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Integration of a fall detection system into the intelligent building

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Abstract: Health monitoring and the integration of such systems into homely environments can support healthy aging. In this paper, we focus on the integration of a fall detection system into the intelligent building. We present a low intrusive way to detect falls and locate people inside a building based on the low power wireless technology Bluetooth Smart and a concept how well designed human computer interaction (HCI) concepts inside a building can help to save lives or at least prevent people of heavy injuries.

Keywords: fall detection, human computer interaction, smart home, intelligent building, indoor localization

1 Introduction and Motivation

The United Nations estimates that in 2050, the first time in history, our globus will accomodate more old people than young humans under 15 [UN12]. Beside the problems for our whole health and welfare system, these progress will especially make high demands on our healthcare system. To take care of these consequences and to provide a safe and viable environment for humans, preventive measures will acquire more significance. Falls constitute a large proportion of domestic accidents. They are one of the most significant causes for life-threatening injuries and show a close link between the duration until the emergency services arrive and the severity of the injury [WNI81]. Because an expansion of medical care for the growing group of elderly is not possible, measures for autonomous care and surveillance of persons will be more and more important [TV00].
This paper describes the integration of a fall detection system into an intelligent building, otherwise known as Smart Home. Beside the technical aspects of the integration, the system provides a way to integrate an information technology system into the domestic environment, and especially to achieve a better user adaption and faster initiation of the prevention in case of an accident. The system is characterized by the low costs and energy-saving components as well as good integration into the physical environment to improve the human computer interaction (HCI), which is especially important for the elderly, e.g. [Ma03].

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2 Related Work

2.1 Integration into the intelligent building

Fall detection in general is a widely discussed field in research (see the work of Mubashir et al. [MSS13]), while the integration of those systems, especially with regard to designing HCI for elderly, receives far less attention. The acknowledged problems of smart homes in general are above all the high costs and the difficult management of the system, in combination with a lack of flexibility and inadequately developed safety concepts [Br11], which lead to a lot of obstacles especially for older people. One approach to examine and solve these problems is the project "Casa Vecchia"[5] of the Alpen-Adria University of Klagenfurt which studies ambient assisted living in rural areas interdisciplinarily by installing smart home technology into households of elderly and monitoring them scientifically. The researchers underline the calm integration of components and describe how physical objects can be used for optical signalling of variable information [Le13]. Addtionally, they conclude that a real intelligent environment should adapt to the social structure and not vice versa [LMH12]. Beside these generalized papers on technical integration and HCI inside the intelligent building, there are several specific approaches to integrate a fall detection system into the living environment. Yu et al. describe a system which detects falls visually by classification based on support vector machines (SVM) [Yu12]. The notification of a fall is realized by classic communication techniques like SMS or internet-based messaging services. In the work of Lee et al., the fall detection is supported by acceleration sensors of a standard smartphone in combination with a monitoring system and notification by email [JYK13]. Huang et al. present a system based on the wireless standard ZigBee where the fall detection is again realized by acceleration sensors. Unlike the previous systems, the position of the fallen person will be determined and sent to a Remote Telecare Provider by GSM or the Internet [HC14]. Another approach to the integration of a fall detection system is presented by Klack et al. who used a grid of piezo-electric sensors inside a sensitive floor to detect a fall and the position of the person. In the showcase, this information is visualized on a videowall [Kl11].

2.2 Wireless Networking Protocols

In the field of the wireless connections of components, a broad range of different protocols are available to choose from, where Bluetooth Smart [Bl15a], ZigBee/802.15.4 [Zi15], Z-Wave [Z-15] and ANT [AN15] seem to be future-proof and are thus often referred to in scientific literature [De13] [Si12] [Ca09]. Because power consumption is a direct quality characteristic, papers which focused on the energy efficiency of the protocols are relevant. For this topic, the papers of Demetyev et al. [De13] and Siekinnen et al. [Si12] deliver results. Both state that Bluetooth Smart is the most energy efficient variety. Demetyev et al. compared Bluetooth Smart, ZigBee/802.15.4 and ANT, while Siekkinen et al. focused

[5] Casa Vecchia, ital. = old house; project acronym: Carinthian Association of Smart Ambience – Venue Enabling Collaboration and Communication in the accustomed Home to support Independent Aging (www.casavecchia.at/).

on the comparison between Bluetooth Smart and ZigBee/802.15.4. Beside the aspect of power consumption, the focus of the technology is a quite relevant factor. Cao et al. concluded that Bluetooth Smart offers special benefits for the usage as „Wireless Body Area Networks“ [Ca09].

2.3 Indoor localization

The localization of persons or objects inside a building by radio transmission techniques is a widely discussed field in the scientific literature. Unlike the localization outside of buildings, the use of GPS is not feasable because of the high shielding of the outer building structures. The methods and techniques for indoor localization can be condensed into two approaches : fingerprinting- and model-based approaches. The fingerprinting method is based on the analysis of the environment and their surrounding signatures to build a database and uses this for a later localization process by pattern matching [YWL12]. Examples for this are RADAR [BP00] or Horus [YA05]. Model-based techniques estimate the location based on geometrical models and the behaviour of electromagnetic waves when they are transmitted [YWL12]. A lot of these models make a relationship between the signal strength and the distance between sender and receiver, e.g. the *log-distance Path loss model* (LPLM) [BS13]. Others use the Time of Arrival (ToA) [Yo06], Time Difference of Arrival (TDoA) [PCB00] or the Angle of Arrival (AoA) [NN03] to estimate the location.

3 Smart Fall System

As described in the previous section, there are many different approaches for detecting and reporting a fall. Many fall detection systems do not focus on the user-friendly and supportive integration of the system inside intelligent buildings. The system „Smart Fall“described here addresses the gap between the technical process of detecting a fall and the user involved.

3.1 System description

Our fall detection system is based on three independent components: the fall detection module, the integration module and the proper point of integration into the intelligent buildung, the base station running OpenHAB [Op15]. The fall detection module is a small wearable device, while the integration module is a single-board computer. Communication between these submodules is realized by both the wireless standard Bluetooth Smart (former known as Bluetooth Low Energy) and wireless LAN. Figure 1 shows the associated structure of the system. Here we see the monitored person equipped with the fall detection module. Additionally, there are transponders which are located in every room near the door to make the process of localization possible. Every transponder is integrated in the network by wireless LAN. For complete coverage in wider areas, additional transponders can be installed in any location inside the building. The base station, in form of an OpenHAB, can be positioned at an arbitrary location with the restriction that it must be connected with the network by LAN or WLAN. Beside the described submodules, LED light strips are embedded into the floor. These strips are connected to the system by KNX [KN15] which is a standardized, OSI-based network communications protocol for intelligent buildings. The process of communication between the module *fall detection and localization* and the KNX module *LED light strip* is realized by the OpenHAB and its integrated „bindings“.

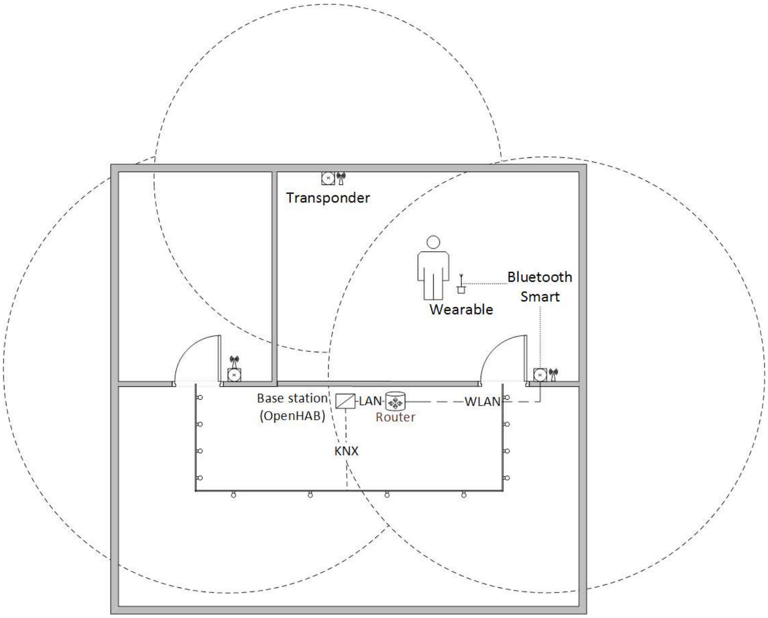

Fig. 1: System architecture Smart Fall

3.2 Scenario description

The environment of the scenario is an assisted living complex for elderly. In this special form of housing, the elderly live mostly independently with a high standard of self determination and with concurrent support by trained staff as well as neighbors. Person A, in the following Alice, and person B, in the following Bob, are equipped with a fall detection module. The whole facility is prepared for the operation of such system. This includes a regular deployment of the components and the installation of light strips. In this example every apartment consists of three rooms. The rooms are identified by the label pattern „apartment.roomnumber“(Figure 2). In our example Alice is located in room *A.1*. To use the radio, she walks into room *A.2*. When she walks through the door, the check-in process in room *A.2* is detected by the transponder and reported to the base station. Now Alice stumbled over the edge of the carpet and falls, bumping her head and entering a state of quantitative consciousness disturbance. Now she is not able to move by herself or to get help. The fall detection module detects this state and reports a fall to the base station, which processes and aggregates both, the previously obtained localization data and the fall data. As a result of the emergency, the emergency notification process will be initiated, which consists of two subprocesses. On the one hand, professional help will be called via the notification of a carer or doctor and on the other hand, for the first aid, a neighbor will be informed. Enabled through the process of localization, the system is capable of accomplishing the localization of Bob which is located in room *B.3*. The fall detection system draws attention to the emergency and supports Bob with the discovery of the accident patient by activating the lights strips which guide him to Alice.

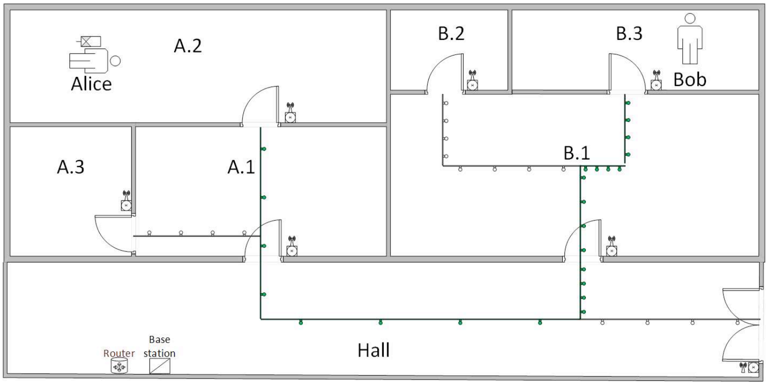

Fig. 2: Scenario description „Fall“

3.3 Hardware

The following section deals with the components used by the system and the underlying hardware. As described in brief in Chapter 3.1, the system consists of three different physical components. On the user side, a wearable consisting of two main parts is located: A System on Chip (SoC), which is made up of a 32-bit ARM Cortex M0 with 256 KB flash memory, 16 KB memory and a Bluetooth Smart component (Table 1) and a tri-axial acceleration sensor measuring linear acceleration in three orthogonal directions. The component is designed as an ultra low power Integrated Circuit (IC) and shows a power consumption of 130 μA, which leads to a greatly extended battery life. The accelerometer supports a bandwidth up to 1kHz with a resolution of 12 bit and a range of ± 16g (Table 2).

CPU	ARM Cortex M0, 32-bit
Flash	256 kB
RAM	16 kB
Digital IO	SPI, I2C, UART
Power supply	1.8 V - 3.6 V

Tab. 1: SoC key characteristics

Measurement range	±2, ±4, ±8, ±16 g
Digital resolution	12 bit
Bandwidth	1000 Hz - 8 Hz
Digital IO	SPI, I2C
Power supply	2.4 V - 3.6 V

Tab. 2: Accelerometer key characteristics

CPU	Allwinner A10 (Cortex A8)s, 32-bit
Weight	14 g
RAM	512 MB DDR3-SDRAM
Digital IO	USB-2.0-Host, Micro-HDMI (Typ D), Mini-USB, GPIO FPC
Power supply	5V/150mA - 5V/220mA

Tab. 3: Integration module key characteristics

Both components are assembled on a 2.6 cm x 3 cm sized chip (Figure 3). The second essential component is the transponder or integration module. Due to its small size and the high performance and low power consumption, we use a single-board computer. It consists of a Allwinner A10s with a Cortex A8, 512 MB DDR3-SDRAM and a power consumption of 150 up to 220 mA. The Bluetooth Smart connection is realized by a Bluetooth 4.0 enabled USB-Dongle. The total dimension of the transponder is 40 x 40 x 32 mm (Figure 4).

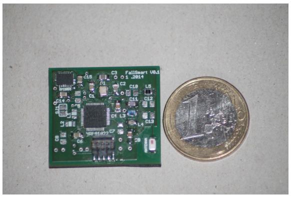

Fig. 3: Fall detection module

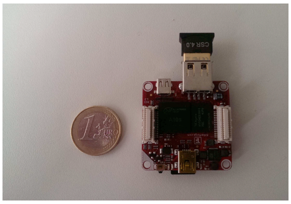

Fig. 4: Integration module

3.4 Fall detection

We describe the fall detection sensor briefly. The fall detection itself is realized by a threshold-based method (TBM). The acceleration data are collected by the tri-axial sensor and evaluated on the SoC. The foundation for the process of evaluation is a state machine with the five states : *Before Fall*, *Free Fall*, *Impact*, *After Impact* and *Fall*. Before a fall occurs, the measured acceleration value is nearly 1 g, which is caused by the gravitational acceleration and its force. In the transition to a fall, there is a short period of time with an acceleration value close to 0 g, before the impact causes a value $> 3g$. In order to be able to make the distinction between a real fall and a similar situation, e.g. stair climbing, the user's posture is analyzed and classified as „Stable“or „Unstable“ based on the horizontal or vertical pose of the person after the impact. A detailed description of the approach can be found in [Sp15].

3.5 Integration into the intelligent building

A lot of the described systems in Chapter 2 have no or only rudimentary integration into intelligent buildings, which is mostly realized by messaging services, e.g. SMS or E-Mail. The following system presents an approach to integrating a fall detection system into the intelligent building with particular regard to user adoption and the involvement of the physical environment.

3.5.1 Bluetooth Smart

To enable the integration of the system into the intelligent building, the system is founded upon established standards in the building automation. Based on the insights discussed in Chapter 2 regarding wireless network standards and their power consumption with respect to their operationality in WBANs, we have chosen Bluetooth Smart as the wireless connection standard.
Bluetooth Smart, formerly known as Bluetooth Low Energy, was announced in 2010 as part of the new Bluetooth standard 4 and provides advantages particularly with regard to energy efficiency and interoperability. The basis of the technology is a hierarchical profile definition (Generic Attribute Profile) with services and characteristics contained therein. In case of the Smart Fall system, a service with four characteristics is defined, which enables the fall detection component to provide values, e.g. dimensional acceleration data, for the transponders. Further, the characteristics *VSA* (vector sum of acceleration data) as well as *Fall* which is a binary flag for the fall indication are assigned with a notification property which enables the providing component to notify the receiving components only in the case of a change in value (Table 4). This behaviour enables a power saving process in which every component can stay in low energy mode until a possible fall is detected and reported.

Name	UUID	Format	Properties
XVal	00001411-0000-1000-8000-00805f9b34fb	IEEE-754 32-bit Float	READ
YVal	00001412-0000-1000-8000-00805f9b34fb	IEEE-754 32-bit Float	READ
YVal	00001413-0000-1000-8000-00805f9b34fb	IEEE-754 32-bit Float	READ
VSA	00001414-0000-1000-8000-00805f9b34fb	IEEE-754 32-bit Float	READ, NOTIFY
Fall	00001415-0000-1000-8000-00805f9b34fb	Boolean	READ, NOTIFY

Tab. 4: Smart Fall Service Definition

3.5.2 OpenHAB

The set of problems related to the heterogeneous protocol landscape in wireless networks, introduced in Chapter 3.5.1, can be transferred on the wired connections as well. The most popular representatives are KNX, HomeMatic [Ho15] and iNELS [iN15]. To address these problems, OpenHAB was developed. The system is a vendor- and protocol independent integration platform with low hardware requirements and a userfriendly App- and Web-based user interface to provide an easy way to configure and control home automation components. With an integrated domain specific language, OpenHAB provides a low-level approach to program procedures and behaviour in the context of home automation. The event-based architecture enables the integration of all kinds of different devices and components which are addressed over specific protocol bindings. For the integration of the Smart Fall system into the OpenHAB ecosystem, a proprietary binding was implemented which provides the interface to the various transponders and enables the localization and the notification of falls.

3.5.3 Localization

ITU indoor propagation model The localization or the distance estimation is realized with a model-based approach founded on the *ITU indoor propagation model* described in [In12]. The model is based on the path loss prediction which is an empirical mathematical formulation for the characterization of radio wave propagation. The general *ITU model* is a site-generic model founded on the insights of the free-space loss model [BKW11] (Equation 1) derived by the Friis power transmission equation [Fr46]

$$FSPL(dB) = 10log_{10}\left(\left(\frac{\lambda}{4\pi d}\right)^2\right), \tag{1}$$

where λ is the wavelength in meter and d is the transmitter to receiver distance in meter. The free space path loss model is only applicable in an area with no RF obstacles. Over time, researchers have applied a path loss exponent n which is intended to stabilize the model in different environments. Based on this, the ITU released the *ITU model for indoor attenuation* (Equation 2) which handles the particular obstacles in buildings, e.g walls, and estimates the path loss an indoor link may experience.

$$L_{total} = 20log_{10}(f) + N * log_{10}(d) + Lf(n) - 28 \quad [dB] \tag{2}$$

In Equation 2 is f the frequency of the protocol in Mhz, which is approximately 2400 MHz for Bluetooth Smart [Bl15b]. N is a coefficient for the power loss of the connection which is specified in [In12]. The variable $Lf(n)$ describes the floor penetration factor which is determined as $4n$ in residential apartments where n is the number of floors [In12].
For our purpose, N and $Lf(n)$ are not sufficient for Bluetooth Smart. Our empirical evaluation of the values determined $N = 16$ and $Lf(n) = 14$ as parameters for an acceptable modeling of the path loss, especially for lower distances (Figure 5). The distance between sender and receiver is represented as d. With the knowledge of the total pathloss $L_{total} = P_{Tx_{dBm}} - P_{Rx_{dBm}}$ between sender and receiver, we can estimate the distance d and use this for the localization process. Because the Bluetooth RSSI data is subjected to electrical interference, an estimation based on the RSSI raw data is nearly impossible [JKB13]. For this reason, we use the arithmetic mean to stabilize the measured data and make a coarsely estimation possible (Equation 3).

$$A = \frac{1}{n}\sum_{i=1}^{n} L_{i_{total}} \tag{3}$$

We determined a value $n = 30$ as an appropriate value. As the setpoint value for the check-in process, we set a limit of $d < 1m$. In case of this value being undercut, the transponder notifies the base station which then decides if it is a check-in or a check-out for the corresponding person in a specific room.

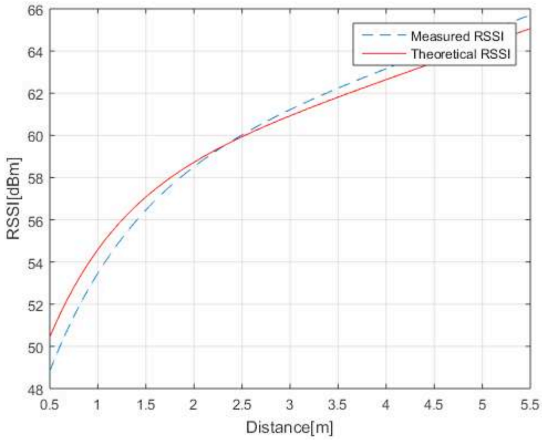

Fig. 5: ITU Model RSSI vs. Measured RSSI

3.5.4 Human computer interaction

This chapter discusses the concrete integration of the process into the physical homely environment of the elderly. We use an LED light strip actuator based on the KNX network communication protocol for intelligent buildings. As briefly described in Chapter 3.2, after a fall the base station will be informed and the alert process begins. First, the fallen person will be located based on the previously collected data. Then, a potential rescuer will be determined on an individual basis. The next step is the inclusion of the physical environment. We use the KNX-binding of OpenHAB to control the light strip by sending data telegrams which are converted into actions. Every LED in the light strip can be swiched on or off to visualize a path on the floor from any room *A* to any other room *B*. Moreover, a chaser light can be toggled which visualizes the direction of the path and enables other persons to find the right room immediatly (Figure 7).

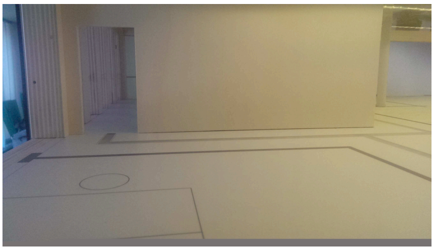

Fig. 6: LED light strip off

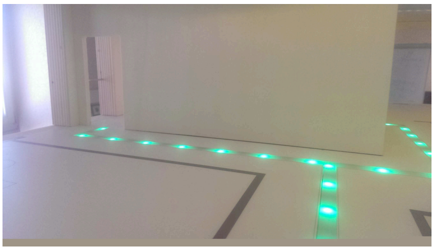

Fig. 7: LED light strip on

4 Conclusion and Future Work

We presented the principles of our system to detect a fall and locate a person, discussed the concrete integration into the home environment of the elderly. According to the HCI

framework of Saizmaa et al. [SK08], our interaction inside the system focuses especially on the Human/Technology (H/T) and Technology/Home (T/H) perspective. On the one hand the ease of use and acceptability is a very important point but the automation and standardised characteristics are necessary as well. To address these points, we have designed a system which uses a very minimally invasive method of fall detection. Other systems are founded on camera-based approaches or use a lot of large hardware. Through the usage of an non-proprietary integration system without any cloud architecture like OpenHAB, we have made a high level of automation possible without the loss of privacy and self determination. A further important point is the ubiquitous characteristic of the system. The whole system consists of small sized components, which are easy to deploy. All of the processes are designed to make a very low need of adaption for the user possible. The report functionality of the system is embedded into the physical environment of a home which leads in the end to a very minimally intrusive technology with focus on the user and not on the technology itself.
In future work, we will consider the possibilities to integrate more building components, e.g. smart locks or smart windows, to make the acute care possible faster and more efficiently. Further, we want to determine how we can use sensors like air quality, temperature or sound intensity to enable the system to report a brief overview of the environmental situation to the skilled personnel and to stabilize and improve the situation for the accident victim.

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