Fall Detection Analysis with Wearable MEMS-based Sensors

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***Abstract*—Accidental falls are frequent and dangerous events for the elderly population, which can result into serious injury or fracture of bones especially hip bone injury or other joint fractures. There are several methods for detecting falls of elderly, such as camera-based, personal emergency response System (PERS), and wearable sensor-based. However, the camera-based method is limited by instrumented spaces and the PERS is suffer from inability to give an alarm after a fall. The wearable sensor-based fall detection is not limited to instrumented spaces, moreover, it is easily to detect the falls through tracking the kinematic information about the monitored person. In this paper, a wearable Micro-electromechanical Systems (MEMS)-based sensors module is designed for fall detection including one three-axis accelerometer, one three-axis gyroscope and one three-axis magnetometer. However, falls from activities of daily living (ADL) make it difficult to distinguish real falls from certain fall-like activities such as sitting down quickly and jumping. An approach is proposed using attitude angles to reduce false falls through tests of static postures and dynamic transitions. Meanwhile, the proposed method has real-time response and high computation efficiency.**

Keywords—fall; elderly; wearable; MEMS; attitude

I. INTRODUCTION

With the aged population increased continuously to 15% of population in developed countries, the elderly will suffer from more injuries caused by fall [1,2].Falls not only cause physical injuries such as disabling fractures [3], but also have dramatic psychological consequences that reduce elderly people's independence. Hence, reliable fall detection for elderly is of great importance for the whole society. However, falls are a common issue. It is difficult to distinguish real falls rigorously from activities of daily living (ADL) such as sitting down quickly and jumping, which are easy to result in many false positives.

There are some fall detection approaches to be researched including camera-based sensors, proximity sensors and wearable electronic. The main drawbacks of camera-based sensors are their inability to track the user out of the cameras' range of visibility and high cost [4]. The problems of proximity sensors are short proximity range and significantly expensiveness. The wearable electronic for fall detection is drawn researchers attention for its low cost and feature track easily. Accelerometers are a type of wearable sensors that are widely used in fall detection systems [1,2,5,6]. The gyroscopes are also applied for detect fall as well as accelerometers [7]. Most fall-detection systems detect the shock received by the body upon impact using accelerometers. A tri-axial accelerometer and gyroscope both placed at the chest successfully distinguish between falls and ADL were reported in [1,8]. These approaches could detect the fall detection, however, these fall detection algorithms were not good enough for real falls and ADL.

In this paper, a fall detection algorithm using attitude angles is proposed. The attitude angles of wearable electronic fixed on elderly are determined through Kalman filter algorithm. The comparison of attitude angles-based and accelerometers–based is given in this paper. The rest of this paper is organized as follows: a wearable electronic hardware is introduced in section II; the fall detection based on attitude angles is given and comparison tests between attitude angles-based and accelerometers-based are expressed in section III.

II. HARDWARE

A wearable electronic module is designed with commercially low cost MEMS-based sensors as Fig.1. Its size is 23x23x5mm. The module consists of a three-axis accelerometer, a three-axis gyroscope and a three-axis magnetometer. The microprocessor is STM32f103 to deal with the output of three sensors. The main features of sensors in the wearable electronic module are expressed in TABLE I. In this paper, the sample frequency of wearable electronic module is 100Hz. The attitude angles are determined with Kalman filter, which is a popular algorithm in attitude determination of low cost MEMS-based sensors[9,10].

TABLE I. FEATURES OF SENSORS IN WEARABLE ELECTRONIC MODULE

Sensor	Manufacture	Model	Range
Accelerometer	ADI	ADXL312	±8g
Gyroscope	Bosch Sensortec	BMG160	±500°/sec
Magnetometer	Honeywell	HMC5883L	±8.1Gauss

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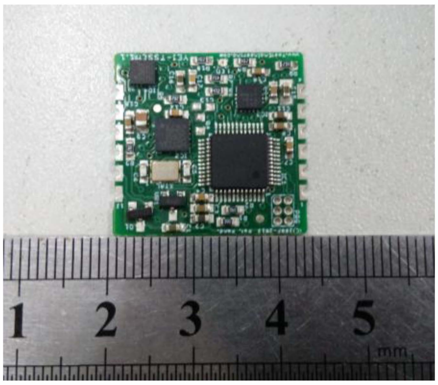

Fig.1 Wearable electronic module

III. EXPERIMENTS AND RESULTS

A. Fall Detection Approach

In this paper, the three attitude angle pitch, roll and yaw are used for fall detection. At the same time, the nom of accelerometer and gyroscope Kalman filter is applied for attitude determination by fusing the collecting data from accelerometer, gyroscope and magnetometer [11-13]. The discrete Kalman filter is simplified as follows:

$$\begin{aligned} X(n+1) &= F(n)X(n)+w(n) \\ Y(n) &= h[X(n)]+v(n) \end{aligned} \tag{1}$$

$$\begin{cases} \hat{x}_n^- = F_{n-1}(\hat{x}_{n-1}^+) \\ P_n^- = F_{n-1}P_{n-1}^+F_{n-1}^T + W_{n-1}Q_{n-1}W_{n-1}^{\ \ T} \end{cases} \tag{2}$$

$$\begin{cases} K_n = P_n^- H_n^T \left(H_n P_n^- H_n^T + R_n^-\right)^{-1} \\ P_n^+ = \left(I - K_n H_n\right) P_n^- \\ \hat{x}_n^+ = \hat{x}_n^- + K_n\left[y_n - h_n\left(\hat{x}_n^-\right)\right] \end{cases} \tag{3}$$

The attitude angles can be obtain through (1) to (3). Errors of low cost MEMS-based sensors can be eliminated by time updating process (2) and state updating. Finally, a series of data can be exported including accelerometer output, gyroscope output, magnetometer output and attitude angles output. The accelerometer data, gyroscope data and attitude angles are chosen for fall detection. The nom of accelerometer is calculated in (4):

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2} \tag{4}$$

The nom of gyroscope is calculated in (5):

$$\omega = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2} \tag{5}$$

There are several fixations of wearable electronic module on elderly's body including chest, waist and thigh. Because the chest position has higher center of gravity, there is obvious position changes when the elderly fall or sit. The tests are designed with wearable electronic module fixed on chest of user. According to real activities the tests are classified to three groups: ALD, fall-like activities and fall activities. The ALD is walk, walk upstairs, walk downstairs, sitting, running. The fall-like activities are sitting down quickly, lying down quickly. Fall activities are fall forward, fall backward, fall right, and fall left. The following sections present some of the collected data and discuss the efficacy of the proposed fall detection solution.

B. Fall Detection Tests

The wearable electronic module was fixed on chest to carry out the three tests: ADL, fall-like activities and fall activities. Test 1 is the ADL experiments. The activity sequence is walking, running, walking upstairs and walking downstairs. Results of test 1 are expressed as Fig.2.

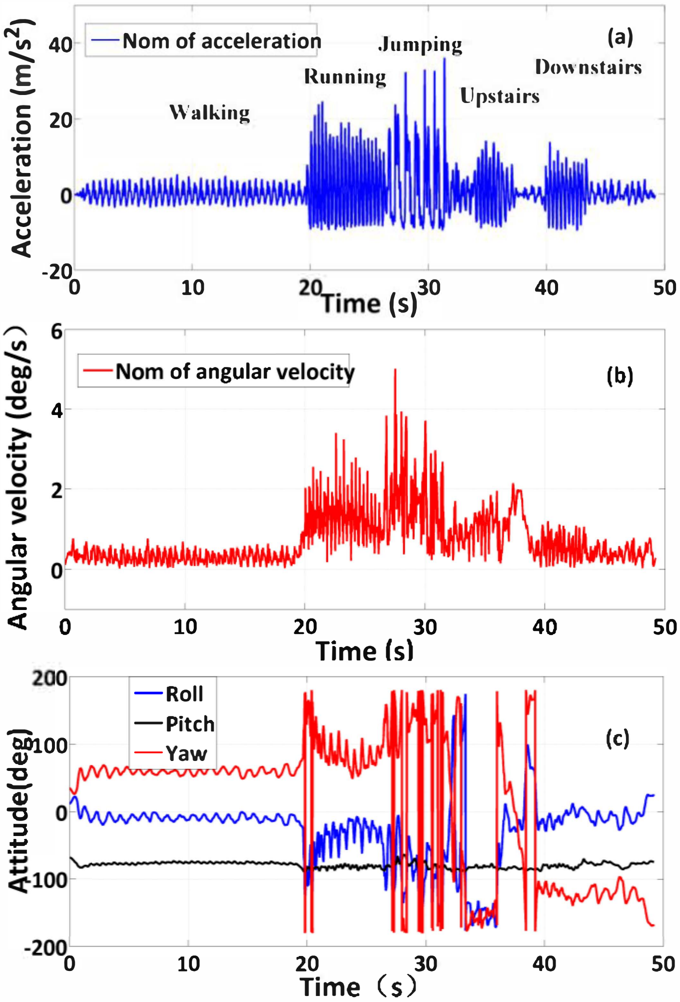

Fig.2 ADL test results with wearable electronic on chest: (a) acceleration-based, (b) gyroscope-based, (c) attitude angles-based

Through comparison the Fig.2 (a), (b), the accelerometer output has more obviously in reflecting the normal activities in daily. However, Fig.2 (c) has three angles, and the pitch angle keeping stable means no left and right changes, the yaw angle changes seriously during jumping. The roll and yaw angles are consistent with accelerometer-based results.

The fall-like test results are expressed in Fig.3. Accelerometer-based and gyroscope-based detection can reflect the serious change. However, attitude angles are quite complex, it is easy to find out their trend is similar.

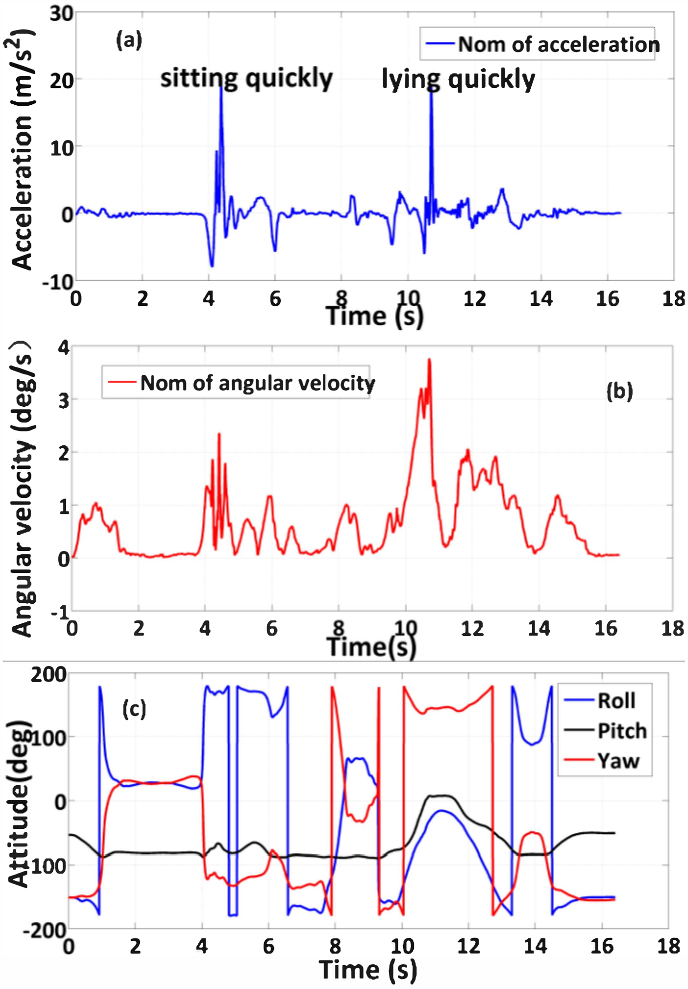

Fig.3 Fall-like test results: (a) accelerometer-based, (b) gyroscope-based, (c) attitude angles-based

The real fall tests are carried out in order: right fall, left fall, back fall, front fall and vertical fall. The test results are shown in Fig.4. From Fig.4 (a) and (b), the real falls can be easily find out from the peak values. However, the accelerometer-based and gyroscope-based fall detection can hardly distinguish the fall direction. The attitude angles for fall detections are complex, because there are three parameters for wearable electronic fixed on user chest. But the accelerometer-based and gyroscope-based fall detection values between fall-like test and real fall test are so similar that can hardly to be distinguished.

C. Conclusions

From the three tests with wearable electronic module fixed on user chest, the accelerometer-based and gyroscope-based fall detection methods can be considered as simple method. Through comparison between fall-like activities such as sitting quickly and lying down quickly and real fall, we know that the accelerometer-based and gyroscope-based fall detection methods are not quite reliable. The attitude angles for detecting fall proposed in this paper are complex. However, the attitude angles for fall detection can prove falling direction and quantified analysis the falling of elderly.

With the fall detection algorithm and Internet of Things (IOT) developed, in future, the wearable electronic will offer reliable fall detection and get the medical personnel and family known for elderly, which can reduce injuries for elderly.

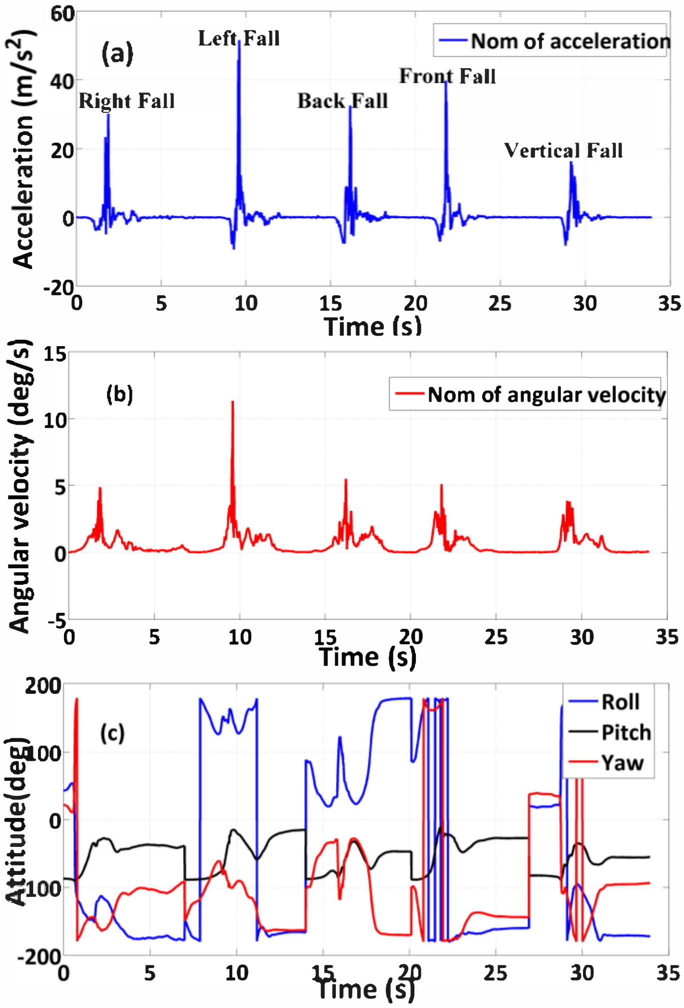

Fig.4 Real five kinds fall test results: (a) accelerometer-based, (b) gyroscope-based, (c) attitude angles-based

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