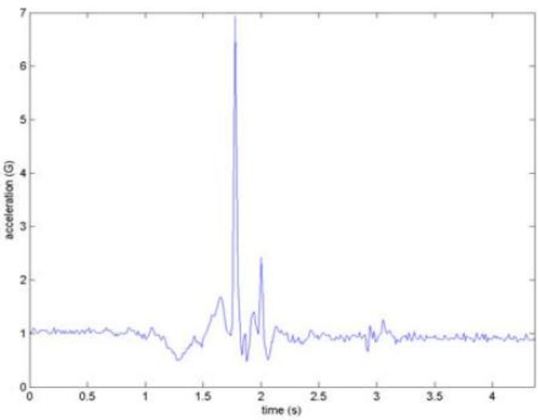

Fig. 6 Acceleration observed while falling backwards

Fig. 6 shows the norm of the acceleration observed during backward fall. There are several important points which must be taken in account. 1) Between time $t = 1s$ and $t = 1.5s$, there is a small dip, signifying a short duration of free fall; 2) At time $t = 1.75s$, there is a large peak, signifying impact; 3) After peak of impact, there is a dampening effect, whereby the force of impact is partially absorbed by the body and the ground.

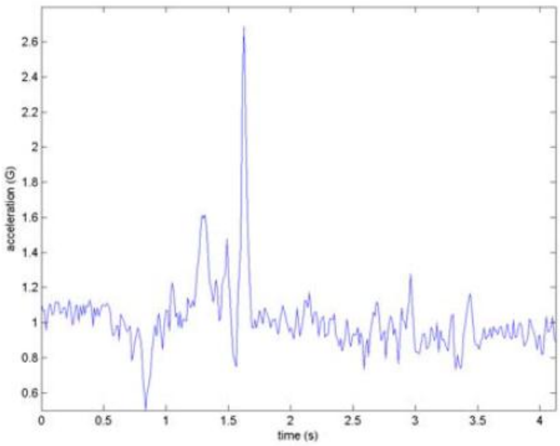

Fig. 7 Acceleration while sitting

In Fig. 7, it can be seen that the acceleration profile of sitting looks the same as to that of falling, with the conspicuous difference that the magnitude is much smaller.

Pros: simplicity of system, device is small, low cost.
Cons: limited power supply, limited alarm coverage, inaccurate results if device is not worn properly.

IV. Fall Detection Involving Ambient Analyser

A. Detection of Fall among the Elderly by a Floor Sensor using the Electric Near Field

Reference [5] introduced the idea of detection falls with the use of a floor sensor. This method tracks people with a near-field imaging (NFI) floor. The system consists of three main steps which are feature extraction, pose estimation and experimental performance evaluation. The sensor detects the locations and patterns of people by measuring impedances with a matrix of thin electrodes under the floor [6]. It will monitor any vibrations created and perform matching processes to determine whether there is a fall. If there is a fall detected, an alarm will be triggered.

An example of the implementation of the system is shown in Fig. 8.

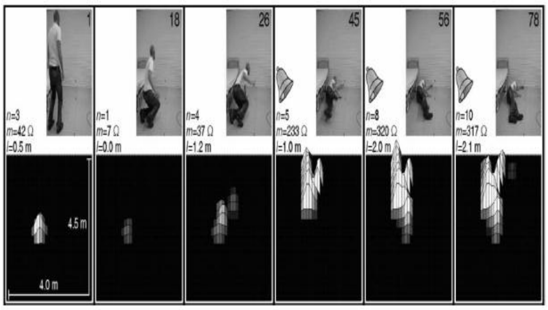

Fig. 8 Implementation of the system

Pros: immune to shading, minimal computing needs.
Cons: false alarm might occur for a non-human object fall, difficult to set up.

V. Fall Detection Involving Motion Detection

A. Multiple Object Tracking for Fall Detection in Real-Time Surveillance System

Most fall detection systems use worn sensors, by which the sensor is to be attached or carried around by the user. However, there is catch. If the user forgot to wear the detector, how is it possible to detect fall? Therefore, visual detection based fall detection system has been introduced to overcome these problems. Reference [7] introduced multiple objects tracking for fall detection. This system uses a low-cost USB PC camera and comprises of three main modules which are multiple object detection, multiple persons tracking with occlusion handling and fall detection.

In the first module which is multiple object detection, it is based on the background subtraction and the double-difference image. A clean background model similar to an adaptive background modelling algorithm capable of reducing noise generated from a camera is created. Then, the method builds the double-difference image and creates 2D/3D temporal templates. The image provides important clues for detecting the object and detecting fall events.

The second module is multiple objects tracking with occlusion handling. Occlusion is a major problem in visual tracking. Therefore, the 3D information obtained using 3D spatio-temporal templates and the $\alpha - \beta - \gamma$ filter is employed to deal with this problem. The filter is capable of tracking an accelerating target without steady-state error. In the event of a new target object entering the scene, the system will initiate a foreground model taken by 2D/3D temporal templates and the features to track the object are stored. If an occlusion occurs for two individuals, objects will be merged and a merged object is created with a new foreground using the segmentation algorithm. The new foreground is classified as a group and recorded as a group list. After a split event for the objects, each object is searched to find whether it can fit with any match by comparing the recorded data record list.

The third module is fall detection. The motion magnitude of an object is greater than that of any other objects or activities. Thanks to the enhanced motion information [8] contained in the double-difference images, detecting fall activities are made easy. The ratios of width to height during fall activities are significantly higher than the ratios of normal activities. The ratio is then compared to a threshold value to decide whether as fall has occurred or not. If the ratio is above the threshold value, this means a fall event has occurred, with the frame on the test video sequence being set to 1, otherwise 0.

Fig.9 shows the result of multiple people tracking and fall detection results collected by the system. In the figure, (a) shows two people entering the scene, (b) shows two people walking, (c) shows two people standing, (d) and (e) show one person standing and another falling aside and (f) shows one person walking and leaving while the other person fell down.

Variations of width to height of bounding box enclosing each object is depicted in Fig. 10. For Person 1, (a.1) is entering and walking, (a.2) is standing and (a.3) is walking and leaving. As for Person 2, (b.1) is entering and walking, (b.2) is standing and (b.3) is falling aside. It can be seen that during the fall activity of Person 2, the ratio is significantly higher than the ratio of activities of Person 1.

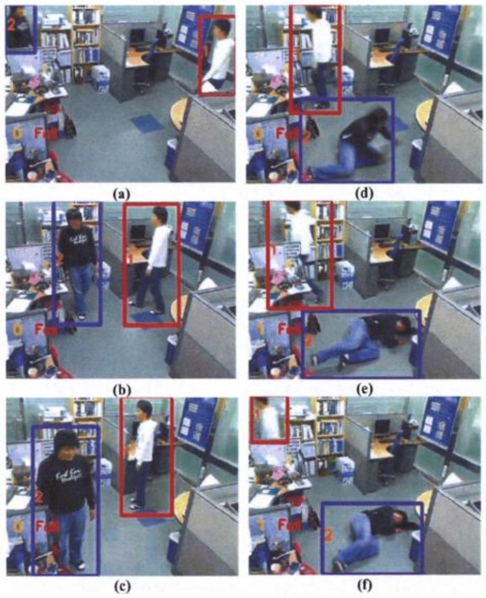

Fig. 9 Multiple people tracking to and fall detection

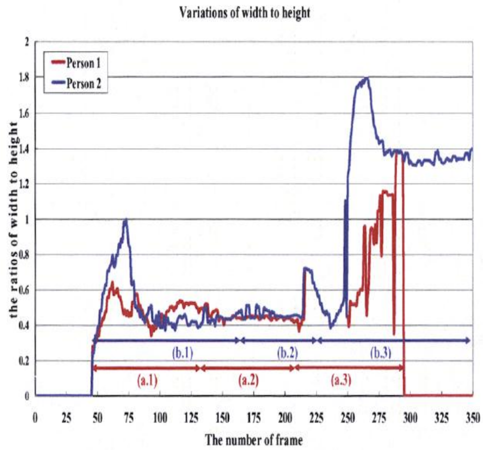

Fig. 10 Variations of width to height of the bounding box enclosing each tracked object on the test video sequence

Pros: easy to deploy, low cost, no device to wear, applicable to existing surveillance system.
Cons: privacy violation, sensitive to change in ambient, limited monitoring area.

B. A Multi- Camera Vision System for Fall Detection and Alarm Generation

Existing implementations of fall detection systems mostly are applying worn-on sensors, for example the device is worn on the wrist or place inside a garment as explained previously. Owing to the systems which are based on low-level sensors, they are somewhat inaccurate in environment sensing. Besides that, they can be intrusive and prone to be forgotten especially by the elderly. Reference [9] has introduced the use of computer vision technique to overcome this issue. This system uses camera to detect events and this is not that intrusive since it requires no devices to be worn. It is recommended to use a high-resolution camera for better image quality to process later on. Multiple cameras should also be deployed to monitor at multiple angles. The overall schema of the system is shown in Fig. 11.

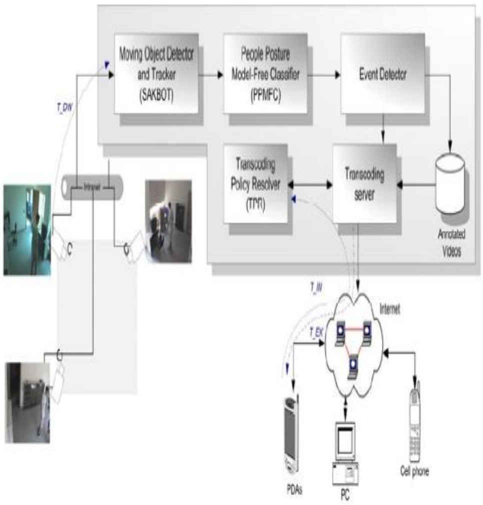

Fig. 11 Overall schema of the system

Based on the system, a moving object detector and tracker (SAKBOT) is used to extract out the moving objects from each camera. Next, tracks that fulfil some geometrical and colour constraints are sent to the people posture model-free classifier (PPMFC). The purpose of this is to detect an occurrence of an event. In case of a detection of a falling activity, the system then sends an alarm via the internet to any computers or handheld devices.

Pros: it involves no worn-on devices, accurate.
Cons: privacy intrusion, sensitive to change in ambient.

VI. Conclusion

In this paper, various techniques of fall detection have been researched. Existing methods may not be perfect in solving the problem of fall detection, however, the knowledge used in the existing algorithms has provided a foundation to improvise and develop new techniques to improve its former to achieve better efficiency and effectiveness. The techniques have their own pros and cons. The usage of these techniques depends mainly on the condition where it is applied to as well as the preference of the user. From my point of view, an on-going study and exploration in this particular field is a must so it can be further improved in the future.

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