SMART CARPET

Developing a Sensor System to Detect Falls and Summon Assistance

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ABSTRACT

Cognitive deficits experienced by older adults with dementia limit use of wearable devices (necklaces or bracelets) that summon assistance after the older adult falls. To use these wearable devices, older adults must choose to wear them, remember how to use them, and be conscious after falling. Devices such as the Smart Carpet substitute pre-programmed or automatic functions for functions requiring deliberation and decision. After development of a Smart Carpet prototype, 11 volunteers participated in tests to measure sensitivity of sensors embedded in the Smart Carpet. The embedded sensors were not perceptible to the volunteers as they walked across the Smart Carpet and successfully detected gait characteristics. Findings confirmed the feasibility of fall detection. Measurements obtained of gait characteristics will be used in development of more advanced versions of the Smart Carpet.

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In the well-known 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 wristband, 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 it. 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 if the older adult falls and becomes unconscious during or after the fall. Risk of fall-related head injury and loss of consciousness is not

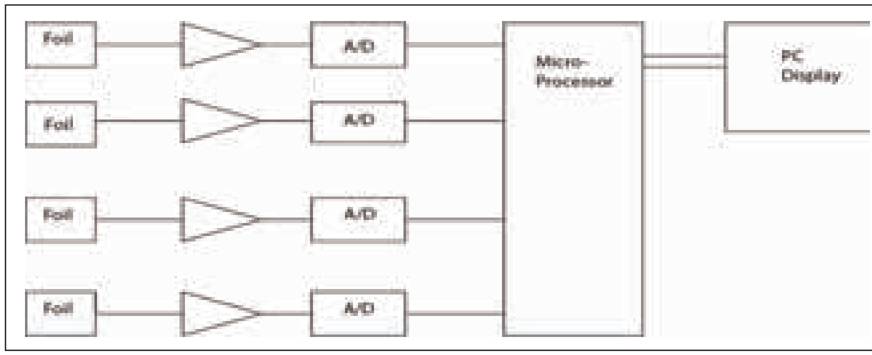

Figure 1. Foil reading electronics.
Note. A/D = analog to digital converter; PC = personal computer.

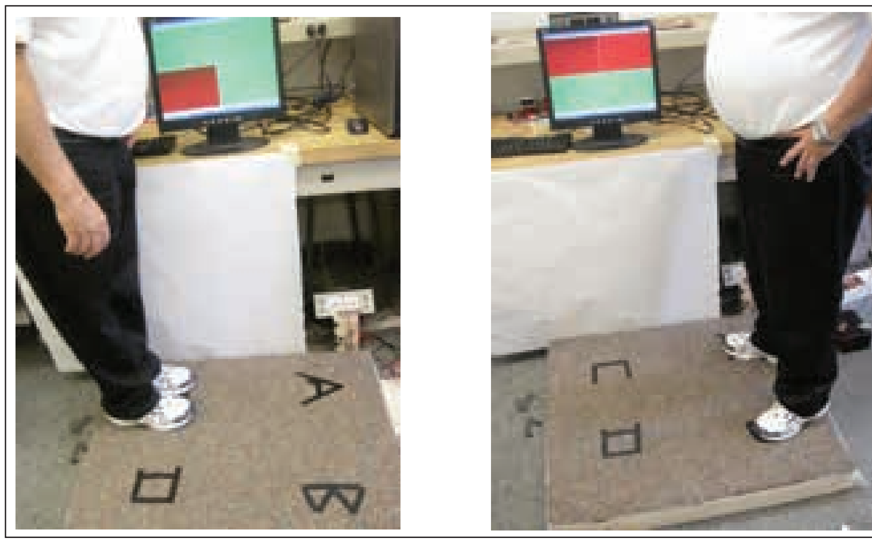

Figure 2. Activation of one sensor C (left image) and two sensors A and B (right image).

insignificant. In a survey of traumatic brain injuries, 95% of 9,303 non-traffic-related traumatic brain injuries in older adults were caused by falls (Langlois et al., 2003).

According to the Alzheimer's Association (2010), 5.3 million older Americans have Alzheimer's disease or another form of dementia. 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 the development of a technological device that would detect falls and send a signal to summon assistance while avoiding the three drawbacks described above. The device would be unobtrusive and 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 in this article.

SMART CARPET DEVELOPMENT

The Smart Carpet consists of an array of sensors placed under an expanse of carpeting. Walking or falling on the Smart Carpet transmits signals to a central processing computer. Fall detection messages from the central computer alert caregivers.

The sensors do not require an external power supply or batteries. Instead, signal scavenging sensors—unpowered sensors that use energy available throughout the environment—are used. Energy scavenging sensors convert ambient energy into useful electrical energy (Tyrer, Neelgund, Mohammed, & Shriniwar, 2009). Signals for electromagnetic 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 energy.

As delineated in **Figure 1,** an amplifier reads the signals, and one is able to identify when a person is walking or lying prone on the Smart Carpet. These signals are converted to digital signals and formatted for display on a computer screen.

As shown in **Figure 2,** a research assistant stands on the development, and the LCD screen displays the activated sensors in red against a green background. First, a single sensor C is activated (left image). Then, sensors A and B are activated simultaneously (right image).

The performance of each sensor in the four-sensor developmental system was evaluated by 50 consecutive activations of each sensor. **Figure 3** shows the results of 50

50	A	B	C	D
A	1	1		
B		4		2
C			4	
D				3

Figure 3. Performance of array of four sensors after 50 activations of each sensor.

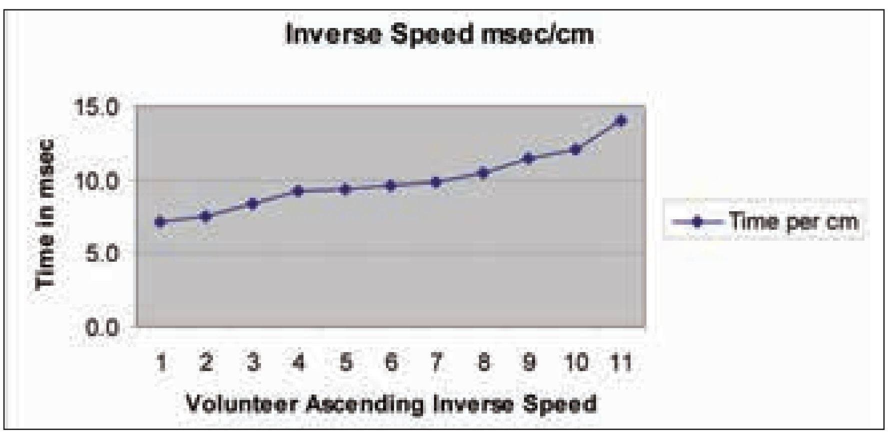

Figure 4. Inverse speed (velocity): The time the foot is in contact with the floor.

steps (activations) on each sensor. Each sensor displayed approximately 50 activations, but there were several false positives and false negatives. The numbers in the diagonal cells indicate the number of times a sensor did not cause the display to turn red (activate) (e.g., one time for sensor A). The off diagonal cells contain the number of times the row sensor caused the column sensor to activate the display (i.e., stepping on sensor A 50 times causes sensor B to illuminate the display once). 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. Early results are encouraging for detecting falls.

TESTING THE SMART CARPET PROTOTYPE

To further the development of the Smart Carpet, the team proceeded with testing walking characteristics and how they may affect the design. 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 kind 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 faux wood floor in a hallway of the engineering building. Placing the prototype on a faux wood 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 it. All 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 gait characteristics. 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, the team 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; Heitmann, Gossman, Shaddeau, & Jackson, 1989). The 11 volunteers participating in the prototype testing were weighed. Then, research team members attached 1-inch, self-adhesive moleskin 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 each volunteer's gait pattern, which were then 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 participants 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 a perpendicular line drawn to the opposite line of progression. Velocity was calculated in seconds for the time it took to walk a 10-foot distance on the walkway. A minimum of five sets of footprints were used to calculate the average gait parameters.

The team obtained the average values of each parameter (velocity, maximal pressure, stride, step, and base) and sorted them 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 the team was the time that the foot is on the floor, so they plotted the inverse of velocity in msec/cm (**Figure 4**). It can be seen that (from the original data) the smallest value is at 7.2 msec/cm, and the largest value is 14.0 msec/cm. As expected, the figure appears monotonically increasing.

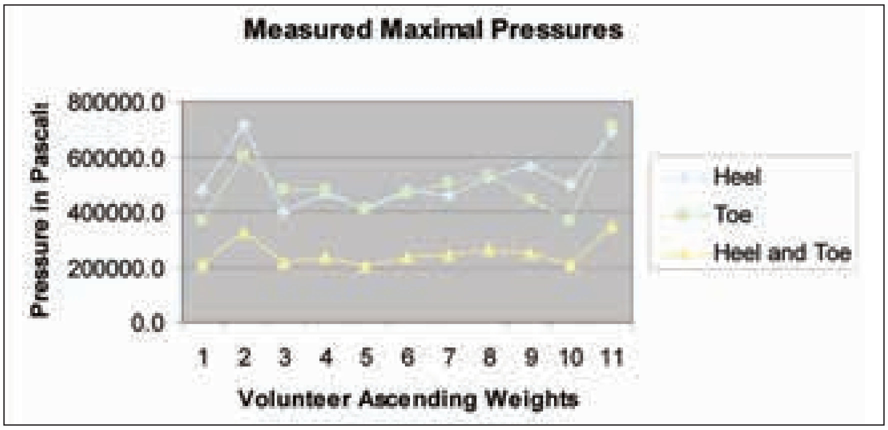

Figure 5. Maximal pressures at heel, toe, and combined heel and toe.

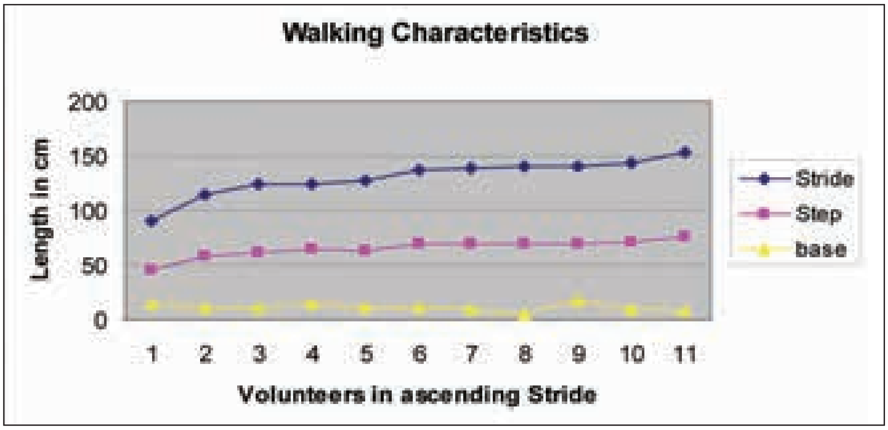

Figure 6. Walking characteristics: Stride, step, and base.

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 6.45 cm^2 (1 $inch^2$) spots on the heel and toe for calculation of areas of impact. Plotted in **Figure 5** is the calculated maximal pressure.

The team collected data related to three walking characteristics: 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) (**Figure 6**).

From these pedograph measurements, the team 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.

From these data, the team concluded that the Smart Carpet prototype is able to detect human gait characteristics and that detection of a fall—an event triggering a larger number of sensors than a footstep—is feasible. In addition, 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 after a fall. With fall detection by the sensor array and communication to a designated emergency responder initiated by the computer, the team anticipates 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 in addition to fall detection for older adults with dementia and their caregivers. Because the sensor array embedded in the Smart Carpet identifies footsteps, the older adult's location is tracked. Depending on the programming of the computer, the family caregiver or health care provider can 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 Smart Carpet prototype, 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 well-being of older adults who have fallen by ensuring prompt rescue and assistance.

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