Future Care Floor: A sensitive floor for movement monitoring and fall detection in home environments

Lars Klack, Christian Möllering, Martina Ziefle, and Thomas Schmitz-Rode

Human Technology Centre, RWTH Aachen University,
Theaterplatz 14, 52062 Aachen, Germany
`{Klack,moellering,ziefle}@humtec.rwth-aachen.de,`
`smiro@hia.rwth-aachen.de`

Abstract. This paper describes the conceptualization and realization of a sensor floor, which can be integrated in home environments to assist old and frail persons living independently at home. Its purpose is to monitor the inhabitant's position within a room, to detect (abnormal) behavioral patterns as well as to activate rescue procedures in case of fall or other emergency events. This floor is part of a living lab ("The Future Care Lab") developed and built within the eHealth project at RWTH Aachen University. The lab, which is part of the European Network of Living Labs (ENoLL), serves as a test environment for user centered design of Ambient Assisted Living (AAL) technologies.

Keywords: sensor floor, position monitoring, fall detection, pattern recognition, living lab.

1 Motivation

In order to minimize daily life health risks for old and frail people and to increase the independency and mobility of an aging society, new concepts for unobtrusive health monitoring within home environments are needed. Implementation and integration of medical technology in living spaces require a new conceptualization of medical device design. Invisibility and unobtrusiveness of technical components combined with high technical reliability have to be major aspects to be respected within the guidelines for the design of future health monitoring devices. In addition to technical features, technology at home also needs to be architectonically integrated in the personal living space and should not change the character of a comfortable and cozy home, respecting individual requirements for intimacy and privacy. For a successful scenario in which both patients and health care institutions profit from home care solutions the technology has to be unobtrusive, affordable and reliable. The Patient has to be and feel as save as in a hospital combined with the comfort and the privacy of his normal home environment.

Many vital parameters like body temperature, weight or blood pressure can be monitored within such an environment [15] but especially the prevention and recognition of falls are important for the elderly. 30% of the persons older than 65 and 50% of the persons older than 80 years suffer from a downfall every year [26]. 20-30% of those downfalls lead to severe injuries [2, 6]. In many cases old people live alone, are not able to call help after a fall and are sometimes not being found for days [4]. The long-term consequences of downfalls are even more dramatic: functional deficits, increased need of care, loss of self-confidence and life quality may lead to morbidity and mortality of persons [18, 19]. A time critical help after a fall or even a preventive identification of atypical movement patterns would represent a considerable improvement for patients and physicians.

The goal of this research is to develop an intelligent floor that may detect characteristic walking patterns, fall events or other abnormal movement behaviors that would indicate an emergency situation for the user. In case that such an emergency situation is detected the system may contact a relative or professional medical personnel. Thus, users do not have to activate the emergency call themselves, which in a lot of cases is not possible, for example when the person is immobile after the downfall or even lost his conscience. Furthermore, older users with high risk for downfalls have an alternative to portable emergency buttons, which are often perceived to be stigmatizing and have a low compliance.

2 State of the Art

The non-invasive monitoring of peoples positions and movements within a limited environment is widely discussed in literature. Technological approaches range from wearable sensors like accelerometers and pressure sensors [20, 21], contact free methods using acoustic (microphone) [11] or visual (video camera) [12, 16, 24] sensors till solutions, which measure the contact forces that are applied to the ground by the users feet [1, 8, 23]. Each approach offers advantages but also drawbacks in certain scenarios. Wearable sensors are mobile and can be used in various locations, however they are not invisible and require a high amount of care and maintenance of the user. Acoustic and visual sensors provide very reliable information but require visible obtrusive technology that may bring up privacy and intimacy concerns. For the research focus of fall detection in a very private environment a ground sensor based approach seems to be the most promising.

Orr et al. created and validated a system for biometric user identification based on footstep profiles [23]. In their approach the ground reaction force of the users foot is measured by load cells and analyzed in order to generate user identification profiles. Addlesee et al. developed a sensor system called Active Floor, which aims at capturing the time varying spatial weight distribution within a given area using the hidden Markov model technique [1]. While the latter approaches are on a prototype level there are commercial projects as well, like the Sensfloor of Future-Shape GmbH [8]. The Sensfloor consists of a pressure sensitive textile layer that can be installed under a carpet. It detects the position of a person on the floor and gives alarms according to predefined scenarios (no movement for a longer period of time, etc.).

3 Future Care Floor

The approach presented in this paper aims not only at detecting a users position on the floor but also at measuring qualitative aspects of moving behaviors, especially downfalls or abnormal patterns which would indicate emergency situations for the user. The following part will explain the systems technical conceptualization and realization.

The basic concept is that of a floor that is equipped with a grid of piezoelectric elements (see Image 1). Those elements represent an inexpensive way of measuring forces applied to the ground. When a force is applied to the piezo it will deform and its atomic structure shifts. This causes a charge transfer and a voltage proportional to the applied force is induced within the piezo. This voltage signal we measure between the two poles of the sensor element (red and black cable, Image 1).

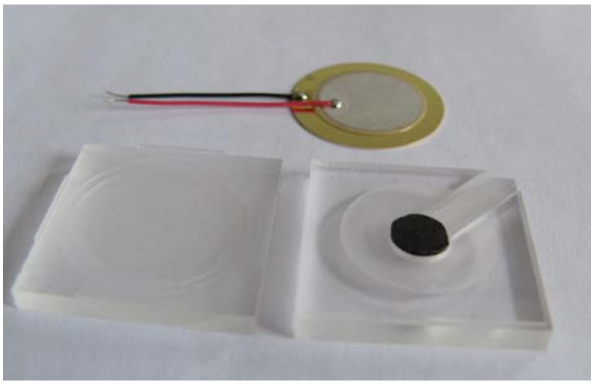

Image 1: piezo sensor and perpex support structure

In order to achieve a good resolution, a net of 240 piezo elements was installed under the 20 m^2 floor surface of the test lab environment. The underlay structure of the floor is a metal grid consisting of steel sections which form squares of 0,6 x 0,6 m^2. At all cross points of this metal grid four piezo elements are installed, they serve as free support for the floor tiles. The floor tiles have a dimension of 0,6 x 0,6 m^2 aswell and a wooden upper surface and a metal basis.

So in each of the four corners of every tile a sensor is positioned and gives information about the force applied to the tile. In order to guarantee good signal quality and safe bedding, the piezo elements are positioned in a custom made perspex support structure. The support structure (Image 1) has a height of 5 mm, which makes the actual sensor part very thin and opens the possibility of installing the sensor floor within existing home environments.

Due to the geometry of the support structure primarily bending stress is applied to the piezo element when a user walks on the floor, which result in better signal quality. The voltage signal induced by mechanical deformation of the piezo material changes according to the type of load that is applied to the panel, which is the basis for robust fall detection and pattern recognition.

All sensors are directly wired to operation amplifiers. We use a setup of 15 operation amplifier boards (as shown in Image 2) to connect all 240 sensor units. The operation amplifier circuit consists mainly of a logarithmic unit and a voltage adjustment unit (see Image 3).

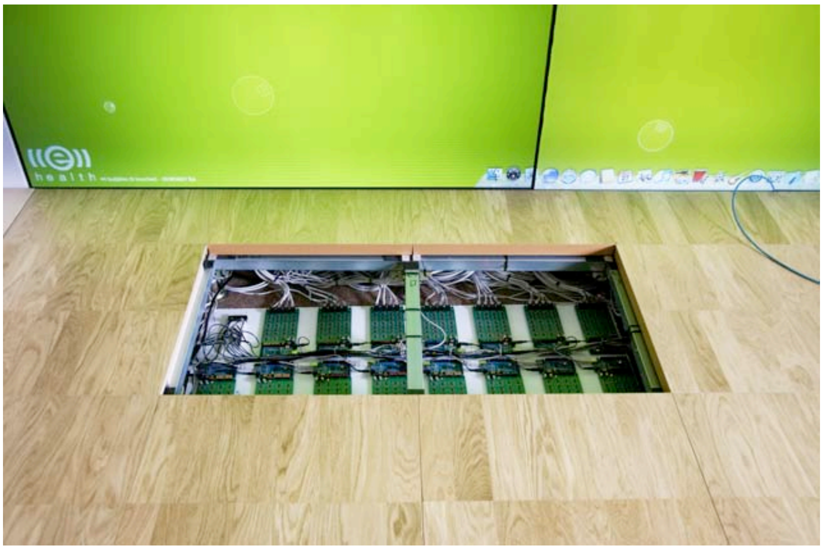

Image 2: operation amplifier and microcontroller boards under the metal support structure for the sensors and the floor tiles

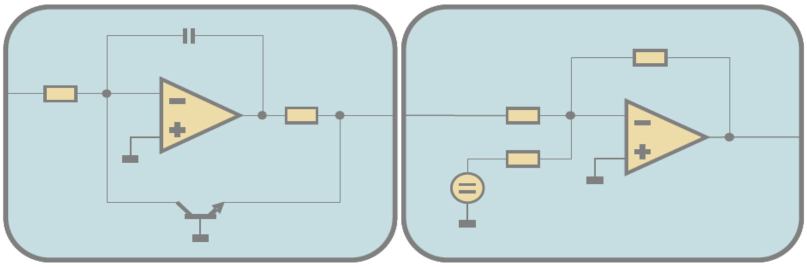

Image 3: circuit diagram of the logarithmic unit (left) and voltage adjustment unit (right)

This setting is used due to the unequally distributed information within the raw voltage signal. Considering the research goal of detecting distinct movement patterns and especially downfalls, we found that the highest information density can be extracted in the voltage range of 20 – 40 Volts. In order to evaluate this range in more detail, without losing the basic signal information of the lower voltage ranges, a logarithmic unit is used. The voltage adjustment unit on the other hand is necessary in order to scale the complete voltage range of the sensor units to the 5V input maximum of the microcontroller boards. The relation of in- and output voltage is defined by the following function, with the virtual zero-point of the output voltage at +2.5 V:

$$U_o = U_T * \ln[U_i / I_{ES} * R]$$

We use 15 Arduino Mega microcontroller boards with serial interface to carry out the analog-digital conversion of the signals. A 10 Bit resolution at a sampling rate of 370 samples per sensor and second can be achieved in the experimental setup.

All further signal processing is done digitally. The data is acquired by a software and gathered in a two dimensional array which represents the structure of the piezos under the floor. This array of raw sensor signals is the basis for the extraction of various features and patterns within the signals. In order to do this, distinct parameters have to be identified and connected to other parameters or sensor information by a superior software entity (context manager). The determined parameters can be for example:

- User enters/leaves the room
- Position of the user within the room
- Pose of the user (standing, sitting, laying)
- Weight of the user

Those parameters combined with the time information provide a relative exact picture of the users movement behavior. For example:

- Velocity of pace
- Movement direction
- User identification

For specific tasks like for example fall detection, the patterns have to be subdivided in different classes, in order to calculate the probability of a fall according to the identified user.

In order to generate robust pattern recognition different machine learning approaches are followed. Supervised learning seems to be the most promising way to structure the signal data. In this approach the users live signal data is constantly compared to previous fall or movement scenarios, evaluated and updated. As the database increases the detection and extraction of different features becomes more and more reliable. In this context the use of Vector Support Machines seems promising. Also other approaches like Hidden Markov Models, Conditional Random Fields or Nearest Neighbor Algorithms [13, 22, 23] are evaluated.

Each signal peak is mathematically analyzed in real time, provided with a time stamp and stored in a database. This opens the possibility of reacting immediately on emergency events like downfalls. As the database is continuously increasing with each step, the systems knowledge about the normal behavior of the user rises constantly.

4 Integration in the Living Lab

The floor is one component of a Living Lab " The Future care Lab" (Member of the European Network of Living Labs [7]) that is being build at the Human Technology Centre of RWTH Aachen University (http://www.humtec.rwth-aachen.de) [27]. In this context the floor is connected with a wall sized interactive multi-touch display (Image 4). The overall goal of the research program is to develop adaptive interfaces and novel, integrative prototypes for personal healthcare systems in home environments. This includes new concepts of electronic monitoring systems within ambient assisted living environments. The technological design follows iterative cycles, in which technology development is carefully harmonized and weighted with acceptance and/or usability demands. Patients differing in gender, age, health status, emotional and cognitive factors, and severity of disease will be involved in the design.

To examine how patients communicate with smart homecare environments, how they deal with invisible technology, and how the information is to be delivered such that it meets the requirements of timeliness, data protection, dignity as well as medical demands, an experimental space is necessary, which enables to study patients "life at home". The room consists of a simulated home environment, which enables researchers to use experimental interfaces with test persons of different ages and health states. Out of validity reasons, the experimental space is of central importance, as patients and care givers need to experience and "feel" the technology to be used, in order to fairly evaluate it [25]. Further, persons might overemphasize their sensitiveness towards privacy violations if their judgments only rely on the imagination of using it [5].

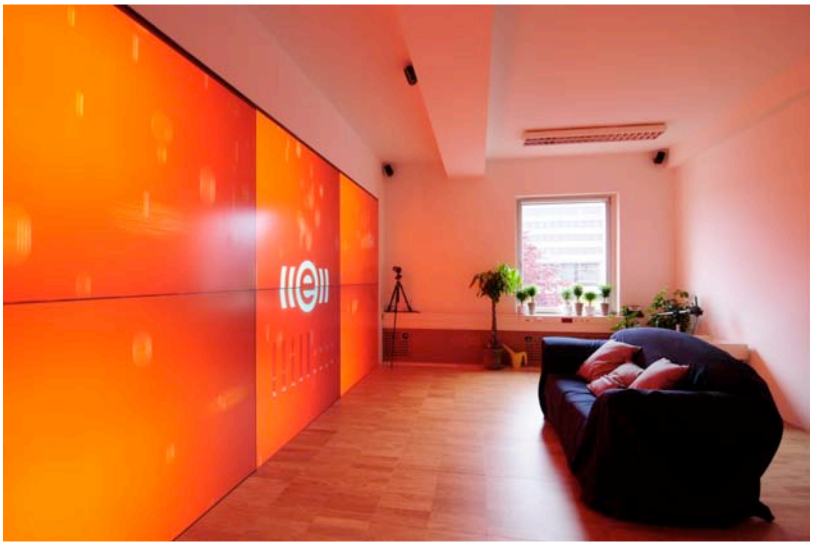

Image 4: Future Care Lab. Based on the information provided by the sensitive floor wall applications can react interactively on the users position by zooming in and out or changing perspective.

Medical applications supported by the display wall are life size video consultations with the doctor or physical rehabilitation programs supported by interactive advises or games using the feedback channels of the floor and the wall [14]. One first application realized is a sound game in which the user is able to play music by changing his position on the floor (not pictured here, http://www.ehealth.humtec.rwth-aachen.de/), encouraging users to move and take exercise. The sound provoked by each step, may enhance patients' compliance and to support medical aftercare.

Another huge advantage of the living lab approach is the expandability of the system, which is interesting from an economic point of view. It is not restricted to medical services, but can be expanded to completely different services, ranging from information and communication services (e.g. getting information from the internet), over entertaining services (cinema, video-phoning with relatives), to social services (virtual meetings, visiting remote family members), to living services (ordering food from the supermarket or drugs from the pharmacy). Also, the digital room components might be used for atmospheric issues: light, tones, music can be integrated, which can have therapeutic or hedonic effects [3].

However, there may be also disadvantages, which need to be carefully addressed. Smart mobile technologies have already fundamentally changed the nature of social, economic and communicative pathways. The omnipresence of information may be perceived as a violation of personal intimacy limits, raising concerns about privacy, and loss of control [9, 17]. So far, we have only limited knowledge about the fragile limits between the different poles: the wish to live independently at home and to feel safe, secure, and fully cared on the one hand and the feeling of loss of control and the disliking of intrusion in private spheres on the other. Future studies aim at an "acceptance cartography" of using motives and barriers, which are assumed to depend on the specific using situation, living contexts and on user diversity. Here, user-centered designs and a consequent inclusion of patients in all phases of system evaluation are needed in order to understand users needs and wants [3, 10].

References

1. Addlesee, M.D., Jones, A.H., Livesey, F., Samaria, F.S.: The ORL Active Floor, IEEE Personal Communications 1997 Volume 4(5) pp.35-51 (1997)
2. Baker S.P., Harvey, A.H. Fall injuries in the elderly. Clin Geriatr Med., pp. 501-512. (1985)
3. Beul, S., Klack, L., Kasugai, K., Möllering, C., Röcker, C., Wilkowska, W. & Ziefle, M. Between Innovation and Daily Practice in the Development of AAL Systems: Learning from the experience with today's systems. 3rd International ICST Conference on Electronic Healthcare for the 21st Century (2010)
4. Campbell, A.J., Reinken, J., Allan B.C., Martinez G.S. Falls in old age: a study of frequency and related clinical factors. Age Ageing 10, pp. 64-70 (1981).
5. Cvrcek, D. Kumpost, M., Matyas, V., & Danezis, G.: A Study on the Value of Location Privacy. Proceedings of the ACM Workshop on Privacy in the Electronic Society, pp. 109-118, New York: ACM (2006)
6. De Ruyter, B., Pelgrim, E.: Ambient Assisted Living research in CareLab, ACM Interactions, Volume 14, Issue 4, (2007)
7. European Network of Living Labs (ENoLL) http://www.openlivinglabs.eu (2010)
8. Future Shape (Sensfloor) http://www.future-shape.com (2010)

9. Fugger, E., Prazak, B., Hanke, S., Wassertheurer, S.: Requirements and ethical Issues for sensor-augmented environments in elderly care. In C. Stephanidis (ed). Universal Access to HCI. Berlin: Springer, Vol. 4554, pp. 887 - 893 (2007)
10. Gaul, S., Ziefle, M.: Smart Home Technologies: Insights into Generation-Specific Acceptance Motives. In: A. Holzinger et al. (eds.): HCI for eInclusion. Berlin: Springer, pp. 312 - 332 (2009)
11. Haines, W.D., Vernon, J.R., Dannenberg, R.B., Driessen, P.F.: Placement of Sound Sources in the Stereo Field Using Measured Room Impulse Responses. Lecture notes in computer science - Computer Music Modeling and Retrieval. Sense of Sounds 2009. Springer (2009)
12. Kahn, S.M., Shah, M.: A Multiview Approach to Tracking People in Crowded Scenes using a Planar Homography Constraint, European Conference on Computer Vision (2006)
13. Kim, E., Helal, S., Cook, D.: Human Activity Recognition and Pattern Discovery, IEEE Pervasive Computing, Vol. 9 (1) pp. 48 - 53 (2010)
14. Klack, L., Wilkowska, W., Kasugai, K., Schmitz-Rode, T.: Die intelligente Wohnung als medizinischer Assistant, VDI Wissensforum "Kunststoffe in der Medizintechnik" (2010)
15. Klack, L., Kasugai, K., Schmitz-Rode, T., Röcker, C., Ziefle, M., Möllering, C., Jakobs, E.-M., Russell, P., Borchers, J.: A Personal Assistance System for Older Users with Chronic Heart Diseases. In: Proceedings of the Third Ambient Assisted Living Conference (AAL'10), January 26 - 27, VDE Verlag, Berlin, Germany (2010)
16. Kourogi, M., Kurata, T.: Personal Positioning based on Walking Locomotion Analysis with Self-Contained Sensors and a wearable camera, Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality (2003)
17. Lalou, S.: Identity, Social Satus, Privacy and Face-keeping in the Digital Society. Journal of Social Science Information, 47(3), 299-330 (2008)
18. Lawrence R. et al.: Intensity and correlates of fear of falling and hurting oneself in the next year: Baseline findings. Journal of Aging and Health 10, pp. 269 - 286 (1998)
19. Liddle J., Gilleard C.: The emotional consequences of falls for older people and their families. Clinical Rehabilitation 9, pp. 110 - 114 (1995)
20. Lüder, M., Salomon, R., Bieber, G.: StairMaster: A New Online Fall Detection Device. 2nd Congress for Ambient Assisted Living, Berlin (2009)
21. Mann, S.: Smart Clothing: The Wearable Computer and WearCam, Personal Technologies, Vol. 1, No. 1 (1997)
22. Pirttikangas, S., Suutala, J., Riekki, Röning, J.: Footstep Identification from Pressure Signals using Markos Models, Intelligent Systems Group, Infotech Oulu (2002)
23. Robert J. Orr and Gregory D. Abowd, The Smart Floor: A Mechanism for Natural User Identification and Tracking, Graphics, Visualization and Usability (GVU) Center, Georgia Institute of Technology (2000)
24. Schäfer, R., Müller, W., Ceimann, R., Kleinjohann, B.: A Low-Cost Positioning System for Location-Aware Applications in Smart Homes, CHI 2007 Workshop on "Mobile Spatial Interaction" (2007)
25. Woolham, J. & Frisby, B. (2002). Building a Local Infrastructure that Supports the Use of Assistive Technology in the Care of People with Dementia. Research Policy and Planning 20(1), 11-24.
26. World Health Organisation (WHO), http://www.who.int (2004)
27. Ziefle, M., Röcker, C., Wilkowska, W., Kasugai, K., Klack, L, Möllering, C. & Beul, S.: A Multi-Disciplinary Approach to Ambient Assisted Living. In: C. Röcker & M. Ziefle, (eds.). E-Health, Assistive Technologies and Applications for Assisted Living: Challenges and Solutions. Hershey, P.A.: IGI Global (2010)