A Smart Carpet Design for Monitoring People with Dementia

Osamu Tanaka, Toshin Ryu, Akira Hayashida, Vasily G. Moshnyaga, and Koji Hashimoto

1 Introduction

1.1 Motivation

Dementia is a syndrome which deteriorates memory, thinking, behavior and the ability to perform everyday activities. There many different types of dementia although some are far more common than others (e.g. Alzheimer's disease). According to World Health Organization over 35.6 million people worldwide suffer from dementia and there are 7.7 M new cases every year [1]. The growth in the number of people having dementia is so fast that it is predicted to almost double every 20 years, to 65.7 M in 2030 and 115.4 M in 2050 [1].

Dementia care is difficult because it depends heavily on patient's behavior, surrounding and assistive equipment. Because a person with cognitive impairment can make a judgmental error if left unsupervised, caregivers must alter their behavior, working hours and sleep pattern in an effort to provide supervision. The combination of unsupervised nighttime awakenings and cognitive impairment is particularly difficult in the home setting. In many cases family members of a person suffering from dementia become physically and mentally exhausted taking care that they consider placing him or her into mental hospitals. The hospitalization tends to be long-term, averaging several years [2] and usually is very expensive [3]. Neither dementia people nor their spouses and families want to opt for the nursing home. However, almost 70 % of families are forced to do that because of the ongoing sleep disruption and stress they suffer as a result of erratic night- and day-time activity of a person with dementia [4]. Hiring a personal caregiver is already difficult and is going to be harder with the fast aging of population. Hence, the only solution to this pending crisis is the development and deployment of smart technologies that compensate for the specific physical and cognitive deficits of older people with dementia, and thereby reduce burden of family caregivers.

Numerous technologies have been developed to assist old people with cognitive impairment. Such technologies can enable remote monitoring of individuals and early detection of potential problems; so that early interventions can help older adults remain as healthy and independent as possible. The technologies can be active, enforcing a person wear a sensor, pull a cord or push an alarm; or be passive embedded into environment to detect potential problems [5]. A survey of assistive technologies and systems can be found in [6].

Active technologies usually are wearable (e.g. fall detection pendants, watches, etc.), inexpensive, and easy to identify and track. However users of active devices must always wear them. Majority of users are not willing to wear the devices. Some question the need for device. Others consider it an unwelcome admission of vulnerability [7].

Furthermore, many active devices require their users not only to remember how to use the device but also be conscious to push a button to call for help. It is assumed, the user has quick access to transmitter and is able to activate it and initiate the call, even if he or she has fallen and is immobile. However, not all old people especially those with cognitive impairment can do that. People with dementia have problems recognizing things and their purposes; they frequently forget how to use objects, tools or appliances. Even if an older adult knows how to operate the device, there is a high risk that he or she may become unconscious during or after the fall [8]. Consequently, it is necessary that tools satisfy the following requirements:

- Non-intrusiveness. The devices have to be neither worn nor operated by a person with cognitive impairment;
- Independence of device operation form the person's condition (conscious or unconscious);

O. Tanaka (✉) • T. Ryu • A. Hayashida • V.G. Moshnyaga
K. Hashimoto
Dept. Electronics Engineering and Computer Science, Fukuoka University, 8-19-1, Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan
e-mail: td132011@cis.fukuoka-u.ac.jp; td132020@cis.fukuoka-u.ac.jp; td142012@cis.fukuoka-u.ac.jp; vasily@fukuoka-u.ac.jp; khashi@fukuoka-u.ac.jp

H. Selvaraj et al. (eds.), *Progress in Systems Engineering: Proceedings of the Twenty-Third International Conference on Systems Engineering*, Advances in Intelligent Systems and Computing 1089,
DOI 10.1007/978-3-319-08422-0_92,

- Automatic fall detection;
- Automatic alerting the caregiver if fall occurs.

A general approach to satisfy the aforementioned requirements is to put intelligence into the home environment, making it able to monitor human. Several solutions have been proposed. One of them is to install wireless motion sensors on inside the home, and use their readings to detect the fall [9]. Another solution is to equip a home with multiple infra-red video cameras [10] of Microsoft Kinect devices [11] and use computer-vision techniques for fall detection. Although these solutions are promising they still lack fall detection accuracy.

In this paper we focus on embedding intelligence into a carpet or a home floor and present a novel smart carpet design.

1.2 Related Research

Many proposals for the smart carpet have been reported in literature over the years. Paradisso, et al, [12] use a grid of piezoelectric wires hidden under carpet and a pair of Doppler radars to monitor motion, velocity, dynamic foot position and pressure of people. Adlesse, et al [13] utilized small rectangular plates, each of which having four load cells at the corners. Each load cell measures Ground Reaction Force (GRF) caused by the weight and inertia of the body while walking. A nearest-neighbor classifier computes the GRF profile and feds it to a Hidden Markov Model to identify an individual. An algorithm optimization for profile identification is reported in [14]. The main problem of the design is that the tiles are very rigid and expensive.

Aud, et al, [15] develop a Smart Carpet from an array of signal scavenging sensors that use energy available throughout the environment. Although this design does not have a power supply, the electronics put into the carpet make it thick and heavy. For instance, a small mat of the carpet has four blocks of foil reading electronics parts, four AD convertors, one microcontroller and one wireless transmitter. A similar drawback is inherent in Z-tiles [16], which have 24 sensors per a hexagonal tile.

To make the smart flooring unperceivable for the users, researchers from Univ. of Manchester place a 2D mesh of optical fibers beneath the carpet [17]. These fibers can detect and plot movements as pressure blend them, changing the light at the edges of the carpet. Sensors around the carpet's edges then relay signals to a computer which analyzes the 2D footstep pattern. When a change is detected - such as a sudden stumble and fall - an alarm is produced [17]. Similarly, Savio and Ludwig [18] proposed to embed electronics in textiles and interweaving them in Smart Carpet.

An extension of smart carpet to determine the weight, age, and sex of the individuals stepping across has been reported in [19]. The carpet's intelligence is derived from a layer of silicon rubber with built-in electrodes to measure changes in electrical resistance and current flow caused by someone walking across it.

A more fundamental implementation of Smart Carpet is the ELSI Smart Floor [20][21] from Aalto University, Finland. It is a copper based sensor installed under the floor surface, such as vinyl flooring or laminate and when connected to the system creates a very low power capacitive field. A person positioned over this flooring, conducts the sensor, changing the capacitive field as it done in touch panel. This solution looks well but seems to be more suitable for hospitals or nursing homes due to expensive installation. Moreover, it is difficult to maintain and repair, since if anything happen someone has to lift the entire floor.

1.3 Contribution

In this paper we present a novel design of intelligent carpet for in-home monitoring of a person with cognitive impairment. The proposed smart carpet is capable of tracking a person non-intrusively, detecting falls and alarming the caregiver wirelessly. Unlike existing systems, the system is inexpensive, provides high quality of fall detection, is easy to install, maintain and extend.

In the next section we describe architecture and prototype implementation of the smart carpet. Section 3 shows results of experimental testing. Section 4 presents conclusion and outline work for the future.

2 The Proposed Smart Carpet

2.1 Architecture

The proposed smart carpet is dedicated to unobtrusively detect location of a person in apartment or room, his/her status such as walking, staying on the floor, sitting on the floor and lying on the floor. The carpet consists of an array of mats or carpet tiles, each of which having a pressure sensor FSR406 [22]. The sensor is placed under an expanse of carpeting and connected to a corresponding row- and column-lines, as shown in Fig.1. When a pressure is put over the mat, the sensor produces an active signal on both the row and the column lines. These signals are coded and sent wirelessly to server, which decodes the signals received, evaluates the pressure pattern, and if it corresponds to a fall or another pre-defined risk event (e.g. no motion), an alert is sent to the caregiver through the internet. Because each mat has a fixed position within the carpet, the location of a person

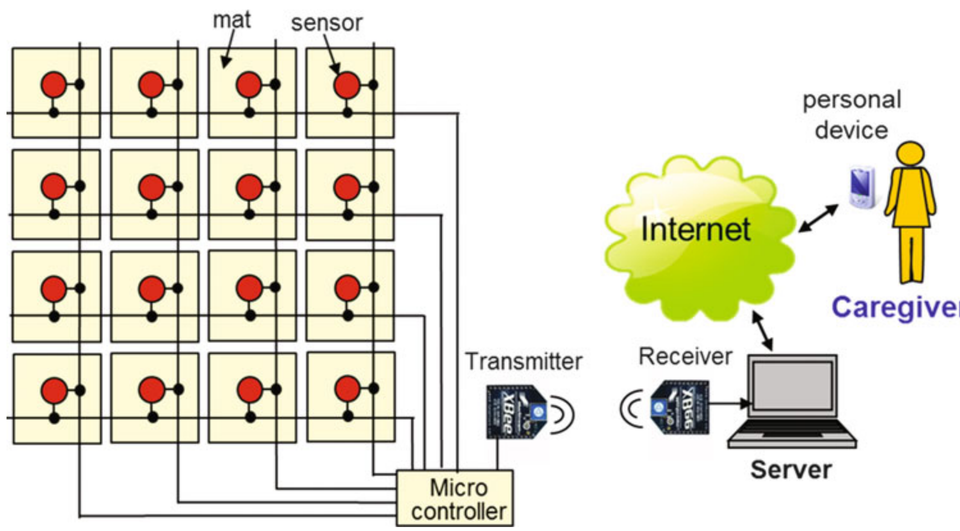

Fig. 1 An illustration of the proposed smart carpet (4x4mats)

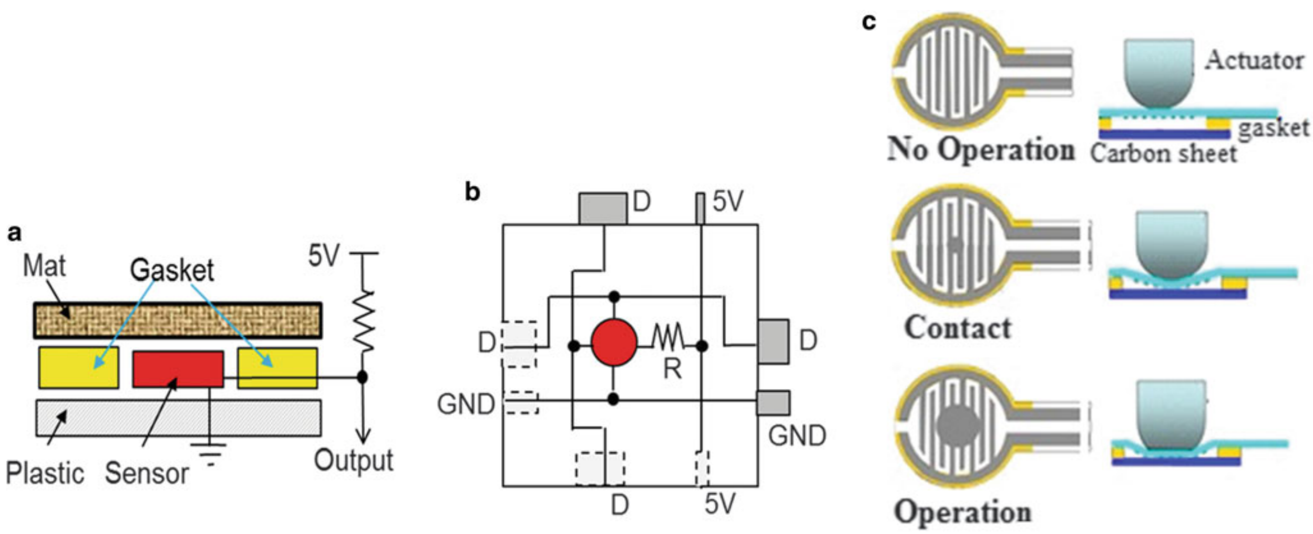

Fig. 2 (a) Cross-sectional view of a mat; (b) electronic circuit embedded into the mat; (c) sensor operation

over the mat can be easily defined through the reading of mat sensors. Walking, staying, sitting or lying down over the mats is reflected by a proper signal pattern.

2.2 Mat Design

Fig.2 (a) and (b) show cross-sectional view of a mat and the electronic circuit, embedded into the mat, respectively. As one can see the design is simple and has minimum electronics. The circuit embedded into a mat contains one small sensor FSR406 [22], one (10kΩ) resistor, and four wires crossing the mat top-down and left-right. The D ports of the mat are for the row- and column-line connections, respectively; 5 V and GND are the voltage supply and the ground ports, respectively. The left-right or top-down ports that have same label provide male-female connectors.

Fig.2(c) illustrates the sensing operation. When no pressure is applied to the mat, the sensor idles. Otherwise, the sensor's actuator makes a contact with the carbon sheet (see the center-right picture of Fig.2, c) reducing the sensor' resistance and causing voltage at the output to change. With increase in force applied to the mat and to the surface of the sensor, the contact area grows in size, increasing the current flow through the sensor (see Fig.2(c), the bottom-right picture). The output signals from the mat sensors are delivered to microcontroller and then sent wirelessly (via XBee transmitter) to the server.

The main feature of our mat design is simplicity and low cost. All mats have same shape and same number of

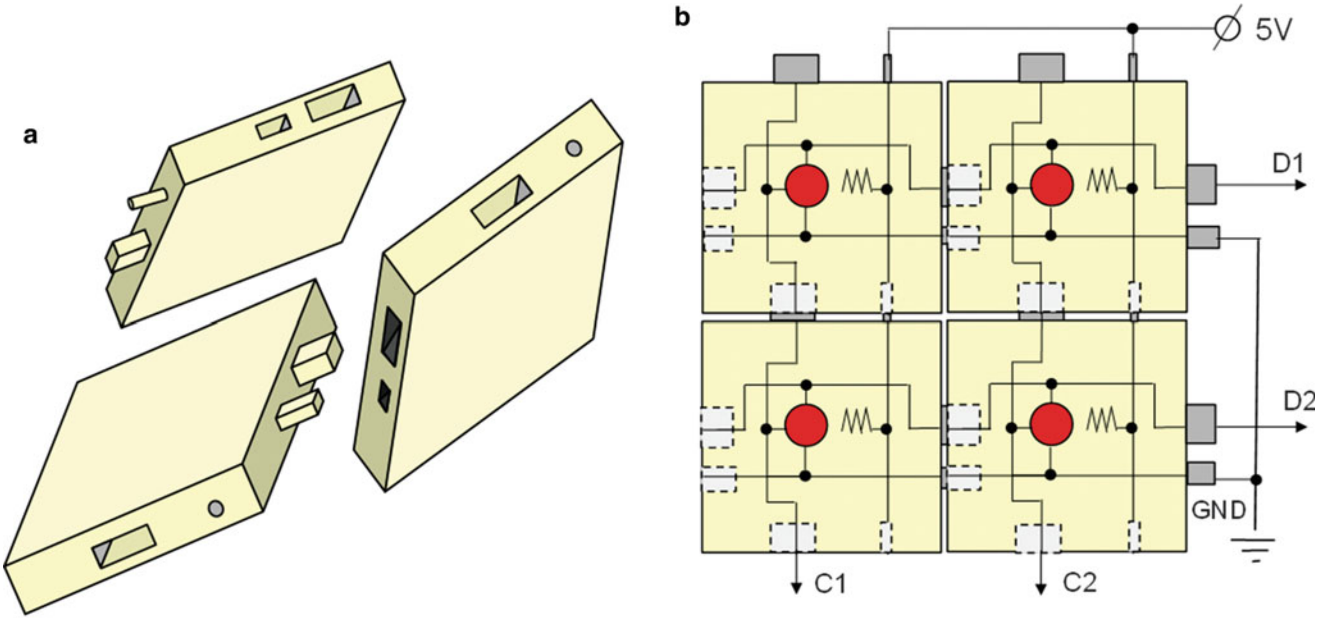

Fig. 3 Views of mats (a); the circuitry of 2x2 smart carpet (b)

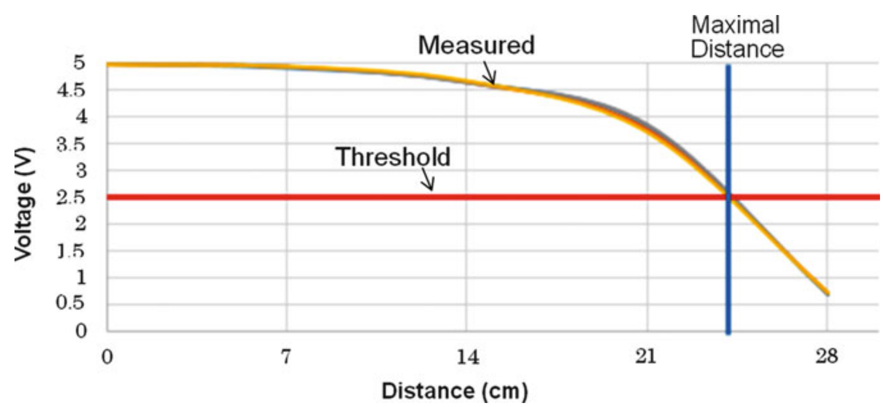

Fig. 4 The voltage variation observed at the mat ports (D and C) with the distance between the person's location and the mat center.

connectors. In order to prevent error connections, the connectors have different shapes: the voltage supply connectors are cylindrical while the others are rectangular of different size, as shown in Fig.3 (left). The mats can be grouped very easily just by attaching one to another as Lego building blocks. Fig.3 (right) exemplifies a circuit of a 2x2 smart carpet core built just by joining the mats. Although the number of mats in the carpet is limited by the number of pins on microcontroller, a 18-pin microcontroller, such as Arduino Uno or PIC, allows using up to 8x8 mats in the carpet.

In order to find the optimal mat size, we empirically measured the voltage produced at the Output port of the mat when a person (60 kg in weight) steps over at the different distance of the mat center. Fig.4 shows the results. The yellow line in this figure depicts the measured voltage; the red line shows the threshold voltage (used in microcontroller); the blue line shows the maximum distance from the center which assumed acceptable. Based on the results, we determined that a mat of 40x40cm in size can effectively sense a person weighting 60 kg or more.

2.3 Implementation

For experimental evaluation, we built a prototype smart carpet consisting of 4x4 mats, each of which having 40 cm $\times$ 40 cm in size. The prototype was implemented based on Arduino Uno R3 microcontroller and XBee wireless communication protocol. As server we used Toshiba PC (2GHz

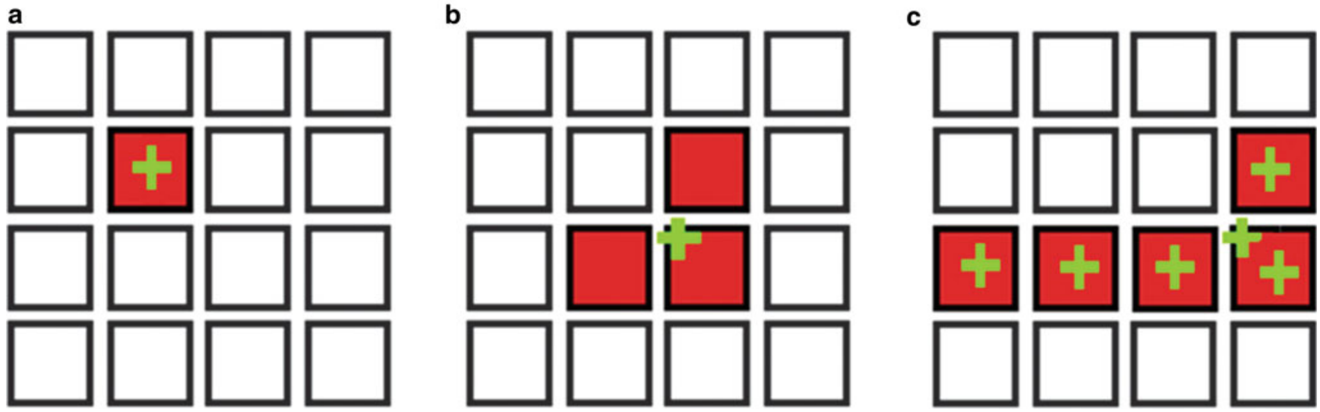

Fig. 5 Examples of patterns sensed by 4x4mats: when a person stands inside a mat (a); when a person stands on the border of 3 mats (b), and when a person lies over the area of 5 mats

Intel Core Duo CPU, 2GB memory), Windows 8 OS. The client device was 2012 Asus Nexus 7 that runs Android™ 4.3 OS and is equipped with NVIDIA Tegra3 T30L, 1.3GHz CPU, 1GB internal storage, 7-inch display. The client-server communication was implemented through Internet Socket API (ws2_32.lib), WiFi Local Area Network (LAN) and TCP/IP transport protocol. To support the OS-based control of the communication, a dedicated programming interface was also created.

We also developed application software that monitored a person by the smart carpet, assessing his/her motion, detecting falls and displaying the results on PC (server) and the mobile device (client). The software decodes data received from sensors, determines the number of mats, which produced active signals, locations of the mats, and the "motion pattern" which had been sensed. Fig.5. exemplifies three motion patterns reflected by the smart carpet when a person stays within area of a single mat, on the border of three mats and lying over the area of five mats. The cross signs in the figures show the pressured places. The mats that sensed the pressure are depicted in red.

Based on the difference between the current pattern and the pattern previously detected, and the duration of the pattern, the system determines whether the monitored person stays or walks or lies on the carpet. For instance, if both the number of active mats exceeds a given threshold ($k = 4$) and the pattern lasts longer than a pre-defined time limit (e.g. $T = 1$ sec), the system detects person's fall, generates alarm and sends it for display at the server as well as the caregiver's device (client).

The software was created in Java using Java-script (Node. js) interpreter, the Android software development kit, Notepad++, the Arduino IDE design environment, and the Dropbox file management and exchange system.

3 Evaluation and Results

To test functionality of the proposed smart carpet design, we conducted a set of experiments with 6 volunteers (faculty and students ages 20 to 60 without health concerns). The subjects were asked to stand, walk, sit, and fall over the carpet in different directions and places.

All volunteers stated that walking on the smart carpet had no perceptible difference with walking on standard carpet. The sensors embedded into the mats were not perceptible to the people as they walked across the smart carpet and successfully detected gait characteristics.

Fig.6 shows the snapshots of the notebook and Nexus 7 screens displaying the monitoring results. The red patterns on the screens show the activated sensing mats as a person walks (upper image) or lies on the carpet (bottom image). The inactive mats are shown by dark squares. The green window in the screen is activated when fall is detected. As one can see, the results, displayed both on the notebook and the Nexus 7 device, are correct. Note the results were obtained in real time as a person walked over the carpet. The delay of displaying the results on Nexus 7 device was very small (0.6 sec).

To evaluate the fall detection accuracy, we asked the volunteers to perform a series of postures, namely walking, standing, sitting, lying down in a "stretched" position, and lying down in a "tucked" position. These five scenarios were repeated four times by each subject in a random order and various directions. These test positions totaled 40 fall-

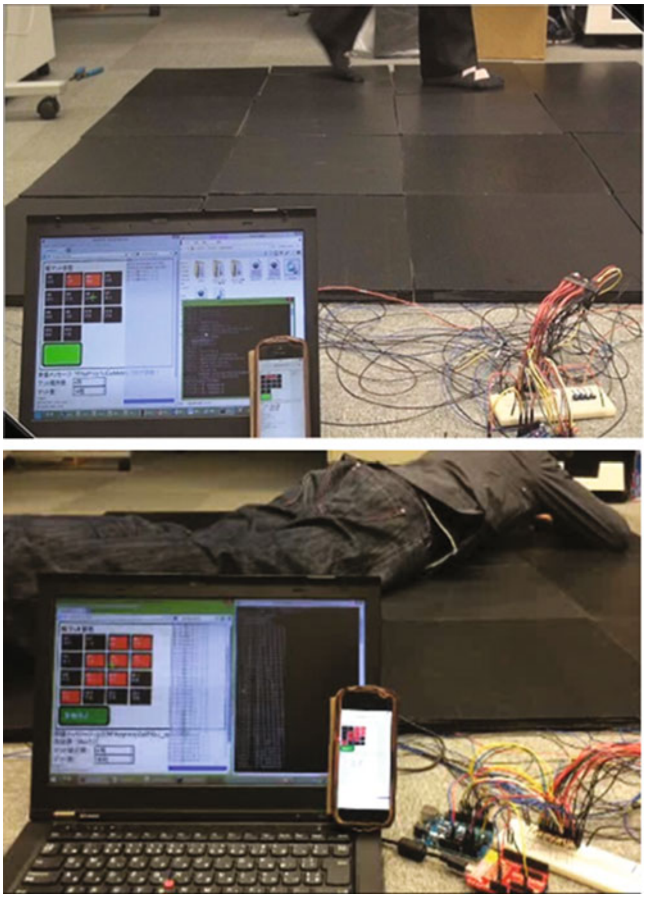

Fig. 6 Snapshots of the smart-carpet results as a person walks (top), and falls down (bottom)

simulated tasks and 60 non-fall–simulated tasks. The true positive rate for fall detection was 98 % with a false positive rate of 0.03 %.

Finally, we tested the smart carpet for different shapes (1x16 and 2x8) and different number of mats in a row/column. The experiment revealed that the carpet shape does not affect the functionality. For the tested shapes, the carpet always produced good results. The total cost of the off-the-shell components to implement the smart carpet (4x4 mats) was 228US$.

4 Conclusion

In this paper we presented a simple yet efficient design of a smart carpet for monitoring persons with cognitive impairment. The tests show that the proposed design can accurately determine the person's position, motion and falls reporting the results online (on server PC and mobile device) in real time. Although much work remains to perfect the design, we plan to install the prototype in a room of dementia person to conduct a rigorous clinical trial.

References

1. New 'flow of care' to steer dementia patients away from hospitals , The Japan Times Sep. 6, 2012
2. Hope T, Keene J, Gedling K, Fairburn C, Jacoby R. Predictors of institutionalization for people with dementia living at home with a carer. Int J of Geriatr Psychiatry, vol.13, pp. 682–90, 1998.
3. CareGiver Technology: independent living through technology (for family CareGiver) http://www.caregivertechnology.com/for-family-caregivers/
4. C.P.Pollak, D.Perlick, G.Alexopoulos, A.Gonzales, "Disruptive nigh-ttime behaviors in elder caregiver pairs", Sleep Res, vol.23, 305, 1994
5. M.J.Raintz, F.M.Skubic, G.Alexander, M.A.Aud, et al, "Improving Nurse Care Coordination with technology", Computers, Informatics. Nursing, vol.28, no.6, pp.325-332, 2010.
6. A.J.Bharucha, V.Anand, J.Forizzi, M.A.Dew, C.F.Reynolds, S. Stevens, H.Wactlar, "Intelligent assistive technology applicationsto dementia care; Current capabilities, limitations and future challenges", Am. J. Geriatric Psychiatry, vol.17, no.2, pp. 88-104, Feb. 2009
7. E.J. Porter, "Wearing and using personal emergency emergency response system buttons: Older frail windows' intentions". J.of Gerontological Nursing, vol.31, no.10, pp.26-33, 2005
8. J.A.Langlois, S.R.Kegler, J.A.Gotsch, et al., "Traumatic brain injury-related hospital discharges: Results from a 14-state surveillance system", 2003, MMWR Surveilance Summaries 52(SS04), Centers for Desease Control and prevention, available from website: www.cdc.gov/MMWR/preview/mmwrhtml/ss5204a1.html
9. Just Checking, Helping people to stay at home, available online at http://www.justchecking.com.au/
10. K.Williams, A.Arhur, M.Niedens, et al, "In-Home Monitoring Support for Dementia Caregivers: A Feasibility Study", Clin Nurs Res., vol. 22, no.2, pp.139-150, May 2013.
11. M.Rantz, T.S.banerjee, E.Cattoor, S.D.Scott, M.Skubic, and M. Popescu, Automated fall detection with quality improvement "rewind" to reduce falls in hospital rooms. J.Gerontological Nursing, v.40, No.1, 2014.
12. J.Paradiso, K. H. C. Abler, M. Reynolds, "The magic carpet: Physical sensing for immersive environments", CHI97, pp. 277-278, 1997
13. M. Addlesee, A. Jones, F. Livesey, and F. Samaria, "Orl active floor," IEEE Personal Communications, vol. 4.5, pp. 35 – 41, 1997
14. R. Orr and G. Abowd, "The smart floor: A mechanism for natural user identification and tracking," Proc. 2000 Conf. Human Factors in Computing Systems, 2000.
15. M.A. Aud, C.C. Abbott, H.W. Tyrer, R.V. Neelgund, U.G. Shriniwar, A.Mohammed, K.K.Devarakonda, "Smart Carpet: Developing a Sensor System to Detect Falls and Summon Assistance", J. Gerontological Nursing, vol.36, Issue 7, pp.8-12, July 2010
16. R. Richardson, J. Paradiso, K. Leydon, and M. Fernstrom, "Z-tiles: Building blocks for modular, pressure-sensing," in CHI2004, 2004.

17. S.Tutoru, "Smart Carpet: detecting falls and predicting mobility problems", Prescouter Journal, Sep.6, 2012.
18. D.Savio, T.Ludwig, "Smart Carpet: A Footstep Tracking Interface", 21st Int. Conf. Advanced Information Networking and Application Workshops (AINAW'07), 2007.
19. D.Murph, Intelligent carpet can autodiscriminate, July 26, 2006, available from http://smart-home-blog.com/2006/07/27/intelligent-carpet/
20. http://telecareaware.com/smart-flooring-that-can-simplify-alerting/
21. A. Ropponen, H. Rimminen, & R. Sepponen. "Robust system for indoor localization and identification for the healthcare environment", Wireless Personal Communications, vol. 59, no. 1, pp.57-71, 2010.
22. FSR 406 Data Sheet, FSR 400 Square Force Sensing Resistor, Interlink Electronics, available at www.interlinkelectronics.com.