Overview of MEMSWeare II – Incorporating MEMS Technology into smart shirt for Geriatric care

Samuel Ng Choon Po, Guo Dagang, Mohammad Dzulkifli Bin Mohyi Hapipi, Nyan Myo Naing, Wei Jia Shen, Andojo Ongkodjojo, Francis Tay Eng Hock

Mechanical Engineering
National University Of Singapore,
Block EA, #02-09, 10 Kent Ridge Crescent, Singapore 119260
Singapore
mpencp@nus.edu.sg, mpegdg@nus.edu.sg, mpemdmh@nus.edu.sg,
engp2492@nus.edu.sg, mpeweij@nus.edu.sg, mpeooa@nus.edu.sg,
mpetayeh@nus.edu.sg

This paper presents a method of using smart sensors for continuous detection of vital physiological and physical gait signals that can be relayed to a fall prediction algorithm for predicting an imminent faint fall. A novel MEMS based BP sensor will be discussed briefly. Once an imminent faint fall is detected, fall prevention and injury minimization devices will be activated. A body area network consisting sensor circuits utilizing short range ISM communication will be used to enable signal transmission to a processor which acts as a communication gateway as well. This processor would then encode and send the signals via Bluetooth to designated devices to effect inform caregivers or family members.

Keywords: MEMSWeare, BAN, microprocessors, fall prediction, fall prevention, injury minimization

1. Introduction
MEMSWeare I was initiated to improve the healthcare for the elderly through a 100% detection of falls [1]. The system comprises of micro sensors such as G-switch, accelerometers and gyroscopes with integrated circuits incorporated into a smart wear. MEMSWeare I was capable of detecting falls based on sensors threshold values. Once a fall is detected, the incorporated Bluetooth technology allows an alarm signal to be sent to a remote mobile device, which allows immediate deployment of assistance to assist the person [1]. Furthermore, to prevent any false alarm, algorithms were incorporated to distinguish eight commonly performed human activities such as walking, stair climbing, sitting and lying. In recent years, among the elderly, accidents are the fifth leading cause of death, whereby falls constitute two-thirds of these accidental deaths [2]. Falls resulting from gait disorder and muscle weakness, and dizziness and syncope are the second and third major cause of falls accounting for more than 30% of falls. Non-death accidents often cause crippling bone fractures. Among various fractures, hip injury is the most serious injury in all fall related ones. Case control studies have shown that falling to the side, compared to other directions, increases hip fracture risk 3- to 5- fold [3].
Here, this paper will describe an array of sensors capable of differentiating gait motion and reading human physiological signs together with an intelligent multi processor system that will be embedded into the smart wear. The system will incorporate a fall prediction model to process physical gait motion and physiological information to predict an imminent faint fall or syncope. Once the fall prediction model which processes both the physical and physiological information reveals a high propensity leading to an imminent fall, a prevention system will be activated. A hip protection device will be deployed to minimize injury should a fall occur which requires response within critical timing. From MEMSWear I, the time between a fall and impact is found to be 200ms as measured from a tri-axial gyroscope [1].

Therefore, MEMSWear II platform would have a processor which acts as a communication gateway to detect vital physiological and physical gait signals using different type of wireless sensors through a Body Area Network (BAN) system. The physiological and physical gait signals can be combined with other falling risk factors to predict the possibility of an imminent faint fall based on an analytical fall prediction model. In addition, it can deploy protective means and minimize the injury when fall occurs. The main benefit from the proposed project, upon successful completion would allow not only improve the well being of the elderly, but also reduce medical cost resulting from fall.

2. Overview of MEMSWear II

With the objective of incorporating multiple sensors and on a low powered platform, a real time system is required to process the critical information. Using a processor array processing in parallel, the data obtained from various physiological and dynamic sensors will be processed, buffered, saved and shared so if there are any possible signs indicating a fall, various actions will be taken to either prevent or cushion the fall and send a signal to a remote mobile device. Derived mathematical model from general medical data set and individual patient history, stored in memory, are used together with the physiological sensors data, and processed in a real time environment to predict a fall. Measures are taken to prevent or minimize an injury by muscle constriction or airbag deployment respectively.

Figure 1 shows MEMSWear II design architecture of the embedded system that will be used to fulfill the fall prediction, fall prevention and fall injury minimization objectives. In essence, a fall prediction mathematical model will be derived using a pool of elderly medical data set and fall history. Thereafter, a fall prediction algorithm will be ported into a processor. This processor will be able to collate both the dynamic and physiological sensor data and together with the prediction algorithm to predict the probability of an imminent faint fall of the wearer. A decision will be made by the processor to decide whether a prevention device or injury minimization device should be activated.

![Figure 1: Embedded Real Time architecture for MEMSWear II](image-url)
3. Fall Prediction

MEMS Wear II with the incorporated fall prediction feature will aspire to execute its task of deciphering physiological and physical measurements of a human being and deciding on the imminence of a fall. The measurements are important data inputs that are pertinent to decide on the imminence of a fall among other medical history of individual patients. After the mathematical model is established with unique patient characteristic medical history, physiological and physical measurements of fall prediction will be conducted continuously to allow comprehensive monitoring of the wearer.

MEMS Wear II will adopt a new generation of smart sensing where new sensor information system transmission can take place. A short range ISM band transceiver will be integrated in the smart sensor for communication via Body Area Network (BAN) to a communication gateway, which relays information to the external devices.

3.1. Mathematical model for fall prediction

The various risk factors for falling, such as gait and balance impairments, chronic conditions and medications, difficulties in activities of daily living, inactivity, incontinence, cognitive impairments, reduced lower limb strength as well as sedative and hypnotic medications, etc., will be evaluated through the mathematical model.

We intend to apply a neural network technique, support vector machine (SVM) in fall prediction [5]. SVM are data-driven, non-parametric models which are less susceptible to the problem of model misspecification as compared to most of the parametric models. SVM are more noise tolerant, and are able to learn complex systems with incomplete and corrupted data. For the area of medical history collection, we will first look into the identification of geriatric who are prone to falls, this is essential to the development of characteristic patient database. Relevance of known predisposing risk factors for falling as well as the establishment of a comprehensive and accurate model adapt to complex medical data sets will be investigated. To accomplish reliable research, professional medical doctors involved in clinical proximity with geriatric who are prone to falls will be contacted and worked closely with. Medical data sets will then be collected from random sample of geriatric through in-home interviews, physical examinations and investigation of medication inventories and hospital records. At the same time, the software for realizing SVM algorithm will be developed and the corresponding model will be trained by medical data sets for fall prediction. The feasibility of applying SVM in fall prediction will be examined by comparing its performance with that of conventional statistical analyses.

3.2. Physiological and physical measurements for fall prediction

Physiological and physical measurements for fall prediction forms part of the inputs needed for the mathematical model involved in conducting real time continuous signal processing [6]. The following segments involve blood pressure, ECG smart sensors and dynamic sensors. Together, they form the fundamental active sensors for accurate and fast prediction for faint falling.

3.2.1. MEMS based blood pressure sensor

Blood pressure sensing is the first physiological sign that we will investigate to determine abnormality in human that might bring about faint fall. A novel single deeply corrugated diaphragm (SDCD) based dual optical fiber pressure sensor will be developed for blood pressure measurement. Such device relies on the relative intensities of the twin receiving fibers rather than on the absolute intensity. Therefore, compared with single optical fiber intensity-modulated pressure sensor, higher linearity can be achieved and “phantom pressure” induced by intensity losses resulting from source intensity fluctuations or fiber microbend losses can be minimized. The key novelty marking the proposed SDCD is that it consists of a flat bottom-region that behaves as a normal flat diaphragm, and suspending sidewalls that serve as stress concentrator and buffer, thereby enhancing flatness of the diaphragm under pressurized deflection while reducing temperature dependence by releasing the
thermally induced stress. As a result, SDCD based optical fiber pressure sensor can successfully reduce signal averaging effect and thermal cross-sensitivity [7,8]. Also, fabrication process of the proposed sensor based on bulk and surface micromachining techniques instead of complicated fusion bonding process, which facilitate the mass production of such biocompatible and disposable pressure sensors.

Figure 2: Schematic view of dual optical fiber Fabry-Perot pressure sensor

3.2.2. ECG smart sensor
ECG sensing is the next physiological sign that we will investigate to determine abnormality in human that might bring about faint fall. A wireless wearable one channel ECG smart sensor will be developed for long term monitoring, continually logging heart rate data and providing detection of life threatening events. An embedded microcontroller will be used to calculate heart rate and monitor the ECG signal for life-threatening arrhythmias. A short range ISM band transceiver will be integrated in the smart sensor for communicating via Body Area Network to a patient worn, battery-powered communication gateway, which can relay information to external devices [9].

3.3. Wireless dynamic sensors
A new and advance design of wireless dynamic sensors, accelerometers and gyroscopes, incorporating embedded wireless data transmission will be looked into.

A new generation of dynamic accelerometer and gyroscope will be developed that are able to transmit data sets from one integrated chip to another processing module located independently from the sensor using wireless technology [10,11]. We will first conduct a technology overview of any development in this arena of research. After which, we will go into design phase where we will look into the pertinent areas of concern for the integration and also drafting of raw designs. Once the design phase is over, we will go into prototyping of the wireless dynamic sensors and also the on-field testing of the sensors. Finally, these sensors will be integrated into the overall design of MEMSWear II.

4. Fall Prevention
Novel finding has shown that leg muscle tensioning results in blood vessel constriction and slows down the blood flow to the legs and thus prolonging the time before fall. A simple way of achieving this is to cross the legs, a maneuver that could increase systolic blood pressure from an average of 65 to 106mmHg [12]. While this is a simple maneuver for adults, it may not be easily performed by the elderly. Therefore alternative methods are required, namely by using low voltage or mechanical excitation.
4.1. Increment of lead time prior to fall

Based on MEMSWear I experimental results, positioning of one sensor at the waist level (position FW) gives around 200 msec lead time and about 40 deg \( \beta \) angle for sideways falls [1]. The key challenge here is the increment of lead time before impact of a fall. We will look into strategic placement of at least 2 dynamic sensors, specifically implementing the wireless gyroscope, onto the smart wear.

To increase lead time, we need to distinguish between falls and normal motion. In order to do that, we will investigate the relative motion of selected locations on a human body. The strategic locations must be able to give a relative signal from micro-accelerometers and gyroscopes. Therefore we need to research on specific dynamic sensors placements on a human body that will maximize the wearer’s comfort yet yield measurable relative motion signals that help to predict imminent faint fall.

4.2. Development of muscle constriction device to execute muscle tensioning

A novel muscle constriction device will be used to tension the muscles around the thigh region to promote blood muscle constriction, increase systolic blood pressure and hence to prevent fall in elderly.

We will investigate practical devices that can serve the purpose of muscle tensioning. Preliminarily, we will explore the possibility of incorporating constriction device used in clinical blood pressure measurement using occlusive methods or other possibilities for example by means of fluid pressure on muscle or MEMS actuators. Electronic stimulation is not abandoned. The placement of the muscle constriction device will be situated at the thigh region where the major blood veins are located. Thereafter, we will decide on a design and then proceed to prototyping.

5. Fall Injury Minimization

Falls in elderly are dangerous as they can potentially result in hip fracture especially at the trochanter region of the hip joint. Up to date, there are not many patented hip protection devices. The more acceptable devices are generally the common hip protectors using hip pads and hip inflatable protection device. Presently, hip protectors using hip pads are widely used to minimize hip injury especially for the elderly whilst the hip inflatable protection device is not commonly found. However, recent review conducted on hip pads protectors commonly found for prevention of hip fractures in older people has shown that it is not likely that present hip protectors are able to prevent hip fracture in elderly [13].

5.1. Development of novel design air-inflatable hip protector

Novel design on the possible incorporation of air-inflatable hip protector is shown in Figure 5 below.

![Figure 5: Proposed MEMSWear II with incorporated fall detection, prevention and injury minimization capabilities (●: Wireless microgyroscope and/or accelerometers; P.M.: Processing module; B.P.: Battery pack; A: Air-bag installation; B: Inflation module)
MEMSWear II will incorporate the inflatable hip protector into the MEMSWear I platform. This inflatable hip protector design will make use of removable air inflation module, B, that will supply the immediate inflation of the air-bag installation, A, which is located at the lap of a shirt. The removable air inflation module will be decided if to use a chemical mean by use of sodium azide or compressed air cylinder. The air-bag installation will be activated to deploy both above and below the air-bag installation to provide effective hip protection.

5.2. Design and implementation of a MEMS G-switch for contactless switching

The contactless switches solve the metal-to-metal contact problems, which are susceptible to arcing, micro-welding, deformable, oxidation, bouncing, etc, while facilitating the advantages of using the field effect transistor for the switching applications. In this research work, a novel contactless G-switch, which is an integration of the bimorph actuator and the field effect transistor (FET) as shown in Figure 6, has been proposed and designed based on the single constrained optimization method using the Simulated Annealing algorithm. This integrated design is mainly used to detect the impact force caused by the fall events. In the future, the design will be fabricated and incorporated into the MEMS-Wear smart shirt for testing upon the fall activities.

This G switch can be also used in the integration of fall prediction, fall prevention and injury minimization together, and upon the detection or actuation of any or all of the three stages of MEMSWear II, the device can activate a current flow such that an additional health care device can be turned ON. The G switch’s ability to switch from one condition or state of use to another by the detection of fall impact forces would add a new enhancement feature to the whole MEMSWear II system. This added ability can be utilized in future for post-fall enhancements.

![Figure 6: Schematic diagram of the G-Switch (bimorph structure) with the electrode attached below forming the field effect transistor (FET) for switching application [14]](image)

6. Conclusion

This paper has presented a research direction—a wearable platform where different physiological (MEMS based BP and smart ECG) and physical (micro gyroscopes and accelerometers) sensors can communicate with a processor ported with a fall prediction algorithm and decide upon a probability of an imminent faint fall. The wearable platform system can also activate fall prevention and injury minimization devices in an event of a detection imminent faint fall. A possible addition of a G switch for future enhancements is also discussed. We have also plans in future to incorporate this system with MEMSWear’s fall and daily activities detection.
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