DESIGN OF A SIGNAL SCAVENGING SENSOR SYSTEM FOR PASSIVE MONITORING IN ELDER CARE TECHNOLOGY

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By

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DESIGN OF SIGNAL SCAVENGING SENSOR SYSTEM FOR PASSIVE MONITORING IN ELDERCARE TECHNOLOGY

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ABSTRACT

This thesis describes sensors designed for a non-obtrusive monitoring system to detect and track the elderly adults walking on the carpet. The sensors are thin metal foils which detect environmental or scavenged energy. The technology aims at addressing the concerns of safety for the elderly under no supervision and without wearable-expensive-tracking devices. Eldercare technology provides support for the growing number of seniors in the world population. Emerging technologies are expected to ameliorate the problems of aging such as loss of balance and falls, causing a potentially serious injury.

The thesis investigates the variation in the power of the signal from the foil sensor after being touched or stepped utilized for sensing and detection applications. Characterization of the scavenged signal shows the dominance of the nuisance 60Hz energy. Change in the foil sensors dimensions and thickness showed significant variation in the signal detected. Sensor performance measures are made using a development board. Results show that foil sensors are reliable for detecting personnel and for tracking a movement. Thus, the foil sensors, through scavenged signals, can be utilized for passive monitoring.
CHAPTER 1

INTRODUCTION

1.1: SIGNAL SCAVENGING:

Signal scavenging is derived from the concept of energy scavenging where the energy is generated from ambient energy in the environment. Scavenged signals are present in the environment in the form of stray electromagnetic waves representing nuisance of 60Hz. The noise captured through the foil sensors developed uses no external power sources for their working. The noise signal obtained using these foil sensors will help in designing a passive monitoring system for motion tracking and fall detection.

1.2: SENSING AND DETECTION:

Noise is the only source of energy for powering up these foils sensors for signal detection. A variation in the signal energy is observed either through a touch or a footstep. This change, considered as an active signal, is the primary source of motivation for developing the foil sensors into sensing and detection system. Foil sensors acts as an antenna picking up low power scavenged signals from the environment.

The variation in this energy represents an increase in electrical voltage in the foil sensors. Precise amplification and digitization of this increase is utilized for sensing and detection. The spectrum analysis of the detected signal shows its behavior and properties.
1.3 PROBLEM STATEMENT:

The noise signal detected due to stray electromagnetic waves from the environment consists of different energy levels varying over a certain range of frequencies. It is necessary to study and analyze the spectrum of the signal in order to understand the behavior of the signal. Spectrum analysis indicates that the scavenged signal picked up by the foils is noise with dominant 60Hz frequency components and its odd harmonics with diminishing signal strength at higher frequencies. Designing a low pass filter eliminates high frequencies which are not useful. A precise amplification process will assure low power signal response detection.

The behavior of the scavenged signal and its variance with respect to the foil sensor dimensions, to the surface they lay on, and to the environmental conditions, constitute the primary part of the problem. Amplifying the detected low power signals and representing an active response electronically forms the secondary part.

From the obtained results of the experiments, we demonstrated the application of signal scavenging concept for foil sensors with the potential of developing sensing and detection system for passive monitoring. This thesis will focus on characterization and detection of the sensor signal for application in passive monitoring.
1.4 ORGANISATION OF THESIS:

While the spectrum analysis of the signal obtained from the foil sensors and its variance are one part of the design process, signal conditioning and digitization process is regarded as equally important part of the overall design process. The magnitude of changes occurring due to activated foil sensors are attributed to low power signals detected.

Chapter 2 familiarizes with technologies developed to address the problems in eldercare technology and different sensing systems designed for monitoring. Details of experimental setup and methods used for detecting the scavenged signal are explained in chapter 3. Chapter 4 shows the results obtained from the signal analysis, signal conditioning, and system performance assessments. Chapter 5 provides discussions on problems influencing the signal detection and performance, the conclusion of the thesis, and suggests future developments in the design process.
CHAPTER 2

BACKGROUND

2.1 LITERATURE REVIEW:

Passive monitoring through scavenged signals is the primary motivation for the study of this thesis. The scavenged signals are low power energy signals abundantly available in the environment. We discovered a concept of signal scavenging through detection using low cost aluminum sensors. The behavior of the scavenged signal can be characterized from the power spectral density of the signal.

Eldercare technology serves to provide unobtrusive support to seniors without any interventions to their daily activities. A structured survey instrument showed that the residents perceived the technology with positive attitude [1]. A study on perception of the cameras by the elders proved to be obtrusive as they were annoyed by a video surveillance on their privacy [2]. One fall detector performed passive monitoring of floor vibration using a piezoelectric transducer to detect the vibrations due to falls. These were compared with a set of pattern to determine the difference and communicate the fall [3].

A Ground Reaction Force device is made using load cells to determine the weight and inertia of a body in contact to the floor. A regular footstep with nominal force was detected with an accuracy of 93% but it failed to detect higher forces of pressure in a footstep [4]. A vocal sound based detection system was designed to detect a location of a person. The system uses 3D location sensing and functions based on the sound
generated by the person which is rarely possible and cannot be a factor for working [5].
The magic carpet uses piezoelectric wires hidden under the carpet to detect the location
of a person but it also uses a radar system for sensing and tracking of the movement [6].

An Electromechanical Film floor measure a 100 square meters recognizes a
footstep through pattern matching using segmental semi markov models. The variance
in the mean square of the noise generated from the floor was matched with a
predefined pattern to determine the footstep [7]. An improvement has been made in
designing Z-tiles which works as pressure sensors with an advantage of flexibility and
transportation. The above mentioned sensing devices used large rectangular shaped
sensing carpets which were difficult to be moved and reconfigured. The Z tiles used
light-weight hexagonal shaped force sensitive resistors interlocked with each other. The
data compression techniques are being designed to manage the data extracted from
these tiles [8].

An electro active fabric was made using polypyrrole polymer which contains
carbon filled rubber. The fabrics are used as strain sensors whose deformation gives a
variation in the resistance. The sensing fabric is a wearable device and requires the
person to wear it which is obtrusive [9]. A pressure sensing floor was developed by
researchers at Arizona State University. The floor uses amount and distribution of force
exerted by a person and integrates with an external system of audio and video sensing
technology to detect a location and movement. The system is mainly used for virtual
reality based entertainment. The amount of data being sent by the floor needs effective
and complex data compression techniques to determine the location [10]. A physical
location is determined by a device designed at MIT called cricket. This location support system determines the location by analyzing information from the beacons spread throughout a building or a room. It uses randomized algorithms on radio or ultrasonic signals received by the beacons. A Radar system utilizes the RF data network created by the beacons and determines the accurate location using triangulation of a transmitter, receiver and radar [11].

A computing device is designed and implement at Oracle research laboratory to determine a fine grain location using ultrasonic transmitter and receivers. The system cannot work accurately at certain instances when multiple signals are received at the receiver, only when one signal is transmitted by the transmitter. This is due to echo and reflection of the sound in the environment. The device requires many transmitters and receivers placed at various locations to determine the location efficiently [12]. An algorithm is developed which can classify a target detected by a distributed sensor network. The technique is implemented in tracking the seismic or acoustic vibrations. It is difficult to track multiple objects at a same time using these techniques [13].

Low noise signals imply low voltage and power of the signal. A scavenged signal is perturbed by various noises and depends largely on the environment. A small differential voltage needs to be amplified accurately to be detected. An instrumentation amplifier is a good alternative to three stage amplification processes as it provides low distortion, unity gain and moderate capacitive and resistive load driving capabilities. Additionally, a minimization in layout area is advantageous when used in large scale [14]. An instrumentation amplifier is used to amplify low frequency signals of 20 Hz
obtained from four-electrode impedance sensor. The instrumentation amplifier promises to improve the accuracy of the measurement at low frequencies [15].

We conducted experiments using a microcontroller developed and programmed by Uday Shrininwar presently working towards his thesis, “Data control for signal scavenging personnel detective system” [16]. The data display was a graphical user interface representing a virtual floor of the development board designed and displayed by Krishna Kishor Devarakonda presented in his thesis on “Data Display for Signal Scavenging Personnel Detective System” [17]. The team worked on developing the sensor system through collaborative effort from Rohan Neelgund working on his thesis on “Sensor Development for a Signal Scavenging Personnel Detective System” [18].

In the paper “Smart Carpet: A sensor system to detect falls and summon assistance”, Myra and team characterized gait performance analysis using prototype board covered with a carpet and supported by two other similar size faux floors. Volunteers expressed no perceivable difference between walking on the prototype board and a normal concrete floor covered with carpet [19].

This work contributed to a low cost human motion tracking system. Such a system can be used to monitor accidents and expedite emergency services for the elderly or disabled people in care, rehabilitation or medical facilities.
CHAPTER 3

METHODS

3.1: FOIL MEASUREMENTS:

Aluminum metal foils (Figure 3.1) are used as potential foil sensors. We used foils manufactured by “Reynolds Aluminum Wrap” for our experiments. These foil sensors were used to determine the signal behavior and variance. Inexpensive and abundant availability is a prime advantage in using these foil sensors. Foil sensors were measured and cut in different dimension of length for conducting experiments. A standard aluminum foil has a thickness of 0.016 mm (millimeter) and a heavy duty aluminum foil has a thickness of 0.024mm (millimeter).

Figure 3.1: Aluminum metal foil sensors
Faux Floors were built with a wooden base and as a support for laying the foil sensors and the carpet. These floors can be easily moved in the case of testing in different environments. A development board was constructed with dimensions of 0.836 m² (square meters) elevated with a wooden square frame of 10.16 cm (centimeter). A small array of four sensors were installed on the faux floor and covered with a transparent sheet of plastic wrap for testing as a part of initial experiments (Figure 3.2).

![Development board](image)

**Figure 3.2:** Development board

A carpet was laid over the sensor array on the wooden floor. Electronics for signal conditioning and digitization was embedded on one of the sides of faux floor
wooden frame as shown in Figure 3.3. The four foil sensors are indicated by the letters A, B, C, and D on the carpet.

![Figure 3.3: Development Board with embedded electronics](image)

For further studies on providing better resolution and testing the reliability of the sensors on the carpet, we constructed a prototype board with dimensions of 1.30 m$^2$ (square meters) rectangle floor elevated at 10.16 cm (centimeter) high (Appendix B.2). The prototype board with installed sensors was supported with two more faux floors with similar dimensions to provide pace and speed while imitating a walking or a fall. The support also helps in analyzing the gait and walking pattern on the carpet. Precautionary measures were taken while wiring the foil sensors which are sensitive to any disturbance causing noise signals.

Signals picked up from the foil sensors need an oscilloscope to record and analyze the spectrum. Tektronix MOS4054 Oscilloscope and Logic analyzer (Appendix
B.3) was used to serve this purpose. It has an ability to visualize multiple signal processing functions on four of its analog channels simultaneously. This oscilloscope has an FFT analyzer with a dynamic range of 50 – 60 dB [20]. This is sufficient to obtain the foil sensor signals which are under dynamic range of 10 dB.

3.2: DEVELOPMENT BOARD ELECTRONICS:

The wire bonding of leads to the foil sensors is of vital importance as the signal is recorded through them. The foil sensors fail to bind to the copper wires as the solder dissipates heat over the surface of the foil and loosens the bonding. Silver epoxy conductive glue, manufactured by MG Chemicals, is used to bond the wires on the foil sensors. This glue provides high electrical conductivity and strong conductive bonding and is mostly used as an adhesive in heat sensitive components replacing the solder. The resistivity of the glue at room temperature is specified as 0.38 Ω/cm [21].

The voltage to ground of the foil sensors is undetectable by a microcomputer for display, amplification of the signal is necessary. A low power precision instrumentation amplifier (INA128PA) was used in the amplifier circuit.

The oscilloscope shows a voltage reading of an inactivated foil sensor in the range of 30mV – 50mV. An activated foil triggered from a step on a development board results in differential increase of about 200 mV. This increase is random and varies according to the environmental conditions of the experimental laboratory. Although, a significant increase is recorded in the oscilloscope, the microcomputer cannot read the
change. A successful detection require a voltage of 1.9V or above at the input of the microcomputer which is achieved through signal amplification.

A D latch is eventually used to convert analog output voltages from the amplifier into digital input signals to the microcomputer. A logic HIGH and logic LOW represents an active step detection and inactive sensor respectively at the input of the microcomputer for display. SN74LSAN Dual type D flip flop was used which contains two D latches producing logic outputs simultaneously. A 555 timer was used externally to synchronize the step with the pulse outputs fed into the microcomputer. Metronome provided accurate beats to record footstep counts.

The above mentioned equipment used in the experiment serves different purpose but are not necessarily needed to run the sensing system.

3.3: EXPERIMENTAL SETUP:

We made voltage measurements on the individual foils. The stray signals picked up by the foil sensor are fed to the oscilloscope through a BNC probe. A square foil of 38.709 cm$^2$ area was used for measuring signal strength and analyzing the spectrum. The measurements were taken directly from the oscilloscope, including spectrum measurements.

For the development board experiments, we constructed the electronics, which is embedded on the side of the wooden floor elevated from the ground. A computer provided a display designed and programmed by Devarakonda and presently working on his thesis on “Data Display for signal scavenging personnel detective system” [17]. We
used microcontroller designed and programmed by Shriniwar for his thesis project described in “Data control for signal scavenging personnel detective system” [16].

3.4: EXPERIMENTAL METHODS:

3.4.1 DISTINCTION OF ACTIVATED AND INACTIVATED SENSORS:

Noise is a major source of energy to power the foil sensors. Scavenged signals vary in signal strength and depend largely on the environment. An active sensor triggered by a footstep or a touch of a hand shows an increase in electrical voltage when compared to an inactive sensor which is untouched. This distinction serves as an indication of a footstep on a LCD display which can be used for application in sensing and detection.

For spectrum analysis, the 6 inch foil sensor was touched by a hand, assumed to be equivalent to stepping on sensors over a layer of carpet. This was a convenient method to record the data from foil sensors with small areas.

3.4.2 DETERMINATION OF SIGNAL STRENGTH:

Electromagnetic energy is ubiquitous in nature. Its availability is dependent on the environment. A few of the major sources of this abundant energy are 60 Hz power lines and radio wave frequency signals. The signals picked up by the sensors are stray energy signals with lot of noise content. It is very difficult to characterize a random signal without proper signal processing techniques. Thus, the signal from the sensors is fed to the multifunctional oscilloscope for analysis. The obtained scavenged signal is
random noise. SIGVIEW 5.0 is utilized to transform the random noise into data points and apply signal analysis techniques. This software helps identifying the behavior of the signal and calculates various signal functions such as autocorrelation and power spectral density.

### 3.4.3 DETERMINATION OF POWER SPECTRAL DENSITY:

One way to look at a signal is in the discrete time domain, which puts a series of values consecutively in time. In this way we can tell something about the behavior of the signal at every moment in time, and can also make some simple statements about its long term behavior. Another way to look at a signal is to view its spectral density (i.e., the Fourier transform of the signal). The fourier transform views the signal as a whole. It swaps the dimension of time with the dimension of frequency. A very strong and slow component in the frequency domain implies that there is a high correlation between the large-scale pieces of the signal in time, while an intense fast component(high frequency) implies correlation in small pieces of the signal in time. Therefore, if our signal $f(t)$ represents values in every single moment of time, its Fourier transform $F(\omega)$ represents the strength of every oscillation in a holistic way in that range of time. These two signals are related to each other by the following formula[22]:

$$F(\omega)=\int_{-\infty}^{\infty} f(t)e^{-j\omega t} dt \quad (3.4.3.1)$$

Parseval’s theorem for energy signals state that:
We can define $F_T(\omega)$ which is the fourier transform of the signal in period $T$, and define the power spectrum as the following:

$$S_f(\omega) = \lim_{T \to \infty} \frac{1}{T} |F_T(\omega)|^2 \quad (3.4.3.3)$$

In another important relationship, the power spectrum is the Fourier transform of the auto-correlation of the time domain signal, and is given by:

$$< f(t)f(t+\tau) > = \frac{1}{2\pi} \int_{-\infty}^{\infty} S_f(\omega)e^{j\omega t}d\omega \quad (3.4.3.4)$$
CHAPTER 4

RESULTS

4.1: SIGNAL ANALYSIS:

Signal scavengers detect stray electromagnetic signals from aluminum metal foils (referred as “sensors”). Significant variance is observed in the electrical energy of the signal during the activation of these sensors. This activation can be initiated either through stepping on the foil or merely touching it over a transparent sheet of plastic. Single measurements of activated and inactivated sensors shows an increase in the electrical voltage obtained. Published papers on signal scavenging (refer Appendix A.1) shows a change in this voltage levels being utilized for tracking motion and sensing falls.

In this chapter we show that the results of activated and inactivated sensor signals used for detection. The results of spectrum analysis and foil properties are studied. An amplifying system is designed to increase the amplitude of the low energy signal. Different surface material show variance in the signal detected from the sensor. A development board is designed and implemented to study the performance of the system.

4.1.1: SENSOR AS A SIGNAL SCAVENGER:

The difference in the voltage levels between an activated sensor and an inactivated sensor for a small foil dimension is about 300 mV. This difference in voltage gradually increases with increase in the sizes of the foil area. The stray energy is picked...
up by the sensor as it acts as an antenna and returns more energy for larger area (Figure 4.1). A graph plotted on amplitudes of energy in mV scale over different foil size gives an idea of utilizing the energy for signal detection and sensing motion. This finds application in tracking a motion or a location of a person standing on the sensors.

**Figure 4.1:** Peak to Peak voltage (mV) for Active (touched) and Inactive (Untouched) foils

The signal strength increases monotonically with every increase in the area of the foil sensors (Figure 4.2). The increase in signal strength over area tends to saturate at a certain dimension of the sensor. Later, the signal strength remains constant for any further increase in the area of the sensor. Hence, it is advantageous to use a smaller dimension foil for sensing as it can provide better resolution while detecting. However, smaller foils will be noisier and less reliable.
Figure 4.2: Average voltage comparisons between activated and inactivated sensors

4.1.2: SPECTRUM ANALYSIS:

Power Spectral Density of a random process is a characteristic of the ensemble of its energy. Spectrum analysis provides insights into signal behavior in the frequency domain [23]. A 6 inch square foil was used as a sample sensor for recording and analyzing the data. The voltage derived from the sensor consists of stray electromagnetic energy abundantly available in the environment. The sources includes, but not pertain to, 60Hz power line energy, stray energy from nearby electrical and electronic equipment or appliances, low frequency radio signals, and possibly other sources dealing with wireless devices. A time domain representation of the signal is given in Figure 4.3.
Figure 4.3: Time domain representation of scavenged signal from the sensor

A logarithmic spectrum of the sensor signal is shown in Figure 4.4. The graph indicates the prominence of 60 Hz noise and its odd harmonics over a frequency range of up to 2 KHz. The signal tends to fade away at higher frequencies. Although, there are even harmonics slightly distinct in the background, the signal is dominated by 60 Hz frequency and its odd harmonics.
A Fourier transform on the above signal gives information on the frequency spectrum of the signal. The signal is confined to low frequency spectrum (2.5 kHz and lower). Figure 5.5 shows the dominance of 60 Hz and its odd harmonics over the frequency spectrum. A graph plotted for amplitude of the voltage (in milli volts) over frequency (in Hertz) shows that the signal captured by the foil is of 60 Hz frequency and its odd harmonics.

**Figure 4.4:** Logarithmic Spectrum to study prominence of frequencies higher than 60Hz.
Figure 4.5: Amplitudes of Nuisance of 60Hz and its odd harmonics
The power spectral density of the signal (Figure 4.6) specifies the amount of power per unit (dB) as a function of frequency. The power units in dB are a function of the frequency component. Also, the power of the signal varies according to the size of the foil sensors and depend on the environmental conditions.

![Power Spectral Density of the signal](image)

**Figure 4.6**: Power Spectral Density of the signal

### 4.2: SIGNAL STRENGTH VARIATIONS:

The frequency spectrum of the 6 inch foil (Figure 4.3) shows dominance of 60 Hz frequency and its odd harmonics (Figure 4.4). Also, the amplitude of the signal (in dB) is maximum at 60 Hz as seen from the Fourier transform of a 10 inch square foil sensors as shown in Figure 4.7.
Figure 4.7: Fourier transform of 10 inch square inactivated foil sensor.

Signal strength monotonically increases with increase in the foil area. This increase is with respect to the uniform thickness of the foil of around 0.016mm. A heavy duty foil of thickness of around 0.024mm was used for the purpose of understanding signal behavior for an increase in density of the foil sensor. The heavy duty foil records an increased gain of 3dB amplitude for the same foil dimensions as a 10 inch square regular foil. Figure 4.8 gives the comparison graph between a regular foil and a heavy duty for the same foil dimensions under no activation. Although, the heavy duty foil promises an increase in the signal strength for the same foil area, it is not recommended due to its cost of manufacturing and thickness.
4.3: SIGNAL CONDITIONING AND DIGITIZATION:

We require amplification of the signal, as stated in methods. First, the signal should be amplified from a low voltage of 300mV (approx) to a voltage of above 1.9V to be considered as a successful detection. This should be high enough to drive a digital circuit to logic HIGH in case of occurrence of a step process.

The first condition could be achieved by employing an industry standard low power instrumentation amplifier which increases the overall gain of the signal using a single resistor from the equation (4.4.1) [24]. An instrumentation amplifier with a gain of 10 is used with a rectifier circuit to obtain the digital output of the scavenged signal. A 0.01µF capacitor is used at the output of the diode to produce short time pulses to be fed to a digital circuit shown in Figure 4.9.
As we stated in the methods, an activated signal has higher amplitudes when compared to an inactivated one and it requires amplification to detect a specific voltage. After some efforts, a gain of 10 (approximately) was found to be useful, set by a 4.7KΩ resistor which then amplifies the signal voltage for detection. This signal is rectified using IN4003 diode to obtain positive dc component of the signal and disregards all the negative voltage. The output of the rectifier is then fed to a D Latch which gives logic HIGH for every voltage of more than 1.9V, and a logic LOW for voltage range of 0V – 1.9V corresponding to an inactivated signal.

Figure 4.9: Amplifier design for signal conditioning

\[
G = 1 + \frac{50 \, K\Omega}{R_G} \quad (4.4.1)
\]
The schematic for the amplifier circuit for a development board system with four foil sensors is shown in the figure 4.10. The active and inactive LED’s at the output of a D flip flop are programmed by a 555 timer to respond for every 10ms. This output from the rectifier is fed to PIC16F877 8-bit CMOS flash microcontroller which activates a logic HIGH for 5V input and logic LOW for a virtual 0V input. The D latch converts the analog voltage as a digital signal to simplify the process.
Figure 4.10: Signal Conditioning and Digitization circuit schematic
4.4: SIGNAL VARIATION: DIFFERENT SURFACES:

Sensors outputs are dependent on the surface on which they lie, that is sensors on different surfaces have correspondingly different signal behavior. Figures 4.11(a-d) represents signals produced by the four sensors on (a) carpet, (b) wood, (c) tile and (d) cement surfaces activated one at a time continuously over the limited trigger scan of the oscilloscope.

Figure 4.11 (a) shows signals obtained after activating sensors simultaneously through a step on a carpet floor. The activated signal remains constant for the duration of the step and jumps to low amplitudes as soon as the step is removed. Hence, this quick transition can be utilized for sensing and a precise amplifier will help in improving the low voltage electrical signals generated.

Figure 4.11(b) represents the behavior of the signal on a wooden surface which is assumed to be baseline conditions for our experiments. Thus, the signal variation is utilized to represent a detection of step for motion and position sensing applications.

Figure 4.11(c) show the signal variation of sensors placed on a tile floor. For every step on each sensor with the same time duration as the previous, the signal attained is represented by a positive pulse at the start of step and negative pulse at the time of removal of step. A modified circuit needs to be designed to meet the specific needs of the signal generated from these sensors due to negative peak voltages.

Figure 4.11(d) shows the sensor behavior on a cement floor surface, which is similar to the behavior on tile surface.
Figure 4.11 (a): Carpet surface used as floor

Figure 4.11 (b): Wood surface used as floor

Figure 4.11 (c): Tile surface used as floor

Figure 4.11 (d): Cement surface used as the floor
4.5: PERFORMANCE: DETECTION:

Performance measures of the system test the scavenged signal, amplifiers, microprocessor and display. Four foil sensors (A, B, C and D) are evenly distributed on a development board without overlapping. Initially, the sensors are activated through a single footstep on one of the sensors. The response displays as active on LCD display (Figure 4.12(a)). Two sensors activated simultaneously with a footstep indicates active on the LCD display (Figure 4.12(b)).

![Figure 4.12(a): Single sensor active response](image1)

![Figure 4.12(b): Dual sensors active response](image2)

System response to footstep speed must be adequate or else delays will cause the system to underperform. In constant environmental conditions, the sensors are tested for their response performance for steps occurring at different speeds. Table 4.1
gives details on active response of the LCD display for every footstep that occurred. A metronome was used to synchronize the step with beats per minute (BPM) scale.

The first experiment was carried at normal speed of 1 step/sec (for 100 steps), the individual step response of sensor A showed up on the display 100 times but also on sensor C for 20 times. In other words, sensor C showed activation without stepping on it for 20% of events. Error is shown in the display at sensor A (100, 20) where 20 represents sensor C displays. Similarly, error display of sensor B (100, 2) and sensor D (100, 31) shows that sensor C is sensitive to either vibrations or noise caused by steps on other sensors.

As the speed of the step is decreased to 1 step/ 2 seconds, the sensor C is displayed as active during the stepping process of all other sensors. Once the speed of the step is increased, the false display of sensor C decreases during other step displays. This behavior of sensor C indicates that it is sensitive to the noise caused by the vibrations during other sensor stepping events. We determined that sensor C was on an uneven surface which caused vibration in the foil when stepped on.
<table>
<thead>
<tr>
<th></th>
<th>1 Step/Sec</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>No Display</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1) 60 BPM – 100 Steps (Normal)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>100</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>100</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>2</td>
<td>31</td>
<td>100</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>2) 30 BPM – 100 Steps (Slow)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>100</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>85</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>100</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>3) 120 BPM – 50 Steps (Fast)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>50</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>50</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.1**: Reliability Test for active sensing and display
CHAPTER 5

DISCUSSIONS, CONCLUSIONS, AND FUTURE DEVELOPMENTS

5.1 DISCUSSIONS:

Energy to the sensors is primarily provided by the scavenged signals in the environment. The self powering capability of the sensors takes advantage over expensive electronic systems. Static electrical energy is also used through the sensors to operate the device.

5.1.1 SIGNAL DETECTION:

Activated sensors show a substantial increase in the signal strength at a frequency of 60 Hz which further helps in correlating this increase to detect a step or a motion. The signal strength is dependent on the noise picked up the sensors. In places isolated from noise signals, the sensors are not likely to behave the same way due to very low energy contained in the sensors. Also, if there are many electronic devices which generate low frequency noise around the device, the sensors pick up more energy and are likely to behave as activated sensors even without activation, producing false positives.

5.1.2 SIGNAL CONDITIONING:

The signals picked up by the sensors during activation are in the milli-volt range which is not sufficient for detection by a microcontroller. Amplification of the milli-volt
signal precisely by an instrumentation amplifier is necessary. As the instrumentation amplifier is built on a three stage operational amplifier design, a complete amplifier system with three different op-amps precisely designed for a particular gain will largely reduce the cost of the system if the sensors are installed in a complete room. It is advantageous to use a digital circuit before the microcontroller which sends logic HIGH and logic LOW for every step and no step process respectively to further simply the circuitry of the device in larger areas.

5.1.3: SYSTEM PERFORMANCE:

The Signal to Noise Ratio (SNR) (dB), defined as the power ratio of useful information signal to a noise signal, can be improved to enhance better performance of the sensors. The sensors perform ideally at room temperatures; the sensors are easily perturbed by vibrations in the surface or variations of humidity in the room. One method in reducing the noise could be from carefully controlling the environment. Other alternatives mentioned above such as better filtering techniques and averaging the measurement could be useful to increase the performance of the sensors, thus increasing the system performance.

5.2 CONCLUSIONS AND FUTURE DEVELOPMENTS:

5.2.1 CONCLUSION:

Active and inactive foil sensors give a detectable electrical voltage that can be used for sensing and detecting applications. Signal analysis of the energy scavenged
signal shows dominant 60 Hz frequency components in the spectrum. Evidently, the signal strength of stray electromagnetic energy tends to increase monotonically with increasing area of the foil sensors. Low power energy signals scavenging in the environment acts a power source for passive sensors.

A prototype board constructed using faux wooden floor is used for sensing and detection experiments. Signal conditioning and digitization further improves the signal strength for positive detection. System performance is monitored through a LCD display. Active response of the sensors indicates possible applications in motion sensing and fall detections.

5.2.2: FUTURE DEVELOPMENTS:

Future developments will help in designing a cost effective system. The industrial standard low precision instrumentation amplifier can be replaced by designing a precise three stage amplifier using three individual amplifiers. This will greatly reduce the cost of the system when a number of sensors are used. However, this leads to complex circuitry and overall increase in the size of the system.

A wireless technology can be implemented to minimize the wiring of the circuits. This includes, sending the information from the microcontroller to the distant wireless display device. Further, this display can be transferred on to a wireless network. The caregivers can use this technology as an alerting system in the monitoring of elder adults.
REFERENCES:


APPENDIX

APPENDIX A

APPENDIX A.1: Published Paper on “Signal Scavenging for Passive Monitoring in Eldercare technology”.

APPENDIX A.2: Paper in Press on “Smart Carpet: A Sensor System to detect falls and summon assistance”.

APPENDIX B

APPENDIX B.1: Additional data that is not included in the thesis text.

APPENDIX B.2: Figure of Constructed prototype board with 21 sensors.

APPENDIX B.3: Logic Analyzer and Multifunctional Oscilloscope used in experiments.
Appendix A.1: Signal Scavenging For Passive Monitoring In Eldercare Technology

Harry W. Tyrer Member, IEEE, Rohan Neelgund, Ashrafuddin Mohammed, Uday Shrinkwiar

Abstract—Signal scavenging is analogous to energy scavenging: seemingly ubiquitous energy in the environment provides the signal for usage as a personnel sensor. Such energy can be used to detect motion, and most importantly falls. Stray signals can be detected in aluminum foil as voltage differences between touched foil (say by hand) compared to that untouched. Spectrum analysis shows the stray electromagnetic noise signal consists substantially of 60 Hz and its harmonics. Also the signal intensity for both touched and untouched monotonically increases with foil area. While personnel monitors find utility in many areas including security, personnel control and activity detection, we believe these putative sensors to be useful in inobtrusive monitoring of elders to provide them with increased independence at a critical time in their lives.

I. INTRODUCTION

Energy scavenging recognizes that energy exists in the environment in a wide array of forms. A common example is the self winding watch that uses wrist motion to provide energy for operation. Other common examples include the use of solar, wind and ocean energy; these sources can and do provide large amounts of energy, as is well known.

The sensor engineer is familiar with the nuisance of 60 Hz and other stray electromagnetic noise that limits the operation of the sensor, and may even require extensive effort to overcome. We propose using this noise as a ubiquitous source of signal. We use the term signal scavenging to describe the use of that noise as a source of energy for signal detection. In particular we are interested in using the fact that the noise level read from a sample of aluminum foil increases when touched by a person.

The motivation for this study is to use signal scavenging as a means to monitor the elderly for motion and falls. There are many applications for unobtrusively monitoring the elderly [1]. Inobtrusive means the individual has given their explicit permission for this monitoring and aware if it, the individual need take no action to effect the operation or performance of the system and the individual’s privacy is not violated. Studies in our group indicate that older adults were concerned about falls and that they perceived technologies that monitor activity levels and sleep patterns as useful. The older adults emphasized the need for non-obtrusive systems [2]. A monitoring system using these foils is passive and will increase the effectiveness of caregivers by providing access to the motion of the individual.

The elderly are particularly vulnerable to falls. Falls are dangerous and require immediate assistance; there are anecdotes of those who have fallen and waited undiscovered for hours or even a day or more. In addition, predilection to conditions such as falls, and changes in daily patterns may indicate impending health problems [3]. Inobtrusive sensing technology can provide alerts. More generally, there is evidence that technology can provide early detection of changes in the health status of the elderly [4], and we believe that a monitoring system with careful attention to the data can provide those benefits.

Monitoring and fall detection is also important for those with Alzheimer’s, since it has been known for a while that falls also are associated with cognitive dysfunction [5]. Some of the published literature indicates that approximately 60% of older people with cognitive impairment fall annually, that’s approximately twice that of older people without cognitive impairment. The increased odds of falling in older adults with cognitive impairment put them at increased risk for major injury such as fracture and head trauma [6]. A more recent study shows that women with mild cognitive impairment have a greater number of fall risk factors compared to older women without mild cognitive impairment [7], and these women had significantly reduced balance and limb coordination.

In this paper we characterize the signal scavenged from aluminum foil for the purpose of developing an inobtrusive sensor system for the elderly. We characterize the voltages detected upon activating (touching) the foil and non-activating. We further characterize the noise by the low frequency spectra appearance the dependence of the detected voltage on foil area.

II. METHODS

We undertook a series of experiments to identify the properties of the noise signals that we read from aluminum foils. For these experiments we used Hewlett Packard 54602B laboratory oscilloscope, with 150 MHz bandwidth, two channels and millivolt sensitivity. A Tektronix 4 Channel Oscilloscope (TDS3054B) was used for the spectrum analysis.
The foils were laid out and connected to the oscilloscope through wires glued to the foil using MCG-8331 MG Chemicals Silver Conductive Epoxy. The glue has high electrical conductivity, although no direct measures of conductivity were made. Figure 1 shows a typical square sample of aluminum foil with glued wires (which connect to the oscilloscope).

![Figure 1](image1.jpg)

Figure 1: Aluminum foil covered by vinyl (for protection and ease of use) with leads glued in place.

We measured electrical energy from foils with and without contact with a person. We refer to activated foils as those touched or in contact with a person. In case of comparisons the contact was applied the same way. In many experiments we stepped on the foil and read the activation, in others we touched by hand, and still others it was most convenient to apply hand pressure on the foil covered with transparent sheet of plastic. Non-activated, inactivated, or non touch foil data was read without touching or stepping on the foil.

III. RESULTS

We compare a single measure of activated and non-activated foil in the plot shown in figure 2. The activated signal level is at hundreds of millivolts compared to the non-activated, at 10s of millivolts. As will be shown and discussed below we also measured the activated and non-activated average voltages of 10.77 mv and 2.33 mv, and the RMS voltages at 53.99 mv and 5.25 mv. These comparisons help characterize the voltages indicating that there is not much of DC component. Secondly, variations in the scope display due to variations in touching can produce noticeable differences in the various voltage readings indicating a temporary variation in DC component.

![Figure 2](image2.png)

Figure 2 shows the peak to peak voltage read when the foil is momentarily touched.

The foil acts as an antenna that when touched acquires a substantial increase in ambient electrical energy. The oscilloscope shows (Fig 3) the signal variation with and without activation. To obtain reasonably repeatable results we touched the foil in similar ways each time. The manner of touching produced different wave forms in comparing differences between activated and non-activated. Clearly a motivation of this study is to learn to tame the signal source.

![Figure 3](image3.png)

Figure 3: Electrical energy added to the foil as a result of a person touching (activating) the foil. The smaller noisy portion of the trace has a level at 30mv p-p, whereas the larger activated portion is nearly half a volt.

We prove here that this electrical energy consists of stray electromagnetic energy ubiquitously available in the environment. The sources include 60 Hz power line energy, stray energy from nearby electrical or electronic equipment or appliances, radio and television station signals, and possibly other sources including wireless Personal Digital Devices. To try to identify these sources we decided to obtain the spectrum of the signal. It was most confinement to focus on the low frequency (2.5 kHz and lower) energy.

We obtained data from activated (touch) and non-activated (non-touch) foils. The data was downloaded onto an excel spread sheet and the plots shown here.

We obtained a linear display of the spectrum from dc to 1500 Hz. Shown in figure 4 is a linear display of signals obtained from non activated foil. The 60 Hz is the dominant component in this display (see table 1).

![Figure 4](image4.png)

Figure 4: Display of the linear spectrum of data acquired from a foil of aluminum connected to an oscilloscope. Note the substantial spike at 60Hz.

![Table 1](image5.png)

Table 1: Linear No Touch

<table>
<thead>
<tr>
<th>Hertz</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>0.4</td>
</tr>
<tr>
<td>250</td>
<td>0.8</td>
</tr>
<tr>
<td>500</td>
<td>1.2</td>
</tr>
<tr>
<td>750</td>
<td>1.4</td>
</tr>
<tr>
<td>1000</td>
<td>1.0</td>
</tr>
<tr>
<td>1500</td>
<td>0.6</td>
</tr>
</tbody>
</table>
It is the most easily identifiable component of the data and includes the 60 Hz signal and its frequency components or harmonics.

The same data was displayed in logarithmic mode to diminish the 60 Hz component and enhance the other prominent components (Figure 5) Note the spikes of components of odd harmonics of 60 Hz, and note the substantial noise levels between the spikes; these remain to be studied. Table 1 lists the frequencies and amplitudes directly read from figure 4. Beyond 900 Hz it is difficult to honestly discriminate the level of the 60 Hz components since they are approaching the level of other data spikes not readily attributable to 60 Hz components.

Table 1 Amplitude and frequency of prominence in the noise energy.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1.226</td>
</tr>
<tr>
<td>180</td>
<td>0.066</td>
</tr>
<tr>
<td>300</td>
<td>0.029</td>
</tr>
<tr>
<td>420</td>
<td>0.018</td>
</tr>
<tr>
<td>540</td>
<td>0.022</td>
</tr>
<tr>
<td>660</td>
<td>0.024</td>
</tr>
<tr>
<td>780</td>
<td>0.021</td>
</tr>
<tr>
<td>900</td>
<td>0.015</td>
</tr>
</tbody>
</table>

The most remarkable fact here is that these are the odd harmonics of 60 Hz (1, 3, 5…). We looked carefully at the time domain signal for this spectrum, which was triangular, with 60 pulses/sec repetition rate. Riding on top of the triangular pattern were small components of amplitude variation. Providing confirmation that we indeed were dealing with odd harmonics of 60 Hz.

We obtained the spectrum of the noise data from 6inch square aluminum foil. We compare the activated (touched) foil to inactivated foil (no touch) to form figure 6. We see that the 60 Hz component spikes were consistently larger in the touch case compared to the no touch case. Remarkable we also see even harmonics of 60 Hz, which were suppressed in figures 4 and 5 above, indicating the statistical nature of the noise. In this case the even harmonics are substantially reduced compared to the nearest odd harmonic. Furthermore in the activated (touch) case the drop in amplitude is more pronounced than that of the inactivated case.

Figure 6 (upper) the log of voltage intensity for activated foil samples. Note the predominance of the odd harmonic, but the even harmonics are distinct from the background. (Lower) The inactivated foil shows a substantially lower harmonics compared to the activated foil.

It has come as a surprise to us that there does not appear too much randomness in these data. This clearly needs substantially more study. But the primary source of energy clearly comes from 60 Hz stray signals. We are so accustomed to calling noise and stray signals random, that it is surprising that the easy call of random signal cannot be yet be affirmed or denied.

Clearly for use as sensors it is important to consider the variation in size. We obtained the touch and no touch values of noise from 6 foils ranging in area from 2, 4, to 64 square inches and plot the results in Figure 7. There is clearly a separation between the activated and non-activated values. We should point out that similar data was obtained for peak to peak voltage (112 mv inactivated, and 900 mv activated). Interestingly the size of the foil is important since
Figure 7 Comparison of activated and non-activated foils by size. The voltage monotonically increases with a linear increase in area. Here we compare the average voltage. At the smaller sizes we risked losing the signal altogether, with increasing area we reach an inflection point at around 32 sq. in. Further increase in size does not improve the signal difference. Larger provides more signal, but smaller provides more resolution. We note the maximal inflection of the activated data at 32 sq in. This point seems to be that at which the method of touch that we used did not increase the noise level appreciably, a trend the non-activated foils did not express. The foils were strips 4 inches long with the appropriate width to fill out the required area (the last though was 8” x 8”). This gives the intriguing possibility of providing improved resolution compared to the larger foils.

IV. DISCUSSION

Signal scavenging takes advantage of stray electromagnetic energy to detect the presence of (or the touching by) personnel in a conductive foil. We used aluminum foil which is cheap and easily available. This is similar to the capacitive buttons used in electronic systems except that we do not use any energy source other than that picked up by the foil. This of course is the chief advantage in that there is no need to provide power and the foils are completely static devices.

Clearly the primary source of energy is 60 Hz stray electromagnetic energy. Furthermore the activated foils show a substantial increase in the main 60 Hz signal, which is 20 to 40 times greater than the higher harmonics of the waveform. Additionally there is some variation in the detected signal where we have seen primarily odd harmonics and other times we see both odd and reduced even harmonics. While this is an interesting insight, it does not really affect the detection of the noise since we use total noise. We continue to explore ways of improving the detection of the signal. There is some satisfaction in using as a signal source the stray energy that is the bane of most sensor engineers, namely the 60 Hz stray noise.

We have been concerned about repeatability and reliability. Are there places where this system will not work? Clearly in Europe where 50 Hz power is used, we should see those frequencies in our data; again this is not a problem for the same reason that amplitude discrepancies at various locales where no electrical energy is present or where it is far away.

V. CONCLUSION

We have shown that it is possible to use passive foils to distinguish between activated and non-activated foils; activation means touching. We have provided low frequency characterization of the scavenged signal to be 60 Hz stray electromagnetic energy with the first 10 harmonic fundamentals.

Furthermore the signal strength, as expected, monotonically increases with foil area.

Future work will be to further characterize the scavenged signal and to develop sensors.

VI. ACKNOWLEDGEMENT

We gratefully acknowledge funding for this project from the American Alzheimer’s Association under the ETAC program. The authors thank Jim Fischer for his help in obtaining access to the spectrum analyzers and for discussion on these findings.

REFERENCES

APPENDIX A.2: *Smart Carpet*: A Sensor System to Detect Falls and Summon Assistance

Myra A. Aud, PhD, RN, Sinclair School of Nursing, University of Missouri-Columbia (corresponding author: audm@missouri.edu), Carmen C. Abbott, PT, PhD (School of Health Professions, University of Missouri-Columbia), Harry W Tyrer, Rohan Vasantha Neelgund, Uday G. Shrinivasa, Ashrafuddin Mohammed, Krishna Kishor Devarakonda, (Department of Electrical and Computer Engineering, College of Engineering, University of Missouri-Columbia)

**INTRODUCTION:**

In the television commercial an older woman explains how technology enabled her to call for help when she fell. By pushing the button on the pendant of the necklace she wore, a signal was sent to a monitoring company who implemented a plan to send help. Whether mounted as the pendant of a necklace or on a wrist brand, these devices have been widely advertised to older adults and their families for promotion of the safety of older adults. However, these devices have three drawbacks: the user must wear the device, the user must be conscious, and the user must remember how to use the device.

The user of the wearable signaling device must make a deliberate decision to wear the signaling device. However, not all older adults are willing to wear the devices. Some question the need for the device. Others consider wearing the device to be an unwelcome admission of vulnerability (Porter, 2005). Furthermore, the wearable signaling device is useless when the older adult falls and becomes unconscious during or after the fall. Risk of fall-related head injury and loss of consciousness is not insignificant. In a survey of traumatic brain injuries, 95% of 9303 non-traffic related traumatic brain injuries in older adults were caused by falls. (CDC, 2003).
According to the Alzheimer’s Association 5.3 million older Americans have Alzheimer’s disease or another form of dementia (Alzheimer’s Association, n.d.). Older adults with dementia may no longer recognize objects and their purposes (agnosia). They may also forget how to use objects, tools, or appliances (apraxia). Use of wearable devices to call for help requires remembering to wear the device, remembering its purpose, and remembering when and how to use it to call for help. Design of devices for older adults with dementia must recognize the impact of cognitive deficits on performance of activities and substitute pre-programmed or automatic functions for functions requiring deliberation and decision.

A research team from the disciplines of engineering, nursing, and physical therapy proposed development of a technological device that would detect falls and send a signal to summon assistance while avoiding the three drawbacks. The device would be unobtrusive; it would not be worn by the older adult. The device would function whether the older adult who had fallen was conscious or unconscious. A signal would be sent automatically when a fall occurred; no manipulation of the device by the older adult would be necessary. The team decided that a device embedded in floor covering, a Smart Carpet, would meet these criteria. Partial funding for development of the device was provided by the Alzheimer’s Association. The development and testing of the prototype of the Smart Carpet is described here.
THE SMART CARPET PROTOTYPE:

The Smart Carpet consists of an array of sensors placed under an expanse of carpeting. The size of the sensor array corresponds to the area of the carpet. Walking or falling on the Smart Carpet transmits signals to a central processing computer. Messages from the central computer alert caregivers that a fall has occurred.

The current prototype of the Smart Carpet does not require an external power supply or batteries. Instead signal scavenging sensors, unpowered sensors that utilize energy available throughout the environment, are used. Energy scavenging sensors convert ambient energy into useful electrical energy (Tyrer, 2009). Signals for electro-magnetic fields, ubiquitous in the environment, are picked up on thin metal foil sheets. Stepping on the foil sheets embedded in the Smart Carpet enhances signal detection. Using a high impedance amplifier to measure the signals we are able to identify when a person is walking or laying prone on the Smart Carpet. Ongoing work on the prototype continues to identify the optimal impedance for circuits leading from the sensors, refine the resolution of signals, and develop programming to send messages to alert caregivers.

TESTING THE PROTOTYPE OF THE SMART CARPET:

After development of the prototype of the Smart Carpet, the team proceeded with testing. All tests followed the protocol approved by the University’s Institutional Review Board. Volunteers participating in the testing reviewed and signed consent forms.
WHAT IS IT LIKE TO WALK ON THE SMART CARPET?

One of the first tests of the prototype of the Smart Carpet answered the question: Is there a perceptible difference between walking on the Smart Carpet and walking on standard institutional grade floor covering? The team defined standard institutional grade floor covering as the type of carpet used in the hallway of the college building where the test was conducted and in the retirement community hallways where future tests will be conducted. The 10-foot prototype of the Smart Carpet was positioned on a wooden faux floor in a hallway of the engineering building. Placing the prototype on a wooden faux floor avoided placing the prototype on top of an already carpeted area and more closely approximated real installation of the prototype on a concrete subfloor. To test perception, 11 volunteers (faculty-researchers and graduate students ages 20 to 60 without health concerns) walked on the Smart Carpet prototype and answered questions about the sensation of walking on the Smart Carpet. Each of the volunteers stated that there was no perceptible difference between walking on the Smart Carpet and standard institutional grade carpet. They added that walking on the Smart Carpet was the same as walking on any carpet.

DOES THE SMART CARPET DETECT FOOTSTEPS?

Testing also included measurement of the sensitivity of the Smart Carpet to detect the gait characteristics of walking on the Smart Carpet. In addition to demonstrating that the Smart Carpet does detect footsteps, these characteristics will be used in the development of more advanced versions of the Smart
Carpet by determining sensor capture area, spacing of sensors, and data production speed.

To determine these characteristics, we used a Pedograph, a reliable and simple method of gait analysis that has been used in the field to measure functional status and outcomes (Cerny, 1983; Heltmann, 1989), was employed. The 11 volunteers participating in the testing of the prototype were weighed. Then, we attached one inch self adhesive mole skin ink pads at the second metatarsal head and heel center of each foot and asked each volunteer to walk on paper placed on top of the 6.096 meter (20 foot) combined walkway and Smart Carpet prototype. The paper with inked footsteps recorded record of each volunteer’s gait pattern was used to analyze gait performance.

Walking pressure, velocity, base of support and length of steps and strides were evaluated from the footprints imprinted on the paper. Measurement of time and distance parameters were made after subjects had walked using their typical gait speed. Measurements were taken from the middle 3.048 meter (10 foot) section to account for acceleration and deceleration in the gait speed on and off the walkway. This middle section of the paper overlaid the Smart Carpet prototype.

Stride measurements were taken from the heel of one foot to the heel center of the same foot when it appeared again on the walkway. Step length was measured from the heel center of one foot to the heel center of the opposite foot. Base of support was calculated from a line drawn from each heel center to perpendicular line drawn to opposite line of progression. Velocity was calculated in seconds for the time it
took to walk a ten foot distance on the walkway. A minimum of five sets of footprints were used to calculate the average gait parameters.

We obtained the average values of each parameter (velocity, maximal pressure, stride, step, and base). We sorted the average values from smallest to largest to form the plots. Velocity was obtained from the time for a volunteer to traverse the 304.8 cm, at full speed; of interest to us is the time that the foot is on the floor, so we plotted the inverse of velocity in msec/cm. This is shown in the figure below. We see that (from the original data) the smallest value is at 7.2 msec/cm and the largest value is 14.0 msec/cm. The figure 1, as expected, appears monotonically increasing.

![Figure 1: Inverse Speed calculations](image)

Measurement of maximal pressure is important because Smart Carpet design must accommodate the maximal pressure to prevent damage to the sensors. Measurement of maximal pressure requires obtaining the weight of each volunteer and use of the stained 6.5 sq.cm. (1 sq. in.) spots on the heel and toe for calculation of areas of impact. Plotted below in Figure 2 is the calculated maximal pressure.
From the pedograph measurements of stride (longitudinal length of the distance between the heels of two steps of the same foot), step (longitudinal length between the heels of both feet in a step), and base (a construction of the lateral distance between the heels), we obtained the very important measure of step distance. For the design of the Smart Carpet step distance indicates the maximal distance for separation of sensors (figure 3).

From these data we concluded that the Smart Carpet prototype is able to detect gait characteristics of persons and that detection of a fall, an event triggering a larger number of sensors than a footstep, is feasible. Furthermore, the data will provide information about the following parameters for Smart Carpet design refinement:

- Required rate of scan for the sensors
• Dynamic range of pressures expressed
• Sensor size and spacing (resolution)
• Relationship of resolution to rate of sensor sampling
• Relationship of resolution required to reconstruct occurrence or shape of footfall.
• Sensor array architecture.

IMPLICATIONS FOR GERONTOLOGICAL NURSES:

Gerontological nurses have heard stories of older adults who live alone in the community and who remain on the floor for hours or days after falling. Technologies such as the Smart Carpet have the potential to decrease the likelihood that older adults will remain on the floor without assistance for extended periods of time after a fall. With fall detection by the sensor array and communication to a designated emergency responder initiated by the computer, we anticipate prompt rescue and treatment, good treatment outcomes, and optimal recovery.

Although the research team began with the intention of developing an unobtrusive sensor system that would detect falls and summon assistance, there may be a benefit to older adults with dementia and their caregivers in addition to fall detection. Because the sensor array embedded in the Smart Carpet identifies footsteps, the older adult’s location is tracked. According to the programming of the computer, the family caregiver or healthcare provider will receive warning messages if the older adult with dementia wanders into a potentially unsafe area such as a garage or attempts to wander away from the residence.
CONCLUSION:

After this successful testing of the prototype of the Smart Carpet the research team plans to install several sections of Smart Carpet in a retirement community and in the dementia special care unit of a skilled nursing facility. Installation outside of the laboratory will allow testing of durability of the sensor array as well as refinement of sensor array output and interpretation. Although much work remains to perfect the prototype, the research team adheres to the ultimate goal of promoting the wellbeing of older adults who have fallen by ensuring prompt rescue and assistance.

ACKNOWLEDGEMENTS:

This work was supported in part by the Alzheimer’s Association ETAC grant program.

REFERENCES:

1. Alzheimer’s Association. (n.d.). Facts and Figure:  
   http://www.alz.org/alzheimers_disease_facts_figures.asp

   http://www.cdc.gov/mmwr/preview/mmwrhtml/ss5204a1.htm.


## APPENDIX B

### APPENDIX B.1: Additional Data not included in the text

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<th>Foil Strip</th>
<th>Type</th>
<th>Average Voltage($V_{avg}$) (mV)</th>
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<th>RMS Voltage($V_{rms}$) (mV)</th>
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<td>Min</td>
<td>Max</td>
<td>Min</td>
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</table>

*Table B.1*: Signal strength variation for activated and inactivated sensor over different foils
APPENDIX B.2: Prototype Board with 21 Sensors

Figure B.2: Prototype Board with 21 Foil sensors
APPENDIX B.3: Oscilloscope used in the experiment

Figure B.3: MSO4034 Tektronix Oscilloscope [23]