A SMART FLOOR TILE FOR AUTONOMOUS AND PASSIVE PHYSIOLOGICAL MONITORING: PRELIMINARY DESIGN AND RESULTS

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INTRODUCTION

Independent living for older adults gives them more freedom and a more fulfilling lifestyle. Independence, however, must be accompanied by protection from potential causes of adverse events (e.g. falls, forgetting to turn off house appliances, etc.) and sufficient assistance as the physical and/or cognitive abilities of older adults are often compromised. The typical problems in older adults living independently are categorized as: medical, functional, psychosocial, and environmental problems [1].

Smart home technology refers to any device designed to assist an individual's living, where a great potential exists in improving the quality of life of older adults and disabled individuals [2]. One example of a smart home technology is a system that can examine one's physiological health at home to aid caregivers in maintaining the person's well-being.

Motivation of medical monitoring at home through smart home technology can be found from the results from social programs such as preventive home visits, where health practitioners (ie. nurses and geriatricians) visit older adults' homes to assess their health and encourage healthy lifestyle [5].

A review of past home visit studies suggests that little effect is observed in the subject's health status as a result of occasional home visits (typically once every three months) [5], whereas with more intense home visits and follow-ups (i.e. 16 visits over 6 months), older adults showed reduced functional decline [1]. Note that the expense of the program increased as the frequency of the visit increased. By mimicking the home visit and increasing its frequency by placing the smart home appliances in the home, it can be postulated that the placement of these equipments would provide positive impact in slowing down the functional decline of older adults.

Many of the current residential medical monitoring devices exist in a wearable form [7][8]. This form, however, results in two major problems, which are: forgetting to wear the device and incorrect usage [3]. These issues become exacerbated among older adult users, especially those with a cognitive impairment. One approach to counter these problems is to use passive devices [3] that do not require any active engagement by the user to collect the required data, but rather are naturally incorporated into the user's everyday life to collect data automatically. A number of passive monitoring devices were developed recently, including a toilet, bed, mirror and bathtub [4][9]. Other devices related to the smart floor tile that can also measure physiological signals are: a weighing scale that measures heart rate through Ballistocardiogram (BCG) [10], another form of a weighing scale that measures heart rate by bioimpedence [11], and also a weighing scale that combines Electrocardiogram (ECG) and BCG to output systolic blood pressure (SBP) [12]. BCG is defined as a small vertical oscillation of the body as a result of the reaction force paired with action force of pumped blood from the heart [13].

Integration of these signals to fully assess the patient would be challenging for health practitioners when examining the data since each listed device measures physiological parameters at different times of the day, and is usually capable of measuring only one or two physiological parameters. This is supported by circadian rhythm of a human, where circadian rhythm refers to periodic fluctuation of human activity approximately every 24 hours based on clinical observations [6]. Therefore, as an improvement to above devices, the aims of this project are: to use a set of sensors to simultaneously measure multiple physiological parameters that are important to assess the health of older adults, thus to provide a more integrated view of the subject's physiological state, as well as to reduce discrepancies caused by temporal differences of each measurement.

In addition, a common characteristic of the previous devices is that they are typically external devices, which the user is aware of their presence. Another aim of the smart floor tile is that the device will be naturally incorporated into the user's environment so that the user is free from the awareness of the monitoring device.

RESEARCH OBJECTIVES

We propose to develop a smart floor tile that is capable of measuring the vital signs of a stationary person when he or she is simply standing on the tile. The proposed vital signs to measure are heart rate, respiration rate, SBP, centre of pressure (CoP), and body temperature. Each measurement from the tile will be validated by gold standards (Table 1).

Table 1: Verification method for each measurement from the tile

Measurement from the tile	Gold standard
Heart rate	3-lead ECG
Systolic blood pressure	Sphygmomamometer
Respiration rate	Respiratory inductance plethysmography
Centre of pressure	Force plate
Body temperature	Thermometer

METHOD

The proposed design acquires 5 different physiological signals using 3 sensors, which are load cells, electrodes, and a thermistor. The heart rate, CoP, and body temperature are measured directly using the sensors, and the SBP and respiration rate are derived from the obtained signals.

Miniature load cells beneath the tile measures BCG and CoP. The hardware system for the BCG measurement is adapted from [13], where the authors successfully measured the BCG using an off-the-shelf weighing scale.

The CoP is estimated by assuming the sum of moments about the CoP in the medial-lateral and anterior-posterior directions are zero. Equations 1 and 2 are used in calculating x, y coordinates of the CoP [15].

$$\mathrm{CoP_{ml}} = \frac{(\mathrm{F_r} - \mathrm{F_l})\left(\frac{\mathrm{D_{ml}}}{2}\right)}{\mathrm{F_r} + \mathrm{F_l}} \tag{1}$$

$$\mathrm{CoP_{ap}} = \frac{(\mathrm{F_a} - \mathrm{F_p})\left(\frac{\mathrm{D_{ap}}}{2}\right)}{\mathrm{F_a} + \mathrm{F_p}} \tag{2}$$

In Equation 1, D_{ml} is the medial-lateral distance between the centres of right and left load cells; F_r is total vertical load applied to the right load cells; and F_l is total vertical load applied to the left load cells. In Equation 2, the subscript *ap* stands for anterior-posterior.

Two electrodes attached on the surface of the tile measure the person's ECG and are potentially used for Electromyogram (EMG). A 2-lead ECG circuit is adapted from www.open-ecg-project.org, which takes 3.3V for input power. Additionally, a thermistor is embedded beneath the electrode to measure the body temperature.

After obtaining primary sensor signals, the temporal parameter between the peaks of the ECG and the BCG is used to calculate the SBP [12]. R-J interval is first extracted from the ECG and BCG measurements (Figure 1). Then, a linear regression equation in Equation 3 is used to estimate the beat-by-beat SBP.

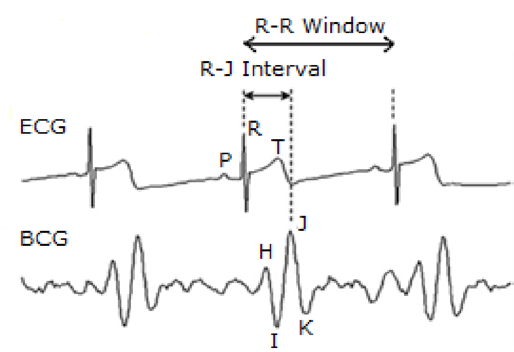

Figure 1: Detection of R-J interval [12]

$$\mathrm{SBP} = \mathrm{a} \times \mathrm{RJint} + \mathrm{b} \quad (3)$$

In Equation 3, a and b are calibration constants; SBP is systolic blood pressure; and RJint is R-J interval.

Respiration rate will be derived from BCG by analyzing the average shift of the BCG [14].

Lastly, since the tile is equipped with an electrode, skin capacitance switch or force threshold switch is incorporated to turn the system on only when the subject is standing on the tile. This switch feature will enable the location detection when the tiles are used in multiples by monitoring which tiles are active.

The proposed design of the smart floor tile is depicted in Figure 2.

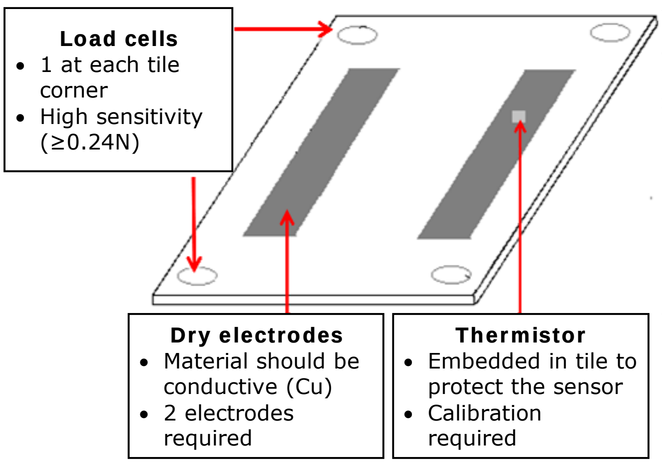

Figure 2: Proposed design of the smart floor tile

RESULTS

The first prototype (Figure 3) was made and preliminary results were obtained.

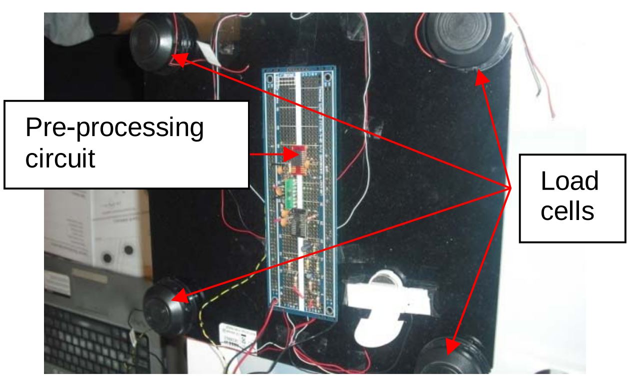

Figure 3: Bottom of the actual prototype developed

The prototype includes load cells from a commercial bathroom scale and a pre-processing circuit for BCG. This first prototype, which is made for the proof-of-the-concept, provides processed signal from the load cells.

Before testing the first prototype, the concept of BCG was verified using a force plate (ATMI® AccuSway dual force plate) as shown in Figure 4.

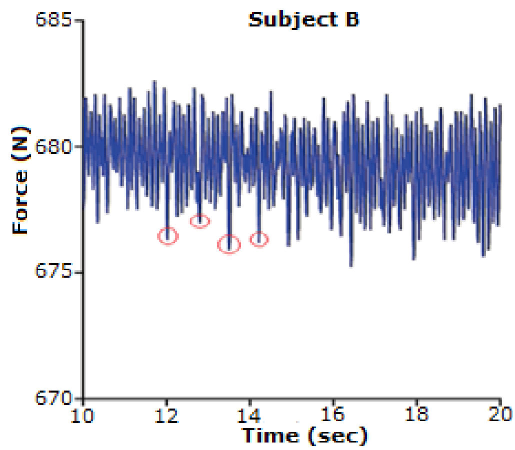

Figure 4: Vertical force variation data recorded from quiet standing of a subject (male, age = 23, weight = 69.5kg) on a force plate. The subject's heart rate was simultaneously monitored using a pulse oximeter placed on the finger. Distinct 1.1Hz spikes were observed (red circles) in the force signal and corresponded to the heart rate measured by the pulse oximeter

Results from the prototype are shown in Figure 5.

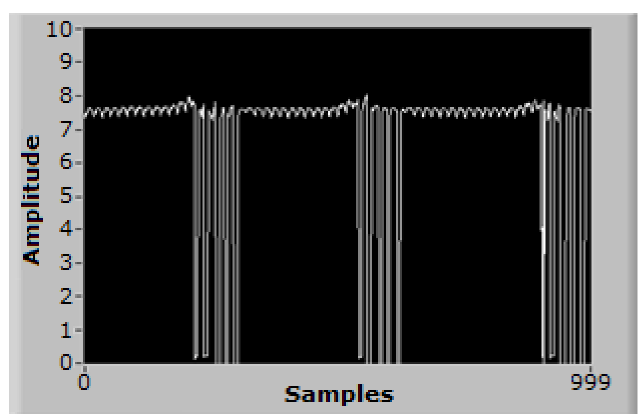

Figure 5: Time trace signal obtained from subject (female, age = 23, weight = 53kg) standing on the tile and periodically applying extra pressure on the platform.

With the prototype to date, it was not possible to extract heart rate from the above measurement because of large noise present. The suspected sources of noise are: 60Hz power noise, 120Hz supply ripple, 180Hz magnetic pick-up, vibration, cable vibration, circuit board.

FUTURE WORK AND CONCLUSION

Future work will include refining the BCG signal by removing the possible sources of noise. The ECG and thermistor circuits will then be implemented followed by necessary algorithms to extract the proposed vital signs, completing the first prototype.

The second prototype will focus on miniaturization of sensors and circuits for embedment in an actual tile. In the second prototype, load cells will be embedded in the tile as well as the circuit components in the internal compartment of the tile. The electrodes will still be on the surface. All of these changes will be tried and modified to increase the effectiveness of measurements.

The second prototype has commenced in parallel to the first prototype with cooperation with researchers in the Faculty of Architecture. As algorithmic details are implemented on the first prototype, the hardware design specification will be built as the second prototype proceeds.

Once completed, the smart floor tile may be an effective tool in physiological monitoring among the smart home devices. The device will unify some of the functions that current passive physiological monitoring devices possess and will be able to provide daily assessment of the user to the user's caregiver, family members, and/or doctor.

The preliminary result from the force plate showed the capability to measure heart rate from the sole of a person while the person is standing. The heart rate extraction from the prototype was hindered by noise and the sensor signal and processing circuit must be refined to output reliable vital signs.

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