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LOW-COST ASSISTIVE TECHNOLOGIES FOR IN-HOME CAREGIVERS OF PEOPLE WITH DEMENTIA

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Abstract. *Caregivers of people with dementia need assistive technologies capable of reducing stress of constant patient monitoring. In this paper, we present low-cost technologies, such as smart carpet, posture sensor, bed sensor, and door sensor, developed for assisting family caregivers of people with mild or moderate dementia. The technologies provide automatic and unobtrusive monitoring of a patient at home, assessing possible risks the patient may face and alerting the caregiver in emergency for assistance by video, audio and text messages. We describe the technologies and outline results of their application in prototype caregiver assisting system.*
Keywords: Intelligent systems, Sensing, People monitoring, Activity identification

1. **Introduction.** Today over 4.6 million people in Japan (15% of population over 65) have dementia or loss of brain cognitive ability due to aging [1]. Caring for a person with dementia (PD) requires constant (24/7) monitoring, as a person with cognitive and perceptual deficits can make wrong judgment or be lost if left alone. The task is very hard; it takes time, disrupts sleep, and puts enormous burden on caregivers, who frequently are relatives of the carried person, live in the same house and do caregiving voluntarily. Most caregivers have their jobs, own families, and obviously cannot supervise around the clock. Therefore, new information and communication technologies (ICT), capable of reducing the overwhelming stress, burden and strain of caregiving are increasingly important [2].

Several ICT systems [3-5] have been proposed to assist family caregivers at home. The systems detect whether the PD is up and moving around the home, generate phone/text/email alerts if medications are missed or the PD fell down or left the premises, support "face-to-face" chatting with the PD via live video calls, send emails without the need of computer, create a socialization and networking environment for the patient, etc. These systems, however, either cost up to several thousand dollars or enforce the caregiver stay in close proximity of the PD, thus limiting the caregiver's ability to do other work.

In our work, we developed a novel system for assisting family caregivers at home through unobtrusive automatic monitoring of a PD. Unlike existing solutions, our system utilizes inexpensive yet effective technologies implemented with conventional off-the-shelf components. In this paper, we present the technologies and describe results of their experimental evaluation in prototype caregiver assisting system. The next section describes the technologies. Section 3 shows evaluation results. Conclusion is drawn in Section 4.

2. **The Sensing Technologies.** The developed technologies are dedicated for helping the caregiver with unobtrusive patient monitoring and automatic assessing of risks to the patient's health. The technologies represent a number of heterogeneous sensors, such as

smart carpet, bed monitor, posture sensor, and door sensor, which are installed in addition to motion sensors, and cameras within the PD's flat or home to provide the following:

(a) To identify and monitor the person's activity such as lying in bed/sofa/floor, sitting on the chair/sofa/bed/floor, walking, visiting toilet, bath, and attempting to open home doors;

(b) To assess the risks that a PD may have in the current situation;

(c) To alert the caregiver in emergency for assistance in form of text and voice;

(d) To record the patient's activities, assessed risks, generated alarms, as well as reminders (e.g., schedule of medical treatment, and exercises);

(e) To display the results of patient's monitoring on caregiver's device (phone or PC), and provide real-time visual and audio communication with the patient;

(f) To provide graphic interface for viewing the history of patient's movement, activities, frequency of visiting facilities, and frequency of alertness.

Below we discuss the sensing technologies in detail.

2.1. **Smart carpet.** The smart carpet (SC) is placed in rooms, hallway leading to the exit door, in pathways, etc., to identify position, motion and activity of PD. The SC consists of an array of mats, each having a pressure sensor FSR406, located under an expanse of carpeting. Figure 1 illustrates the SC organization on example of 4×4 mats (left image), cross-sectional view of a mat (center-top) and the mat electronics (center-bottom). As one can see, the mat electronics is very simple: one small sensor and one diode. In every machine cycle, the microcontroller sequentially activates the vertical lines of the mat array and checks the sensor readings from the horizontal lines of the array. If no pressure is put over a mat, the sensor idles. Otherwise, the sensor connects vertical and horizontal lines producing a signal at the horizontal line. The coordinates of the active mats are detected by the microcontroller and sent wirelessly (via the XBee transmitter) to the server. Because each mat has a fixed position in the carpet, the location of a person over the SC is easily defined through the reading of mat sensors. Walking, staying, sitting or lying down over the SC is reflected by a proper signal pattern and the time-difference between the patterns.

Figure 1, right exemplifies the patterns displayed by the server PC and the smartphone, when a person is lying over the SC (of 4×7 mats, 40cm $\times$ 40cm in size each). The mats that sensed the pressure are shown in gray. The tests [6] revealed that the SC detects person's motion and fall accurately. The sensors in the mats successfully detect gait characteristics and are not perceptible to the people as they walk across the SC. Similar

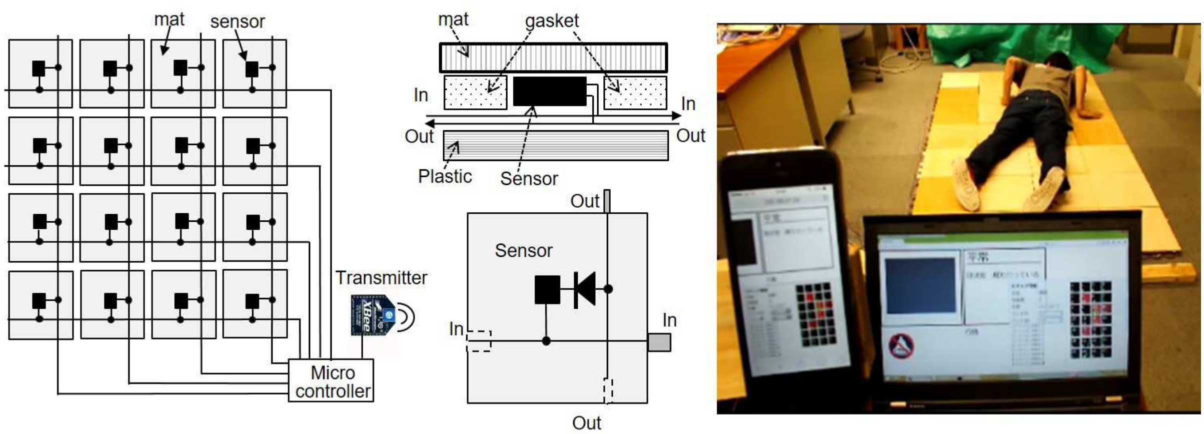
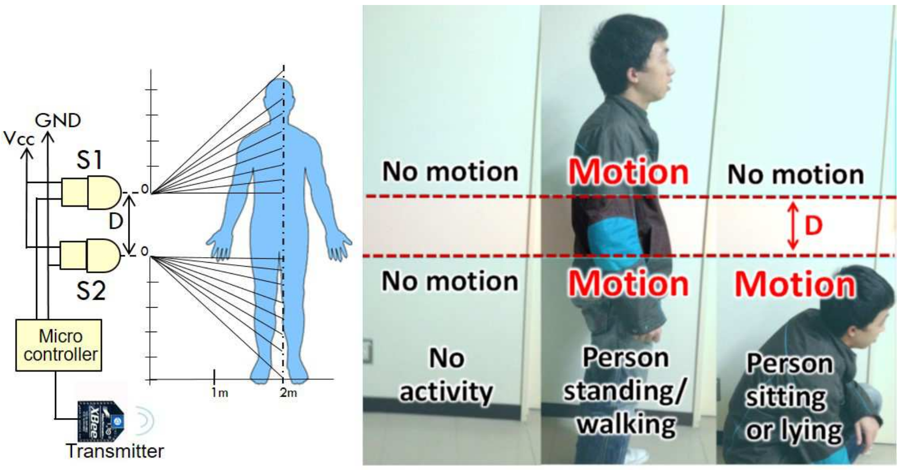


FIGURE 1. Organization of the smart carpet having 4×4 mats (left); cross-sectional view of a mat (center-top); mat wiring (center-bottom); a screenshot of smart carpet prototype (right)

to the mats, the pressure sensors can be embedded in chairs, sofas, etc., to determine the patient's position and trace his/her activity. The total cost of a single mat is around US8$.

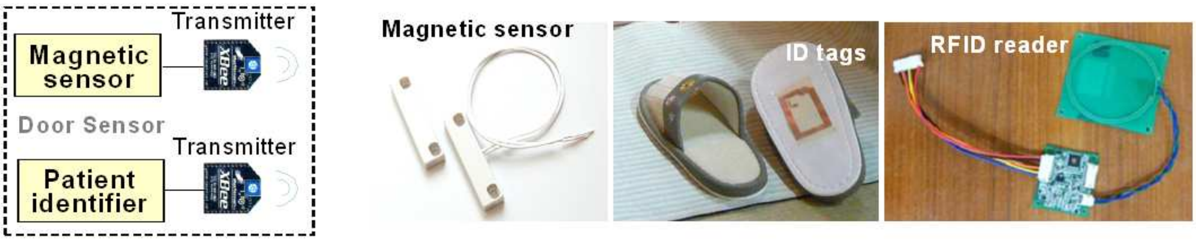
2.2. **Posture sensor.** The posture sensor (PS) is used for detecting the person's fall or events when a monitored person cannot stand up or move in areas where SC is not placed (e.g., toilet, bathroom). The PS combines two motion sensors (S1, S2) placed one over another on a distance (D) in between and connected via microcontroller to wireless XBee transmitter, as shown in Figure 2(a). Each sensor is implemented based on pyro-electric infrared motion sensing module (SE-10 PIR) capable of detecting motion up to 5m. The distance between the sensors is selected to distinguish a standing posture from a posture of a sitting person or a person lying on the floor. Figure 2(b) illustrates the posture detection algorithm. When both sensors sense motion, the standing posture is detected. When sensor S2 reports motion but S1 does not, the sitting or lying posture is detected. When both sensors idle not sensing motion, no activity is detected. We found empirically that placing the sensor S2 at the height of 40cm from the floor and sensor S1 at the 24cm distance (D) from S2 provides good differentiation of postures for a person 170cm tall. Although each sensor was able to sense the person over 2m distance, the best results (100% of correct human pose detection) were observed at up to 140cm. The total cost of the PS consisting of two sensors, the Arduino Uno microcontroller, XBee transmitter, two resistances, and the breadboard does not exceed US50$.

2.3. **Door sensor.** Door sensors (DS) are employed to alert a caregiver when a monitored person exits from his room and/or opens an entrance door. Unlike existing DS that just



(a) (b)

FIGURE 2. Illustration of the posture sensor: (a) structural organization, (b) human activity detection algorithm



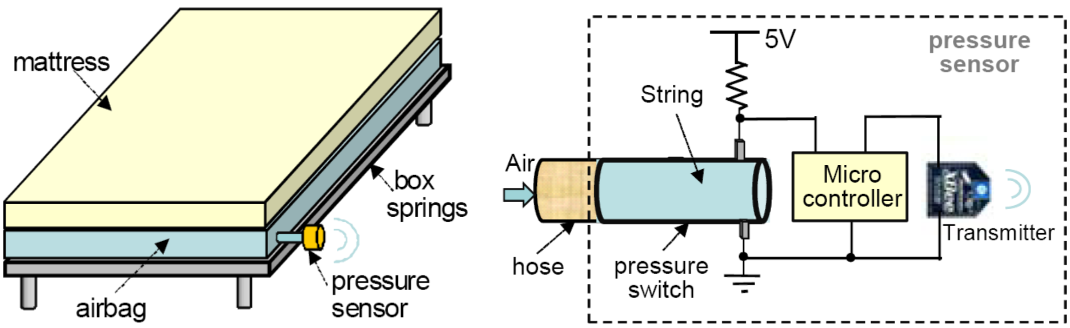
(a) (b)

FIGURE 3. (a) An illustration of door sensor, (b) photos of main implementation components

sense the door opening and closing, our sensor detects who opens/closes the door and alerts the caregiver when it is done by the monitored person. The device combines a magnetic sensor with a radio-frequency identifier of the patient, as shown in Figure 3(a). To identify the PD, we embed an RFID passive tag in his/her slippers, as shown in Figure 3(b), and place antenna of active RF-reader (Figure 3(b)) under the carpet mat in front of a door similar to [7]. However, unlike [7] our RFID readers are wireless. Both the magnetic sensor and the RF-reader are connected to the XBee transmitters, which signal the server whether the door is open or close and whether the person at the door is the PD or not, respectively. Based on this pair of signals, the server assesses it if the door is opened by the PD. The tests confirmed that both tag and the RFID antenna are not perceptible as they walked. Also, using slippers as RFID-tag is an acceptable solution, since elderly people usually wear slippers at home all the time. The passive RFID tags do not require charging batteries minimizing the maintenance tasks. The overall cost of the sensor is US30$.

2.4. **Bed sensor.** The bed sensor (BS) detects the presence of a person in bed. We studied two different designs. The first one consists of an air bag placed between the mattress and the base in the patient's bed, as shown in Figure 4(a). The air bag is connected by a hose to an air pressure sensor that converts pressure changes into electrical signal. Figure 4(b) depicts organization of the pressure sensor. The pressure switch is linked to microcontroller and to XBee transmitter to signal when the pressure switch terminals open or close. When a person sits or lies on the bed, he or she compresses the airbag, increasing the air pressure within it. The high pressure in the airbag pushes the plunger rightward against spring tension, closing the switch and causing the transmitter to send an "ON" signal, reporting the presence of the person on the bed. When the person gets off the bed, the air pressure within the airbag falls, the switch opens and the transmitter sends an "OFF" signal, indicating that the person has left the bed. It matters very little where the person lies or sits on the bed. His weight is distributed over a large area of the air mattress, compressing it almost everywhere and this raises the air pressure within it enough to close the switch.

The second design (Figure 5) is implemented based on a 10mm $\times$ 622mm pressure sensing strip FSR 408 shown in Figure 5(a). The bed sensor contains four strips of pressure sensors each of each connected to a microcontroller and a power source, as shown in Figure 5(b). The sensors are positioned at distance D from each other and fixed over a pad of 160 $\times$ 80cm^2 in size, as shown in Figure 5(c). The pad (shown by the dark pattern in the figure) is placed over the mattress and under the sheet. When a person sits or lies on the bed, he or she presses the sensor strips and thus forces them to generate signals to the microcontroller. Because each sensing strip has a fixed position



(a) (b)

FIGURE 4. Bed sensor design 1: (a) an overview; (b) organization of the air pressure sensor

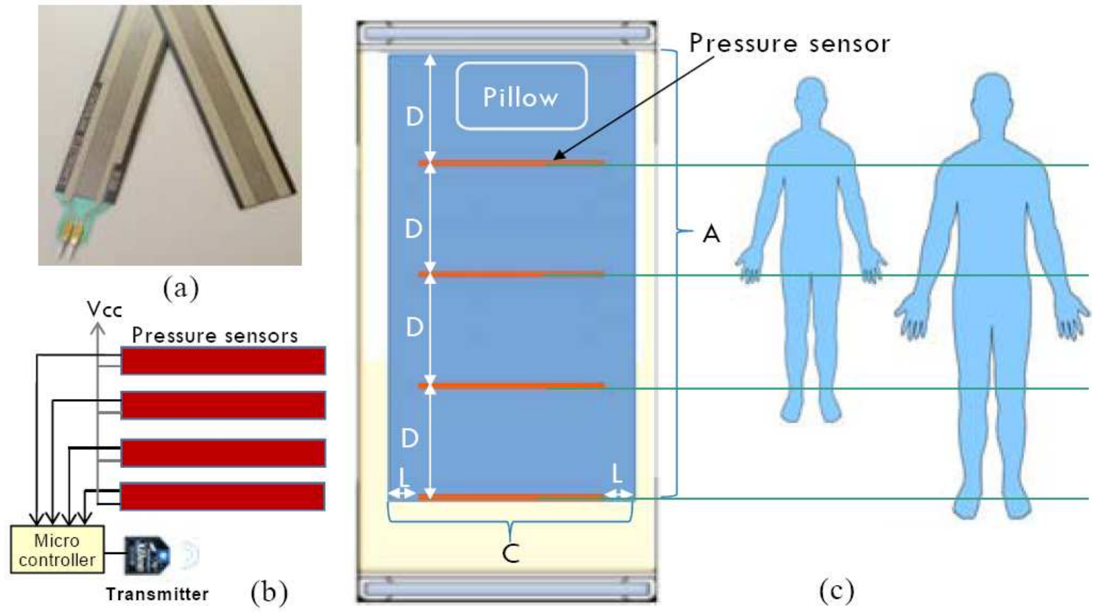


Figure 5. Bed sensor design 2: (a) a photo of FSR408, (b) bed sensor circuit; (c) position of FSR408 sensors over the bed

at the pad, the location of a PD over the BS is easily defined through the reading of the pressure sensors. As our tests revealed, the strips have to be placed at the distance D = 40cm to distinguish correctly the *in-bed* event from the *out-of-bed* event for patients having different heights (see Figure 5(c)) and shapes. A patient is considered *in-bed* if more than 2 pressure sensors are activated. When none of the sensing strips is activated, the patient is assumed to be *out-of-bed*. The cost of BS is US70$ for the first design, and 100$ for the second design, including the 8 bit ATMEGA microcontroller.

3. **Experiments and Results.** For experimental evaluation, we built a prototype system that reads information from the sensors, assesses position and activity of PD and alerts the caregiver if help is necessary by sending messages via Internet to a mobile phone or PC of caregiver. Currently, the system recognizes the following activities: *in-bed, out-of-bed, room exit, in-bath, in bath too long, person fall, entrance door, and home exit.*

Figure 6 shows the activity assessment algorithm. Here, parentheses determine location of the door sensor: room, bathroom or home entrance; T1∼T4 are programmable timers; *alert* and *alarm* are two types of messages that are sent to caregiver. An alarm requires immediate action from the caregiver; an alert is information only. The values of T1∼T4 as well as emergency levels associated with activities can be changed by caregiver based on the PD's condition. For example, the caregiver may assign alarm to '*exit from bed*' for a weak or unstable PD, whereas for a physically stable individual it has alert level. With new message received, the system determines its source, assesses the PD's activity, and generates a corresponding alert or alarm to caregiver. After identifying the activity, the system reassesses its criticality in a timing loop or waits for a new message from the sensors. For example, the '*in-bed*' event usually has low emergency level. However, when the patient has been '*in bed*' motionlessly longer than the time limit T1, the emergency level is elevated to alarm. Any reading from the motion sensor or SC resets the timer. Similarly, when the system detects that the PD is inside the bathroom, it starts timer T2. If the timer goes off, the '*in bathroom too long*' event is detected. An input from the bathroom door sensor resets T2.

We tested the system in a mock-up bedroom setting, with a bed and other typical bedroom furnishings [8]. Each test involved six participants, which were asked to perform

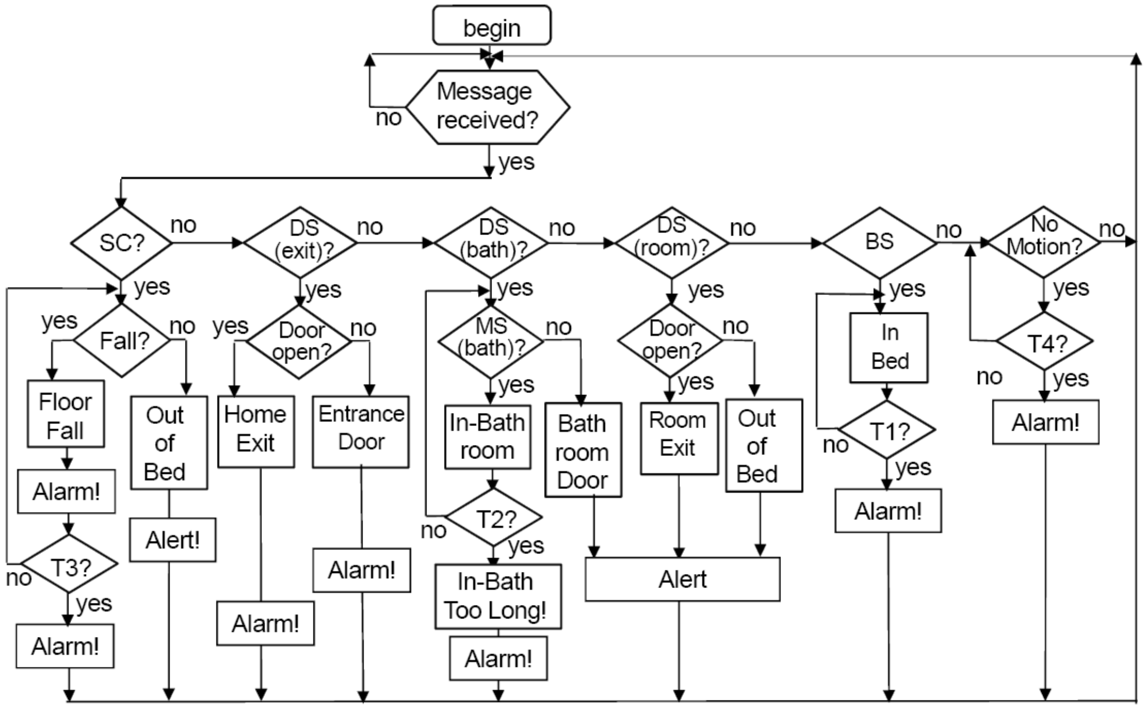


FIGURE 6. The flowchart of activity assessment algorithm

a series of postures, namely, sitting/lying down in bed, walking/standing inside room, falling, lying down on the SC in a "stretched" position, and a "tucked" position, sitting/lying on SC without motion for pre-defined duration, exiting from the room, etc. These scenarios were repeated three times by each subject in a random order. The test positions totaled 90 fall-simulated tasks and 486 non-fall-simulated tasks. The true positive rate for fall detection was 98% with a false positive rate of 0.03%. The BS displayed perfect (100%) accuracy in differentiating the patient in-bed and out-of-bed, respectively. Similarly, the door sensor was confirmed to correctly identify the events, related to room exit, entrance door, exit from home. The posture detection rate of the posture sensor was 94%. (The false positive *in-bed* events were observed when bags were put over the bed). The delay of displaying the results on Nexus 7 device was 0.6s. Overall, the conducted tests have suggested high efficacy of the developed technologies in person monitoring, activity assessment, and alerting the caregiver on emergency for assistance.

4. **Conclusion.** As the number of people suffering from dementia grows, the need for ICT systems capable of remote monitoring of PD will grow. In this paper, we presented several wireless technologies which can assist family caregivers in monitoring PD activities at home. The technologies are inexpensive, and easy to install and maintain. As tests revealed, combining them in a system allows effective monitoring, assessing risks and reporting the events online in real time. By using the technologies, the caregiver does not need to supervise the PD all the time, as the system does it automatically. At the same time, the caregiver can assess the monitoring events from PC or smartphone anywhere and anytime, communicating with the patient remotely. As no alerts or alarms are produced, the caregiver can do any other work, go shopping, or relax. The ambient intelligence of the system enhances the caregiver's monitoring ability and mobility. We are currently evaluating the system in real residential settings of dementia people.

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