Journal of Engineering
Research and Education
Vol. 6 (2012) 25-33

A comprehensive early warning fall detection system using ultrasonic system for accessing gait feature

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ABTRACT

Level of walking ability, hidden chronic disease and aging effect can be detected by use of gait pattern. The gait pattern is normally directly related to the foot and leg health, in addition to other significant factors. Therefore the foot is the most important part of gait system and thus directly affects the gait pattern. This paper reports the development of a comprehensive early warning fall detection system for walking elderly. This paper also analyze the usage of ultrasonic sensor through a gait analysis feature to measured the minimum foot clearance of walking of volunteers that may be reflect to the range of normal minimum foot clearance before triggering the early warning system. The study suggests that ultrasonic sensor is applicable for this application.

Keywords - *ultrasonic sensor; gait analysis; minimum foot clearance; fall prevention.*

INTRODUCTION

Motivation

Healthcare cost especially related to gait continues to increase globally partly due to the large number occurrence of falls among the elderly population. As higher percentage of the world population, the elderly is made up; increasing of the elderly causes the increasing occurrence of falls is expected each year including Australia. Figure 1 shows the percentage of fall among the elderly depending on the particular places. While, Figure 2 shows the activities performed that causes fall among the elderly. In 1999, Australia alone, about $3 billion is reported to be spent as a result of the falls-related injuries as stated in [1, 3]. As widely known, the foot clearance is the important gait parameters that directly influence the risk of fall among the elderly as stated in [2]. It is the spatial parameter of the foot during the swing phase of the gait cycle representing the distance of shoe sole above the ground. In a recent analysis of the tripping and falls risks among the elderly individuals during walking as stated in [3-5], it is found that the possibility of trip-

related fall is causes by the most critical event which is the movement of the foot during mid-swing phase. This highly important parameter is called minimum foot clearance (MFC).

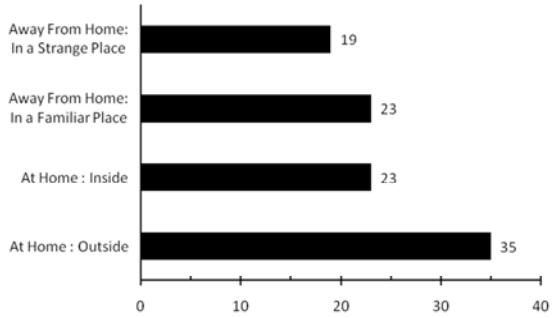

Figure 1: Particular places that cause the occurrence of falls among the elderly

Figure 2: Falling during performing several activities [1, 6]

In order to prevent such incident, a comprehensive early warning fall detection system using ultrasonic sensor are developed with several new useful feature are introduced. An early warning fall prevention system will equipped with Global Positioning System (GPS) module for position of occurrence of fall along with time and date the accident happen. That information then transmitted via 2.4GHz IEEE 802.15.4 protocol to User Interface and Logging module wirelessly along with gait feature senses by ultrasonic sensor. A warning signal generated is sent to user through Bluetooth Module to alert the wearer to take precaution and in event fall accident, a GSM modem can be embedded to early warning fall prevention system which will send the short message service (SMS) to notify the third party, or authorize personnel in preset SMS capable telephone number consisting the where about the user and the time and date.

Related Work

Unfortunately, the current practice of measuring foot clearance required laboratory settings such as the reflective, active markers, one or more video cameras, thread-mill or dedicated floor and specialized computer software running on bulk computers with thousand wires connect to subject as stated in [3]. This conventional method of foot clearance measurement not represent the actual measurement of real life or in natural environment as stated in [7], such as at home or outdoor. Sometimes some problems such as marker slippage may also occur during laboratory measurement as stated in [3]. A more advanced technique is suggest the use of accelerometers, however due to the effect of drift and errors, the calculation that involves double integration of acceleration data is required to minimize the erratic results as stated in [7-8]. The sensing of MFC using accelerometer is sometime can be problematic in certain case depending on surfaces that are uneven, bumpy or during stair descend or ascend as it is not directly measuring clearance but the clearance is determined using acceleration data. As latest instruments that are mostly needing an exclusive research, clinical or rehabilitation laboratories setup, and particularly that they are limited in simulating the real world activities for an individual as stated in [3, 7], an in-shoe method are clearly a better option as medium to measure the foot clearance for actual condition and outdoor environment.

Paper Overview

In this paper, an Early Warning Fall Prevention System with Ultrasonic Sytem Integrated Sensor is designed, built, calibrated, analyzed, and used to measure an unprecedented number of parameters relevant to gait. The system is designed to collect data unobtrusively, and in any walking environment, over long period of time. It is built to be worn on the shoes, without interfering with gait. The sensors are calibrated, and the calibrated data are analyzed the gait pattern of the elderly. Based on real-time gait signal analysis, we can capture the gait pattern that will be used to monitor elderly gait and classification for fall detection. We treat gait as the elderly pattern for an early warning fall detection system.

The sections of this paper are built up as follows. In section II, the Early Warning Fall Detection System will be introduced as an information acquisition platform to sense the foot motion.

The system is small, portable and wearable. The platform is mainly composed of four parts including a sensing module, a computing module, a wireless communication module, and a data visualization module.

We introduce comparison between the elderly and the adult toe clearance during normal and fast walking in Section III.

Furthermore, Section IV is devoted to present experimental result to distinguish the young and older user based on the mean, minimum and maximum foot clearance measurement from ultrasonic sensor.

Finally, the proposed method has produced satisfactory results on early warning fall prevention for elderly during test, and conclusions are presented in Section VI.

HARDWARE DESIGN

The proposed Early Warning Fall Prevention System consists of four subsystems. Figure 3 shows the architecture of our proposed platform.

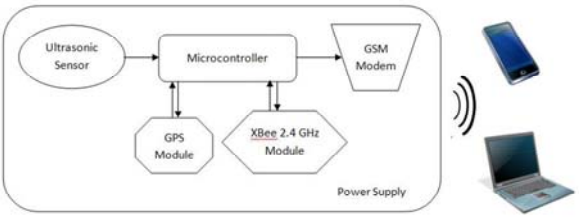

Figure 3: The architecture of proposed Early Warning Fall Prevention System

Subsystem 1 is for sensing the parameters at the back of the shoe. Sensor used is ultrasonic sensor. The ultrasonic is used to measure the clearance between foot and ground or floor within the range 0 cm to 15 cm as initially proposed in [1][8]. The ultrasonic sensing system provides the reading in millimeter scale with 1.0 mm resolution [9].The ultrasonic sensor have a sensing range of 1 cm to 400cm. The dimension of ultrasonic sensor is about 43mm x 20mm x 17mm height. The operating frequency is 40 kHz. It is operate at 5V with current consumption 4mA typically. Echo Pulse is Positive TTL level signal, which is the width of pulse is proportional to the object range.

For the ease of use, we limit the size of each device as small as possible. Existing MEMS technology makes it possible to integrate all the sensors and circuits inside a small module.

Subsystem 2 is the processing unit which is the data from the sensors inside the shoe is being processed and sending the processed data to the wireless module. The processing power of micro-processor is depending on the type of microcontroller used. In this system the PIC16F877A in TQFP manufacturing form with 200 nanosecond instruction execution which make this microcontroller suitable for processing such data.

Subsystem 3 is for wireless communication XBee 2.4 GHz Module. This communication system is composed of an emitter and a receiver. The receiver is for collecting the data from the circuits described in subsystem 2 while the emitter is for sending the data to the host computer for further analysis.

Subsystem 4 is for visualization of the data where the User Interface and Logging module is take place. The received data is stored and displayed in real-time on the screen of the host computer as a visual interface. This visual interface can be used for further applications. The outlook of Early Warning fall Prevention System is shown in Figure 4.

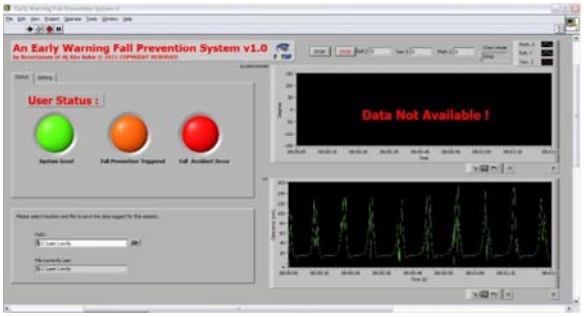

Figure 4: The outlook of Early Warning Fall Prevention System

Subsystem 5 is the embedded GPS module. The GPS received data is indicate the current position of user and very useful to locate the user in event of accident where the user is alone and unknown whereabouts. MEDIATEK MT3329 GPS 10HZ is the best choice for GPS feature in term of size and weight which only 16mm x 16mm x 6mm dimension and weight of 0.3oz or 8 g.

Subsystem 6 is the GSM Modem for SMS feature. The warning and alert signal which is contain the location, status of user and lastly the date and time of occurrence is sending to third party or the authorities.

COMPARISON

It is reported that the minimum toe clearance (MTC) for normal and fast walking for adult in [10] and maximum clearance during normal and fast walking in [11] shown in Table 1 by considering 120 steps per minute of adult walking, the sampling rate of 75 Hz, or every 13.4 ms suits well for this application [10].

Table 1: Toe Clearance for Adult Walking

Toe clearance	Maximum clearance (cm)	Maximum clearance (cm)
Normal walking	1.4-1.6	5.7-6.9
Fast walking	1.7-2.1	6.3-7.8

It is reported that the minimum toe clearance for normal walking for elder in [12] MTC median (mm) 13.8 ± 2.1 (Mean ± S.D), n=1000. MTC median reported in [13] is 0.97 ± 0.43 (Mean ± S.D), n=8.

Table 2: Toe Clearance for Elderly Walking

Toe clearance	Number of Reading, n	Mean ± S.D
Normal walking	8	0.97 ± 0.43
	1000	13.8± 2.1

EXPERIMENTAL RESULT

An experiment was conducted using the different age volunteers in category young (18 - 40 years old) and older (40 - 60 years old). The minimum foot clearance of volunteers is obtained and plotted as well as to compare the performance of walking gait pattern between the young and older volunteers. As reported by Whittle in [10], walking speeds are constantly in normal range but it will slightly reduce for elderly. As others report in [15] mentioned the slower performance in term of walking speed was influent by aging factor. The same phenomenon was observed in our experiment. The experimental setup of our experiment is shown in Figure 5. As shown in Figure 6, the young volunteer shows more gait cycle which is indicated the walking speed relative to time passes. Compared to Figure 7, the number of gait cycle is reduced in given same time frame for elder people.

Figure 5: The Experimental Setup for Early Warning Fall Prevention System

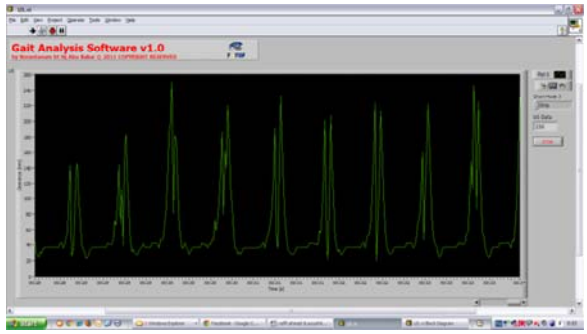

Figure 6: Young Walking Graph Pattern

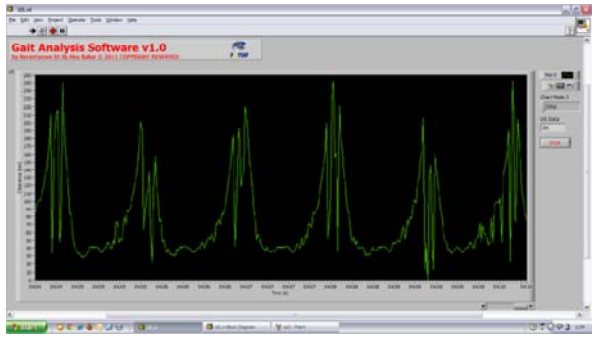

Figure 7: Elderly Walking Graph Pattern.

Table 2 below describe the minimum foot clearance statistical value for young and elder walking which is indicate mean, minimum and maximum foot clearance measurement. The statistic value was derived from the graph pattern.

Table 2: Minimum Foot Clearance Statistic Value for Young and Elderly Walking

Variables (cm)	Young (N=10)	Elderly (N=5)
Mean MFC	3.97	4.5
Minimum MFC	3.7	4.0
Maximum MFC	4.3	5.1

CONCLUSION

In this paper, we have developed an early warning fall prevention system which is use the ultrasonic in this first stage of development. We show that based on the experimental result, the pattern of gait features and the statistic result prove that an early warning fall prevention system is suitable for used for fall prevention where it can distinguish the young and older volunteers walking.

ACKNOWLEDGMENTS

The authors would like to thank Prof. Ali Yeon Md Shakaff for their valuable contribution to this project and also to Ministry of Higher Education (FRGS 900300219) for funding this project. The authors would also to acknowledge School of Microelectronic for the advance facilities provided during complete this project.

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