a) Title: Hearing Aid and Non-Intrusive Fall Detection Monitoring System for the elderly

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c) Summary: Include the outline and conclusions of the research

The research outcome is of great significance to assist the aging population in Singapore to improve their quality of life. To date, there are no fall detection systems that are highly reliable and accurate in detecting elderly person fall occurrences. Many fall occurrences went undetected, and these resulted in the delay of providing the much-needed assistance by the caregivers.

The proposed research reviewed the shortfalls of various existing single sensor based fall detection systems, and capitalized on the fusion of sound and inertial sensing for accurate fall detection and localization, that is far superior in accuracy than any of the single sensor based systems. With the proposed system, any valid fall occurrences will not go un-noticed, hence a dependable and reliable fall detection system that can greatly assists caregivers in ensuring the elderly person are safe.

The addition of hearing aid functionality also helps the aging population due to age induced hearing loss. Elderly person who suffers poor hearing will greatly benefit from this extra addition without the need to carry extra devices.

d) Aim of Research

The objective of this project is to design and develop a wearable, non-intrusive, location-based fall detection monitoring system. The proposed system utilize accelerometer and sound-based detection to detect human fall. With the inclusion of sound sensors, the fusion of accelerometer and sound-based detection will not only improve the detection accuracy by minimizing the number of false positives, it also serves as a location-based fall detection. The sound sensors are strategically mounted at fixed locations around the house. These sound sensors can then pinpoint the location where a fall has occurred. At the same time, the proposed wearable fall detection device has an added value to act as low-cost hearing aid for the elderly with age-induced hearing loss problem. This project aims to provide an affordable and reliable system to the less privileged group of people by improving their psychological and emotional well-being, so they have more opportunities to participate in family, community and social life.

e) Method of Research & Progression

The proposed fall detection monitoring solution consists of two sub-systems:

(I) a Base Station where the detected fall alerts and caregiver notifications are being handled. The data collected can be used for offline analysis to further improve on the fall detection algorithm.

(II) Wireless Sound Sensor Modules which are strategically mounted at fixed locations around the house for continuous monitoring of potential falls based on detected sound, and

(III) Wireless Wearable Module is an accelerometer-based fall detector wearable device in the form of watch or pocket-size that can clip on the belt or shirt's pocket that monitors the motion activity of the target user. This wearable device has additional functionality as a hearing aid. This extra feature is enabled only if an elderly person can benefit from it.

Having established the fact that using only an accelerometer-based motion activity monitoring feature to detect a valid fall is insufficient and prone to false fall detection. Sound sensor modules installed at various spots within a senior citizen's home are used to verify if a valid fall has indeed occurred by measuring the localized sound pressure level (SPL) for potential occurrence of a fall.

In our preliminary studies, in a quiet residential environment, a typical indoor SPL is measured to be in the range of 30dB-50dB. 30dB is a typical bedroom SPL, 40dB typically represents a person whispering, and 50dB represents a typical person talking. A group of people in an intense discussion can have a moderate SPL of 60dB. 70dB SPL represents a noisy office, restaurant or street noise, and 80dB SPL is very loud, representing the sound of a heavy street noise and an average factory floor.

Sound generated from a fall usually emits from an elderly body impacting the floor or a hard object. In our preliminary findings through an experiment conducted where a volunteer emulates several occurrences of falls on a hard floor overlaid with soft rubber foam, the recorded SPL for each fall is within the range of 50dB to 70dB with a sound duration of less or equal to 500ms. Hence, a short burst sound with SPL of 70dB and duration less or equal to 500ms can be associated with an occurrence of a fall, where the large SPL can be associated with the elderly person's body shattering a glass object during impact.

Based on this conducted experiment, sound can be used as an indicator to detect an elderly person's fall occurrence. In order to identify a valid fall and to notify the caregivers, the wearable module which is using accelerometer-based fall detector will send a Fall Alert Wi-Fi broadcast message to the nearby sound sensor module if a valid fall in detected. Once the e-SS module receives a valid Fall Alert signal it will then fuse the result together with the SPL using fuzzy logic as a second level verification. This is an important second level sensing and detection step to minimize the false positive alerts. With the inclusion of sound sensors, these sound sensor modules have the ability to locate the exact location of the person falling.

f) Results of Research

Experiments are carried out to verify the effectiveness of the developed accelerometer-based algorithm and the proposed sensor fusion-based algorithm. Five volunteers are engaged to emulate elderly physical behaviors in performing common daily motion activities such as walking and using stairs, sitting down, standing up, and squatting. Each of the volunteer hangs the wearable device around their neck, it is required to perform all the defined motion activities, and each activity requires 10 repeats.

Table I depicts the false fall occurrence detection results using only the accelerometer-based algorithm, and Table II depicts the detection results using the proposed sensor fusion-based algorithm. Based on the results, the accelerometer-based algorithm has the maximum false fall detection of 20%. With sensor fusion, the false fall detection is further reduced to less than 2.5%.

The same volunteers are tasked to emulate four types of falls namely: front fall, back fall, side fall, and fall from a chair. The experiment was conducted in a lab with a tiled floor overlaid with a 1.5” thick soft rubber foam mat to cushion the emulated falls. Each fall is executed 10 times by each volunteer. Table III depicts the detection results using only the accelerometer-based algorithm, and Table IV depicts the detection results using the sensor fusion-based algorithm. To detect a valid fall, the accelerometer-based algorithm is sufficient as it presents at least 95% accuracy in detecting the various emulated falls scenarios. Thus, the accelerometer based algorithm is sufficiently accurate in detecting a valid fall but is prone to false falls detections. The sensor fusion-based algorithm is very effective in reducing the false falls detections although it does not improves on the overall accuracy of the valid fall detection.

TABLE I: Accelerometer based algorithm in detecting false fall occurrences

Volunteer	Motion Type				Error
	Walking	Sitting Down	Standing Up	Squatting	(%)
1	2	3	0	0	12.5
2	3	3	0	1	12.5
3	3	4	0	1	20
4	2	3	1	0	15
5	3	3	0	0	15

TABLE II: Sensor fusion-based algorithm in detecting false fall occurrences

Volunteer	Motion Type				Error
	Walking	Sitting Down	Standing Up	Squatting	(%)
1	1	0	0	0	2.5
2	0	0	0	0	0
3	1	0	0	0	2.5
4	1	0	0	0	2.5
5	0	0	0	0	0

TABLE III: Accelerometer based algorithm in detecting valid fall occurrences

Volunteer	Fall Type				Accuracy
	Front	Back	Side	From a Chair	(%)
1	10	10	10	10	100
2	10	10	10	10	100
3	10	10	9	10	97.5
4	10	10	9	9	95
5	10	10	10	9	97.5

TABLE IV: Fuzzy logic based algorithm in detecting valid fall occurrences

Volunteer	Fall Type				Accuracy
	Front	Back	Side	From a Chair	(%)
1	10	10	10	10	100
2	10	10	10	10	100
3	10	10	9	10	97.5
4	10	10	9	9	95
5	10	10	10	9	97.5

g) Future Areas to Take Note of, and Going Forward

Utilize neuromorphic memory for AI based pattern recognition to replace the fuzzy inference engine. This replacement may potentially further improve the fall detection accuracy and simplify the hardware implementation of a fuzzy logic system.

h) Means of Official Announcement of Research Results

Journal publication: P. V. Er, and K. K. Tan, "Non-intrusive fall detection monitoring system based on Fuzzy Logic," Measurement, 124 pp.91-102 (2018).