Evolution of an Eldercare Technology System to Monitor Motion and Detect Falls.

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Abstract— **Falls are a major cause of injuries in the elderly, and in some cases, these injuries may be fatal. We are developing a system to monitor the elderly and detect falls. We used a novel technique of signal scavenging to detect presence of the person. Aluminum foil sensors on two faux floor, one sized 1m x 1m (3feet x 3feet) and the other 2.3m x 1m (7feet x 3feet) provided a signal when activated by steeping on the foil. The noisy sensor signal was conditioned and converted into digital format, the digital signal was interfaced to a micro-controller and displayed on a PC. Graphical analysis with ROC space and personal experience with utilization of the faux floor system gave us confidence to develop a full size floor, 3.6m x 3.6m (12feet x 12feet). The results obtained on both floor showed a high degree of sensitivity, with low false positive and false negative rates. Observed problems like cross-talk, noise interference and abrupt output behavior of the sensor system were avoided with careful manufacturing of the flooring. With the development of the full floor, we can create a prototype with high reliability, high accuracy to detect motion, and can be used for further research.**

I. Introduction

FALL detection techniques are important for the elderly including those who suffer from dementia and Alzheimer's disease. We are developing a floor system to monitor individuals and detect falls. Building such a system would improve independence among the elderly including Alzheimer's patients who suffer from forgetfulness, challenges in planning, difficulty completing familiar tasks at home, poor judgment of tasks and so on [1].

More generally older adults are concerned about falls; they perceive technologies that monitor activity levels as useful [2]. The major injuries observed due to falls were fractures and head trauma. It has been found that patients suffering from Alzheimer's disease fall even during their normal gait. And those with Alzheimer's disease and other cognitive disabilities have increased risk of falls over the general population [3]. The literature shows that seniors with cognitive impairment fall at an annual rate of 60% (1) i.e. almost one in two cognitively impaired person falls, and that one in ten falls left the faller unable to get up for at least 5 minutes [4]. Consequently, flooring with the potential to detect falls and provide the potential for rapid response is essential.

Such a system produces data constantly; providing internet and telephony connectivity to a monitoring system informs caregivers and distantly located loved ones of the status of daily living of their loved ones. The Smart Carpet we are developing will be cheap and reliable, consistently detect personnel walking and can detect falls.

We used aluminum foils as sensors to detect the presence of a person. We describe here two floor systems using aluminum foils as sensors and assess their performance: they are distinguished by the number of sensors, either 2x2 or 3x7. These two provided a direction for the evolution of a floor detection system currently under construction and test.

The signals generated from the aluminum foil are a result of signal scavenging technique [5]. These signals, which are 60Hz noise and its odd harmonics, are then fed to a non-linear analog circuit, which performs the signal conditioning on the input wave. The data then passes into a microprocessor and finally into a computer (Figure1).

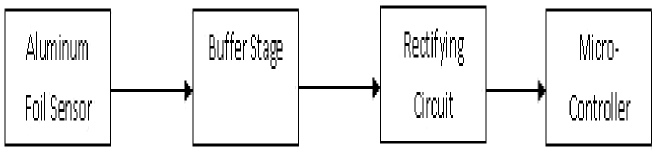

Figure 1: Block diagram summarizing the basic layout of the analog circuit, which fed the micro-controller.

We have successfully built and tested these floors in terms of efficiency, accuracy and repeatability. These results have given us confidence in the operation of a full size floor. In fact our recent results with a full floor appear better than those obtained with these evolutionary efforts.

To be sure, many applications to monitor the elderly have been developed [4, 6-9]. However ours is unobtrusive, which means the individual's privacy is not violated, the individual need take no action to effect the operation or performance of the system, and the individual is aware of it and has given their explicit permission for this monitoring. There have been systems which determine the gait of a person. An algorithm to sense the gait of a person was developed by sensor networks that identified the footsteps and footstep patterns [6]. In a Semi-Markov based footstep pattern matching model, Electro-Mechanical Film was used as a thin, flexible, low-priced electret material to detect and study the motion of personnel [7]. A reconfigurable high resolution floor using pressure sensitive polymer between conductive traces on Mylar sheet was also developed to study the human dance movements. However, this floor incorporated 6mm x 6mm sized 4,032 sensors covering an area of about 4160 square centimeters [8].

Other approaches to detect falls have been developed, with the use of accelerometer, floor vibrations [4], video cameras [9,10]; infra-red sensors [11], acoustic sensors [12]. Radio Frequency Identification (RFID) tags were attached to the upper body (wrists) and to lower body (socks) to detect falls of a person [13], and accelerometers [14]. Several of the sensors used in the above techniques are either obsolete (no more into production), or too expensive to be used in manufacturing of carpet envisioned. Many of these systems require a stationery computer for the data from the sensors to be collected and gathered. The forgetfulness of Alzheimer's patients limits the use of wearable sensors: they forget to wear the device so they need a monitoring system. A cheap and highly efficient fall detection system was developed at the University of Virginia which incorporated the use of piezo-transducers [4]. The piezo-sensor required specialized signal processing algorithm, but the inherently radial nature of the sensor compromised its sensitivity. Also promising is the technology that uses computational intelligence to identify features of falls [10].

II. Development System: A 2x2 Sensor Faux Floor

We constructed a faux floor by placing a 1m x 1m x 16 mm (3 ft sq ¾ inches) piece of ply-board on a square frame of 5 cm x 10 cm (2" X 4") wood studs, with a suitable stud that provided additional support at the center. The 2x2 sensor faux floor consisted of four sensors arranged in a two-dimensional matrix format. An institutional carpet the same size as the wooden frame covered these sensors. The sensor was aluminum foil placed on a plastic sheet substrate, covered by a plastic sheet, and then covered by the carpet. In some cases a ground plane, also suitably separated and protected by a plastic sheet, was added. The arrangement of these aluminum foils and plastic sheet was equivalent to a capacitor design, having a positive and a ground plane and a dielectric medium in between. The top of the faux floor was marked as A, B, C, and D to indicate the four sensors underneath the floor.

A. Prototype System: A 7x3 Sensor Faux Floor

The size of this faux floor was 2.6 m x 1m (7feet x 3feet) and was also called the prototype system. It consisted of twenty-one sensors arranged in seven rows and three columns matrix format. A 2.1m x 1m sized wooden frame supported the sensors and acted as a floor, providing support for a person walking on it. Again a carpet covered the sensors on the wooden frame. The arrangement of the sensors was 7 rows of 3 columns. All the wires from one column were grouped together and crimped into a header connector. Thus, the prototype system had three header connectors; each representing one column.

III. Evolution of the Amplifier

The sensors produced a noisy analog output voltage; the amplifier design converts this noisy signal into a digital signal. For the 2x2 Development Floor Amplifier Design, the detection of the 60 cycles was first performed by a single wave rectifier; this was improved by using a full wave rectifier. Op-amps with extremely high slew rates, at 14V/μsec, provided high speed data capture and transmission, its input impedance is very high, and the output impedance is almost zero. The 7x3 Prototype Floor Amplifier Design used the same amplifier as described above, but this time 21 amplifiers connected to the 21 sensor foils: seven amplifiers were connected for each column. Three such sets of seven amplifiers were developed. In Figure 2, shows two-layered Printed Circuit Board layout for seven amplifiers.

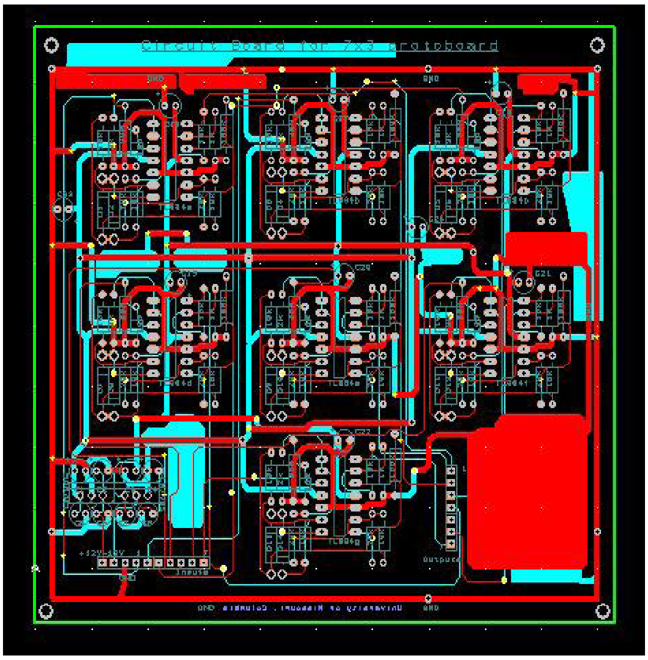

Figure 2: Printed Circuit Board layout for seven sensors in the 7x3 prototype board. This is a two layered board, the top layer is indicated by red color and the blue color indicates bottom layer. Three such Printed Circuit Boards were developed for the complete prototype board.

IV. Microcontrollers and Display Electronics

Apart from the analog electronics, a micro-controller was interfaced via serial communication to a PC for a computer display. Display on computer was made using Java code. The general dataflow started with analog amplifiers, then microcontroller unit (MCU) and finally the computer display.

V. Results

The results displayed in Figure 3 were obtained from a 30.5cm x 30.5cm sensor foil observed on an oscilloscope, to compare activated and non-activated aluminum foil.

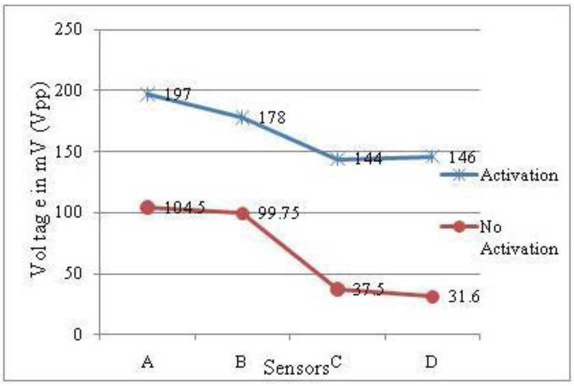

Figure 3: The sensor axis labeled as A, B, C, and D represents the particular sensor excited and the ordinate axis represents the voltages in millivolts observed on oscilloscope. The minimum difference in the output between the two conditions is greater than 200%.

In a 2x2 development system we activated each 30.5cm x 30.5cm aluminum foil 50 times to assess the accuracy of response. Table 1 shows the confusion matrix for with a noise reduction the software filter on. The average accuracy was very high at 98%, the average True Positive Rate TPR for this test was high, 97.5%; the average false alarm (FPR) was 1%, and the misses (FNR) were at 2.5%, each one small. As compared to the foil performance with the filter on, Table 2 summarized the same experiment but this time with the filter off. Here the accuracy was reduced by 12.75% and the false alarms increased by 25% compared to that with the filter on.

TABLE 1
PERFORMANCE MATRIX OF THE DEVELOPMENT SYSTEM USING 30.5cm X 30.5cm ALUMINUM FOIL WITH THE SOFTWARE FILTER ON

Performance of development system with 30.5cm x 30.5cm foil with FILTER ON								
Foil steps = 50 each	MEASURED			CALCULATED				
	True Positive	False Positive	False Negative	True Negative	Accuracy (%)	TPR (%)	FPR (%)	FNR (%)
Foil A	48	0	2	50	96	94	2	6
Foil B	50	0	0	50	97	94	0	6
Foil C	50	2	0	48	97	94	0	6
Foil D	47	0	3	50	99	98	0	2

TABLE 2
THE ACCURACY OF THE SYSTEM IS REDUCED AND THE PERCENTAGE OF FALSE ALARMS GENERATED IS INCREASED WITH THE FILTER OFF

Performance of development system with 30.5cm x 30.5cm foil with FILTER OFF								
Foil steps = 50 each	MEASURED			CALCULATED				
	True Positive	False Positive	False Negative	True Negative	Accuracy (%)	TPR (%)	FPR (%)	FNR (%)
Foil A	47	5	3	45	92	94	10	6
Foil B	50	10	0	40	90	100	20	0
Foil C	50	17	0	33	83	100	34	0
Foil D	47	20	3	30	77	94	40	6

These performance assessments provided what we needed to continue: we were developing a system with high sensitivity and controllable alarm and miss rates.

For the performance of the 21 sensor prototype system, it was clearly impossible to activate each foil so we stepped on each foil and stored the number of activations of the foil on the display. Figure 4 displays the performance of the 7 x 3 prototype system. This graph is an average of the three sets of the readings taken. In this test, we have measured the count of the data samples transmitted by microcontroller to the computer in 5 seconds. Also, the false positives were observed and noted during the excitation of a particular sensor. The maximum false positive is obtained for column C4 which is approximately 23.7%. 33% of the sensors did not have any false negatives. Out of the remaining 67%, the average percentage of the false negatives was only 5. The least number of counts were obtained for column C1 (1273). An average of 1300 counts was observed to be transmitted from the micro-controller to the display computer.

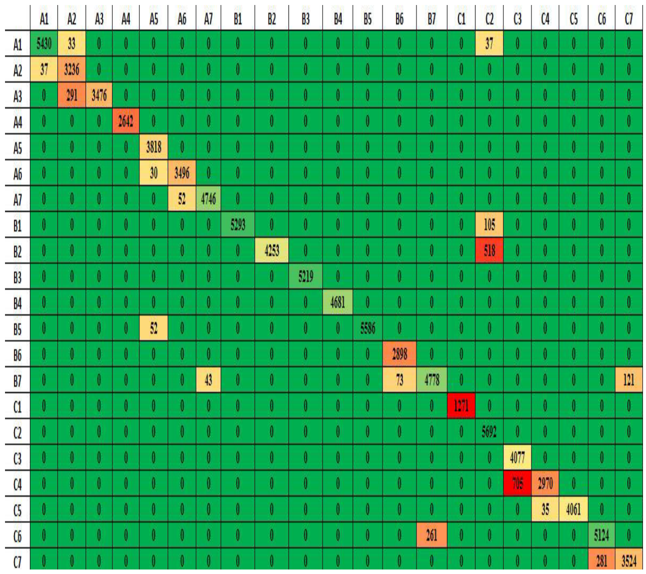

Figure 4: Graph displaying the performance of the prototype system when an individual foil sensor was excited amongst the array of 21 sensors. The rows and columns are marked in array format from A1 to C7 indicating the actual sensors on the development system. The diagonal elements indicate the excited sensors against the false negatives otherwise noted in the rows and columns. The maximum false negatives are obtained in column C4 which is approximately 23.7%.

VI. DISCUSSION AND CONCLUSIONS

We have developed two faux floors using cheap and readily available components to guide in the development of a monitoring carpet to detect motion and falls. The sensors are aluminum, which do not consuming energy, and is cheap. We regularly obtained a change of over 200% in output when comparing activated and non-activated. The values of these readings varied among the foil sensors. The aluminum foil is activated when an increase in the stray electromagnetic field present in the aluminum foils causes a momentary rise in the detected output voltage.

We designed and constructed a development faux floor to have an easily accessible and changeable means of trying out our ideas in the development of a personnel sensing system. This has been a very useful way to test each individual part of the system from the foil, attachment to wires, amplifiers microprocessors, and finally to the display. It was the possible to set up a system that is known to work, make the changes, and observe improvements. The development board provides the capability to make changes in the electronic system and identify the best way to proceed.

The results observed in each faux floor let us identify sources of error. In one instance the performance data led us to observe a slight misalignment due to the drying of the wood that caused but detectable errors on the other foils [15]. It is observed that the false negatives (miss) are extremely low, so the accuracy is very high. This gave us much confidence in the system's reliability and high accuracy.

The effect of using a software filter in Tables 1 and 2 showed results with an improvement of almost 13% in the system accuracy, and 25% in the false positive rates (false alarms). The software filter had higher computations but instantly detected the foil activation. The reduction in the false positive rates with the inclusion of filter would be extremely useful in systems which have high number of sensors. In the prototype system, it was expected that increasing the number of sensors would produce an erroneous generation of stray signals and an increase in the cross talk between adjacent sensors resulting in false alarms. However, the number of adjacent sensors being falsely activated (false alarms) on the activation of only one sensor was very low. We observed that the prototype system was highly sensitive to small movements on the floor.

We have found the appropriate characteristics of the amplifier to allow us to set up the floor in different environments. It is useful to repeat that we are detecting noise and there is considerable influence of the environment on the noise data that we acquire. The amplifiers designed for the faux floor system were three stage amplifiers and provided efficient signal conditioning of the sensor output. The op-amps used had extremely high slew rate to cope with high data sampling rate of the sensor output. The input impedance of the microcontroller when combined with the capacitance of the op-amp creates a filter that results in the damping nature of the signal.

The 21 amplifier prototype board loaded into aluminum box ensured portability. Printed Circuit Boards were developed for the amplifier unit to minimize the noise due to wires, to accommodate a high density layout of components and have a cleaner solution for the analog circuitry(see figure 2).

We expect the system to be extremely cheap and easy to manufacture. The results obtained from the aluminum foil acting as signal scavenging sensor has indeed been encouraging as the results are reproducible under nominal testing conditions. The system is passive and detects presence of people.

The faux floors provide us with a means to arrange foils on flat surface, activate the foils, and connect to the electronics sub-system which can be interchanged. The development system results were repeated in the higher versions of the systems we built.

We are currently extending this technology to a full floor monitoring system. We are undertaking comprehensive experimental tests to assess usability. There are several important applications that will make this system suitable for frail elderly [16], those with mild cognitive impairment, and even in institutional settings for individuals with Alzheimer's disease.

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