Fall Detection System Using Arduino Fio

Cao Shuo
Hwa Chong Institution
Singapore, Singapore

Abstract—**For elderly, falling at home is a serious issue, compounded by nuclear family issue and ageing population. The project aims to build and design an accurate fall detection system using Arduino Fio with marked improvement in accuracy and specificity than existing single-accelerometer based fall detection system. A peer-reviewed benchmark (Bourke *et.al 2007*) is also selected from literature. Phase One experiment includes determination of threshold and designation of the prototype. Phase Two includes three experiments on human subjects to assess the sensitivity, specificity and accuracy of the system. Compared to the benchmark, marked improvement in terms of specificity and accuracy is achieved.** (Abstract)

Keywords:Accelerometer-based threshold- based fall detection system; algorithm; accuracy

I. INTRODUCTION

According to the World Health Organisation, approximately 28-35% of people aged 65 and above suffer fall each year[1]. This proportion increases to 32-42% for those over 70 years old. Falls can lead to injuries, like fracture and soft tissue injuries[2], or even death. Besides physical injuries, falls may have other detrimental effects: threatening the elderly's independent living and restricting their mobility and social activities[3]. This problem is exacerbated by the ageing population issue and the shift in family structure towards smaller nuclear families[4], meaning that the elderly may not get any help if they fall during daytime because their children are working. Around half of the fallers are unable to get up and help themselves[5]. On average, fallers lie helplessly for more than 10 minutes after a fall, and in 3% of non-injurious fall cases the faller had been waiting for more than one hour before getting help[6]. These long lies are associated with hospitalisation, institutionalisation and a high morbidity-mortality rate[7]

II. RESEARCH QUESTIONS AND ENGINEERING GOALS

-To design and build an accurate body attached fall detection system with low-complexity algorithms using Arduino Fio

-The fall detection system is able to notify designated people for help if the user falls down (in this project, via email)

III. PHASES OF THE PROJECT

Phase One: to design and build a prototype.

Phase Two: to test on human subjects to assess the sensitivity, specificity and accuracy and receive feedback on the system from the test subjects

IV. BACKGROUND THEORIES AND ALGORITHM

Arduino Fio is a compact and wearable electronic hardware which is famous for its open-source nature and ability to communicate with computers and phones efficiently via bluetooth[1]. Arduino Fio contains a gyroscope and accelerometer to measure acceleration along the *x, y* and *z* axis. The module can be computed as:

$$|A_T| = \sqrt{|A_x|^2 + |A_y|^2 + |A_z|^2} \quad (m/s)^2 \tag{1}$$

where in equation (1) *Ax*, *Ay* and *Az* are the acceleration readings in directions of *x, y,* and *z*-axis measured by the accelerometer. A fall is directly assumed if the measured module of the acceleration exceeds a predetermined decision threshold.

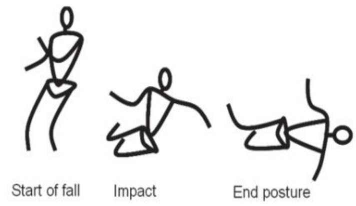

Figure 1 Phases of a falling action[9]

Many existing fall detection systems with low-complexity algorithms tend to focus on the detection of the impact[10] (the second phase as shown in Fig 1). One of them (Bourke *et al.2007*) is used as a benchmark against to assess the sensitivity, specificity and accuracy of the system given the benchmark uses similar experiment set-ups, complexity of algorithm and the type of sensor(mono-accelerometer based).

However, there are two major shortcomings of this algorithm:

Firstly, the detection decision only considers brusque peaks in the acceleration, neglecting the analysis of the complex behaviour of the acceleration vector whenever a fall takes place. As a consequence, this algorithm is prone to the detection of false positives[11].

On the other side, when the threshold is too high to trigger, falls with low acceleration will be ignored, leading to false negative.
Therefore, a more logical approach is to assess the end posture to determine whether the user has fallen down.

V. ALGORITHM

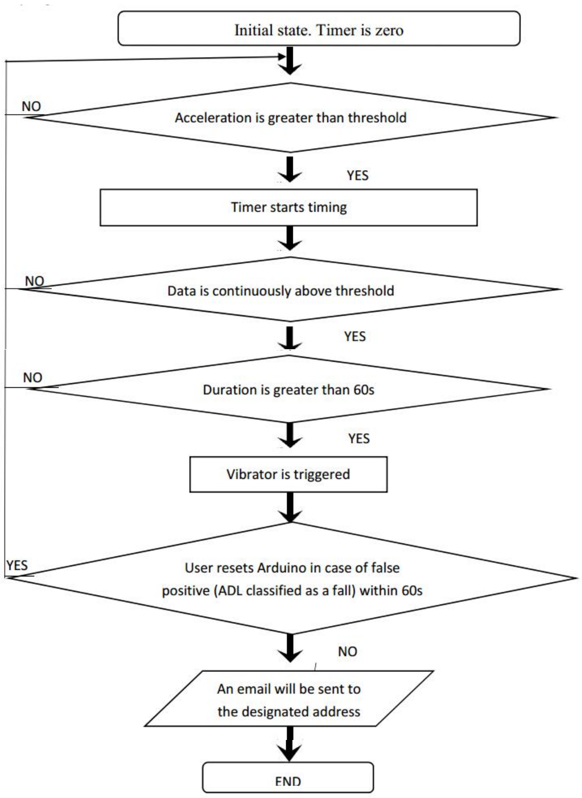

Figure 2 Algorithm

VI. PHASE ONE: BUILD THE PROTOTYPE

Arduino Fio (Fig.3) in this experiment contains an accelerometer, an Xbee element to communicate with the computer and a battery which can sustain the operation of Arduino for 4 hours. Placed in an elastic belt at the calf area of an user (shown in Fig 4), Arduino Fio can automatically detect the acceleration along *x, y* and *z* axis (*Ax, Ay,* and *Az* respectively).

A. Set up the threshold

To determine the threshold, the author wears the Arduino Fio and initiate certain actions which the elderly do in daily life. The results are in the appendices.

In fig 3 and 4, it can be observed that when one falls down, the acceleration along *y* axis (*Ay*) is usually less than 103. Hence *Ay*<103(longitude data) should be set up as the threshold by coding on Net beans.

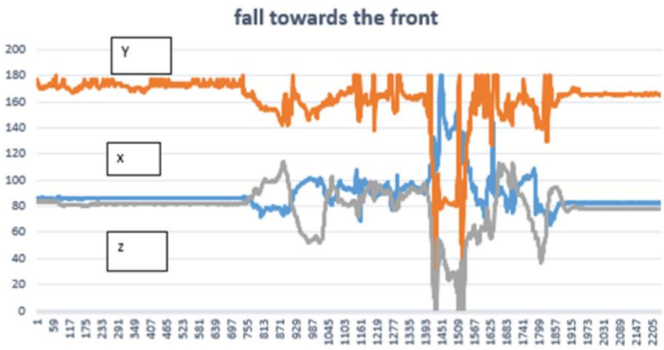

Fig 3 Acceleration when one falls towards the front

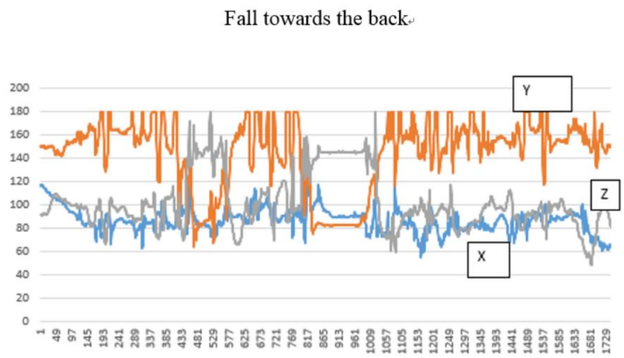

Fig 4 Acceleration when one falls towards the back

B. Set up the vibration motor

The aforementioned threshold which is less than 103 is longitude data and should be converted to the raw data which is used by Arduino Alpha which is y>440. Relevant coding is in Appendix 2.

C. Set up the timer and emailing service

If Ay has been beyond the threshold (103 longitude) for 60 seconds continuously, the system will send an email to a pre-designated address and notify the relatives of the user that he/she may have fallen down. The system will send one email every minute until one reading of Ay is below the threshold. Relevant coding is in appendix 3 and 4.

VII. PHASE TWO: EXPERIMENTS ON HUMAN PARTICIPANTS

This study consists of three sets of tests involved in 3 healthy human participants. Evaluation of fall detection system is based on determining the number of falls detected (true positives TP) or not detected (false negatives FN) by the system, and the number of activity of daily living (ADL) detected (false positive FP) or not detected (true negative TN) as fall events.

In this project, common and standardised experiments defined by specialised practitioners in the field under similar industrial settings are used.

A. Test Subjects

All test subjects are voluntary adults who received oral information about the study and from whom a written informed consent was obtained. The study protocols are reviewed and approved by IRB and medical professionals. Participants will be allocated a participant code and all subsequent actions will be identified solely using this code. All forms involved are kept with the researcher at all times. All digital files that involve experiment results or personal details will be password protected and kept on a password protected laptop. The test process will be recorded by a camera.

B. The simulated fall study

This experiment aims to assess sensitivity (equation 3), the ability to correctly detect and classify a fall as a fall.. Test subjects perform simulated falls onto large crash mats or mattress with protection pads under the supervision of the researcher. Each subject performed eight different four types and each fall-type, including forward falls, backward falls, lateral falls left and right, will be repeated three times to simulate common fall types in elderly people. Results are recorded in table 1.

$$Sensitivity = \frac{TP}{TP+FN} \times 100\% \quad (3)$$

Participant	TP	FN	Total	Sensitivity
1	12	0	12	100%
2	12	0	12	100%
3	11	1	12	91.7%

Table 1 Sensitivity

C. Activities of Daily Living(ADL) study

The second study aims to measure specificity (equation 4), the ability to correctly detect and classify an ADL as ADL rather than a fall, which involves subjects performing ADL at the researcher's home or other appropriate venues. Each ADL was performed three times by every person. The ADL are tasks that could produce impacts or abrupt changes in a person's movement and result in false triggering of a threshold-based fall detection algorithm14. The ADLs include: sitting down and standing up from an armchair, kitchen chair, toilet seat, low stool and sofa; lying down and standing up from a sofa; walking 10 m15.

In total each participant will perform 21 activities. Results are collected in table 2.

Participant	TN	FP	Total	specificity
1	17	4	21	81.0%
2	16	5	21	76.2%
3	16	6	21	76.2%

Table 2 Specificity

$$Specificity = \frac{TN}{TN+FP} \times 100\% \quad (4)$$

D. Accuracy Test

The experiment measures accuracy, the ratio between the number of correct assessments, falls and ADL, and the number of all assessments. It requires participants to perform a random combination of actions but the researcher himself does not know the sequence and number of falls or ADL performed. The results will be recorded in table 3. Each participant is given 10 minutes to perform the actions.

Participant	TP	FP	TN	FN	Accuracy
1	1	1	4	0	83.3%
2	2	4	1	0	85.7%
3	3	2	1	0	83.3%

Table 3 Accuracy

$$Accuracy = \frac{TP+TN}{TP+FP+TN+FN} \times 100\% \quad (5)$$

VIII. Results and Discussion

	Sensitivity/%	Specificity/%	Accuracy/%
My prototype	97.2	77.8	84.1
Bourke *et al.2007(*peer-reviewed results*)*	100	19	21.3

The system has achieved sensitivity of 97.2%, specificity of 77.8% and accuracy of 84.1%, higher than peer-reviewed accelerator-based benchmark (Bourke et al.2007) as seen in table 5, but lower than its multiple-sensor counterparts in literature17. Its performance is relatively acceptable for a single-accelerometer fall detection system and more accurate than counterparts in literature which measures impact (Bourke et al.2007)[18 19].

However, the reliability of my results is constrained by the small number of participants and actions performed. The activities are performed with protection which will be different from real life scenarios. Moreover, the false positive rate is high, a common problem faced by many fall detection systems[16], especially when the user's action (the posture) is similar to the posture of falling down. For example when a person lies down on a sofa, the vibrator will start vibrating and he has to reset the Arduino. If the user does not reset it within 1 minute, an email will be sent. Hence the system is a semi-automatic one which requires the users to reconnect Arduino to computer after resetting. The post-experiment survey also shows inconvenience and high false positive rates experienced by users.

IX. Conclusion and Future Work

Arduino Fio fall detection system is more accurate, sensitive and specific than the selected benchmark. However, the detection system can still be improved to lower its false positive rate. This can be achieved by inserting multiple sensors to monitor both impact and posture. Other than purely accelerometer-based methods, context-aware elements, such as cameras and infra-red sensors can be incorporated as well. Reduction of false positive rate will ultimately improve user-friendliness.

Moreover, more can be done to make the system fully automatic which does not require any operation by the users even though after resetting Arduino.

Furthermore, there are cases where emailing fails to notify the caregivers. This can be improved by modifying the system such that emails will be continuously sent until there is a reply from the care givers.

Long-term experiments on human subjects, especially the elderly, can be conducted to better simulate real life scenarios and better examine the sensitivity, specificity and accuracy of the system.

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