Diploma Thesis

A Patient Monitoring and Lifestyle Management System based on Wireless Technologies in an Ambient Assisted Living Scenario

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ABSTRACT

Due to the demographic change and the resulting constant increase of the number of elderly people in our society, new technologies are crucial which ensure an independent life as long as possible. Furthermore, the prevalence for chronic diseases is increasing as we age. Thus, “Ambient Assisted Living” and telemedical services will play an important role in the future. They provide technologies and services to counteract the increasing economic and social problems in the healthcare system.

In the course of this thesis, a Keep In Touch (KIT) based prototype for the intuitive acquisition of health parameters as well as for the monitoring of “Activities of Daily Living (ADL)” was developed and implemented. NFC technology was used to acquire context sensitive data from objects in the home environment that are equipped with RFID tags. Bluetooth technology was used to send the acquired data wirelessly to a home terminal. The home terminal, realized by a tablet PC, provides visual and acoustic feedback regarding the health status and can remind dementia patients to do daily routine tasks. Furthermore, different RFID technologies have been evaluated in order to find out the best approach for monitoring of ADL.

The results show that the developed prototype of a KIT wand provides an integrated solution for the acquisition of health data and the monitoring of ADL. The Android software application on the home terminal was proven feasible for the collection of data from the KIT wand prototype via a Bluetooth connection. The evaluation of different RFID frequency ranges showed that LF RFID technology performs better than the used NFC technology in terms of reading range and influence by materials. Thus, further developments are necessary to improve the technology and trials have to be conducted to show applicability for dementia patients.

ZUSAMMENFASSUNG

Aufgrund des demographischen Wandels und der dadurch ständigen Zunahme der Zahl älterer Menschen in unserer Gesellschaft, sind neue Technologien, die ein unabhängiges Leben so lange als möglich gewährleisten, von entscheidender Bedeutung. Im Weiteren steigt die Prävalenz für chronische Krankheiten durch steigendes Alter. Deshalb spielen „Ambient Assisted Living“ und telemedizinische Services eine wichtige Rolle. Sie bieten Technologien und Services an, um den steigenden wirtschaftlichen und sozialen Problemen im Gesundheitssystem entgegenzuwirken.

Im Rahmen dieser Arbeit wurde ein Prototyp basierend auf Keep In Touch (KIT) sowohl für die intuitive Erfassung von Gesundheitsparametern als auch für das Überwachen von Aktivitäten des täglichen Lebens entwickelt und implementiert. NFC Technologie wurde verwendet, um kontextsensitive Daten von Objekten in der Wohnumgebung, die mit RFID Tags ausgestattet sind, zu erfassen. Bluetooth wurde verwendet, um die erfassten Daten kabellos zu einem zentralen Terminal zu schicken. Das Terminal, das durch einen tablet PC realisiert wurde, bietet visuelles und akustisches Feedback bezüglich des Gesundheitszustands und kann demenzkranke Personen erinnern, ihre täglichen Routineaufgaben zu erledigen. Zusätzlich wurden verschiedene RFID Technologien evaluiert, um die beste Herangehensweise für das Monitieren von Aktivitäten des täglichen Lebens herauszufinden.

Die Ergebnisse zeigen, dass der entwickelte Prototyp des KIT Armbandes eine integrierte Lösung für die Erfassung von Gesundheitsdaten und dem Monitieren von Aktivitäten des täglichen Lebens anbietet. Die Android Software Anwendung am zentralen Terminal wurde als machbar für das Sammeln von Daten des KIT Armband Prototypen über eine Bluetooth Verbindung bewiesen. Die Evaluierung der verschiedenen RFID Frequenzen ergab, dass LF RFID Technologie in Bezug auf Reichweite und Materialeinflüsse vorteilhaft gegenüber der verwendeten NFC Technologie ist. Daher sind weitere Entwicklungen nötig um die Technologie zu verbessern. Studien müssen durchgeführt werden, um die Anwendbarkeit bei demenzkranken Menschen zu zeigen.

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LIST OF ABBREVIATIONS

AAL	**A**mbient **A**ssisted **L**iving
ADL	**A**ctivities of **D**aily **L**iving
AIT	**A**ustrian **I**nstitute of Technology
BAN	**B**ody **A**rea **N**etwork
COPD	**C**hronic **O**bstructive **P**ulmonary **D**isease
ECG	**E**lectro**c**ardio**g**ram
EOT	**E**nd **O**f **T**ransfer
HF	**H**igh **F**requency
IADL	**I**nstrumental **A**ctivities of **D**aily **L**iving
IEEE	**I**nstitute of **E**lectrical and **E**lectronics **E**ngineers
ISM	**I**ndustrial, **S**cientific and **M**edical
KIT	**K**eep **I**n **T**ouch
LAN	**L**ocal **A**rea **N**etwork
LED	**L**ight **E**mitting **D**iode
LF	**L**ow **F**requency
LPM	**L**ow **P**ower **M**ode
NFC	**N**ear **F**ield **C**ommunication
PAN	**P**ersonal **A**rea **N**etwork
PC	**P**ersonal **C**omputer
PDA	**P**ersonal **D**igital **A**ssistent
PMMA	**P**oly**M**ethyl**M**eth**A**crylate
RFID	**R**adio **F**requency **I**dentification
SPP	**S**erial **P**ort **P**rofile
STB	**S**et-**T**op **B**ox
TV	**T**ele**v**ision
UHF	**U**ltra **H**igh **F**requency
USB	**U**niversal **S**erial **B**us
WAN	**W**ide **A**rea **N**etwork
WLAN	**W**ireless **L**ocal **A**rea **N**etwork
WPAN	**W**ireless **P**ersonal **A**rea **N**etwork

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1 Introduction

1.1 Motivation

The share of the European population aged over 80 years is expected to reach 6% by 2025 and 10% by 2050 (Steg et al., 2006). The fact that there is a steady increase in the number of elderly people in the next decades has deep economic and social impact on different areas. Especially the pension and the healthcare systems are forced to provide new solutions to cope with the challenges and problems that come along with an aging society.

The amount of chronically ill and impaired elderly people will increase due to the demographic change. Therefore, technological and social-economic innovation can help to enhance the quality of life for elderly people. One of the main factors to rate quality of life is the ability to live independent and remain integrated in social life as long as possible. "*For elderly people, home is a place of memories where they want to spend most of their time.*" (Takács & Hanák, 2007). Therefore, new technologies and services in the context of Ambient Assisted Living (AAL) are becoming more and more important nowadays.

1.2 Ambient Assisted Living

Ambient Assisted Living offers technological solutions to reach the following goals. Firstly, it facilitates a social advantage which increases the quality of life of elderly people at home. Secondly, it decreases costs for caretakers, personal nursing services or the transfer to nursing homes. Thereby, AAL wants to increase benefits for the individual (increasing safety & wellbeing), the economy (higher effectiveness of limited resources) and the society (better living standards) (Steg et al., 2006). AAL systems should provide more security and autonomy, complements social contact and includes medical assistance without being a total surveillance intrusing privacy and replacing contact with people (Georgieff, 2008). *Steg et al.* proposes the following areas where AAL applications are used:

- Health
- Safety/Security
- Peace of mind

- Independence
- Mobility and
- Social contact

Thus, the scope of AAL applications is very broad and the potential for technological solutions in this area is tremendous.

1.3 Monitoring of Activities of Daily Living

One important aspect of AAL is to detect and react on changes in mental constitution. Changes in daily behavior such as sleeping, housekeeping, entertainment, food preparation, and exercises can be indicators for physical or mental problems, especially in elderly people. The major challenge is to accurately measure specific Activities of Daily Living (ADL). This provides health researchers with information to implement strategies for encouraging people’s behavior related to diet, exercise and medication adherence. (Tapia, 2003). Figure 1.1 illustrates an overview of basic ADL. ADL are “*the things we normally do in daily living including any daily activity we perform for self-care (such as feeding ourselves, bathing, dressing, grooming), work, homemaking, and leisure*“ (MedTerms, 1998).

Figure 1.1: Overview of Activities of Daily Living (ADL)

Apart from the basic ADL there are also instrumental ADL (IADL). IADL are not necessary for fundamental functioning but they let the individual live independently in a community. IADL are activities such as doing light housework, preparing meals, taking medications, shopping, using the telephone or managing money.

Health professionals are able to make statements about physical and mental status due to changes in the ability or inability of performing ADL. Various studies such as proposed by *Spenkelink* (Spenkelink et al., 2002) showed that there is a difference in the ADL pattern if people suffer pain. Information about these changes is often received through periodic questionnaires. Questionnaires are not accurate enough due to the subjectivity of people’s answers. Therefore, health researchers need technology which helps to collect the necessary sensor data to detect activities and patterns of behavior in actual homes (Tapia, 2003).

1.3.1 Overview of existing technologies

In this section an overview of existing technologies for the recognition of ADL is given. In literature there are two main approaches for the recognition of ADL.

The first approach uses objects in people’s environment to recognize certain activities which are performed when interacting with these objects. This is realized by Radio Frequency Identification (RFID) technology. The following section provides a comparison of different radio frequency ranges.

Low Frequency Range (LF, 135kHz)

RFID-systems in the Low Frequency (LF) range, work on the principle of inductive coupling. The most common frequency is at 135kHz. One of the main characteristics of LF RFID-systems is that they are much less affected by materials compared to High Frequency (HF) and Ultra High Frequency (UHF) based systems. The field is able to penetrate materials like water or body tissue, which makes it suitable for ADL recognition. The limitations are that LF systems can interfere with electric motors in industrial environments. Data transfer rates are low, compared to HF and UHF technologies. Furthermore, only one tag can be read at once.

High Frequency Range (HF, 13,56MHz)

HF systems operate at 13,56Mhz, which is an international standardized and globally accepted frequency. HF signals are also able to travel through most materials including body tissue, water and glass. However, there is a bigger disadvantageous effect of surrounding metals compared to low frequency. The communication speed is higher and the size of antenna coils is smaller than LF antenna sizes. This makes it possible to produce embedded microstrip antennas. HF systems are able to read multiple tags at once. The reading range is less than one meter. One more positive fact is that HF tags have a higher memory capacity.

Ultra High Frequency Range (UHF)

UHF systems operate at the frequencies 868 MHz (Europe) and 915 MHz (USA). Due to the short wavelengths of these frequency ranges, it is possible to design antennas with smaller dimensions and better performance than the frequency ranges below 30 Mhz. RFID systems in the UHF range are also called Backscatter-systems. Backscatter-systems use the reflection of electromagnetic waves for the data transfer between transponder and reader (Finkenzeller, 2002).

The second approach for the recognition of ADL assumes that the activity is defined by motion of the body during its execution. (Stikic et al., 2008). Hereby, uniaxial and triaxial accelerometers are used. The accelerometric technology is based on the piezoelectric effect. Mechanic force is put on a piezoelectric element, due to body acceleration. The force is transformed into electricity and a ceramic element within the accelerometer is reacting with a voltage induction. The voltage is then converted into 'Counts' (unit of accelerometric data) and recorded (Schröckenfuchs, 2009).

Fishkin et al. presented a glove (Figure 1.2) that detects when a user interacts with unobtrusively tagged objects (Fishkin et al., 2005). The research proposed a system that consists of an RFID reader, power supply and a wireless unit. The used SkyeTek M1 (SkyeTek[1], Denver, Colorado, USA) 13.56Mhz reader was able to detect RFID tags. To report sensed events, a Mica2Dot mote radio (Crossbow Technology Inc.[2], Milpitas, California, USA) sent data to a PC base station which was 15 to 30m away. For the power source a rechargable Lithium Polymer battery with a Universal Serial Bus (USB) charge system was used. Several measurements with volunteers, who wore the glove and conducted a variety of daily houshold tasks, were performed. The results showed that both false negatives (a missed touch of an object) and false positives (accidental touches of an object) occurred. Taken together the glove was able to track object use both unobtrusively and effectively but challenges remain with the accuracy of the system.

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[1] www.skyetek.com

[2] www.xbow.com

Figure 1.2: Intel's 'iGlove' (Fishkin et al. 2005)

Czabke et al. presented the iActionlogger system as another possible approach for monitoring of ADL (Czabke et al., 2010). Hereby, 2.4 GHz radio modules were used to detect interaction with objects. The system contained four different device types:

- Active motes,
- Passive motes,
- A basis mote,
- and the initializing device.

Figure 1.3 outlines the system architecture in normal operation mode.

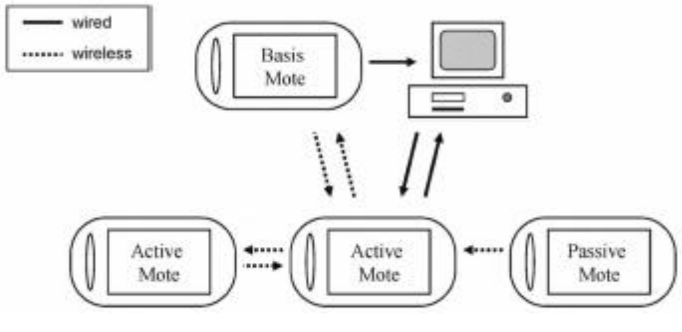

Figure 1.3: iActionlogger system architecture in normal operation mode (Czabke et al., 2010)

Within an experiment three test persons were equipped with an active mote and asked to perform different tasks. The tasks included e.g. getting a cup of coffee or going to the printer to pick up a paper. To recognize the activities, objects in the test environment were marked with active and passive motes and their transmission range was set using the initializing device. The results showed that the system meets the defined demands regarding the usability. The possibility to mark objects without attracting attention is another benefit of the proposed system. However, there were restrictions concerning the use of the 2,4GHz radio frequency. 2,4GHz radio waves are influenced by materials such as water or body tissue. Another disadvantage was that the active motes needed permanent power supply.

Combining the approaches of tagging objects and using accelerometers for the recognition of ADL was proposed by *Kim* (Kim et al., 2007). Three triaxial accelerometers were worn on wrist, thigh and waist. The accelerometers on thigh and waist detected body states like standing, sitting, lying, walking and running whereas the wrist accelerometer was used to detect hand motion. A HF RFID reader of 13,56Mhz was integrated in a glove. The accelerometers sent their data wirelessly via ZigBee[3]. The results of a trial showed that the overall recognition rate of twelve different ADL is over 97%. However, the reading distance of the RFID reader was only 50mm which turned out to be unsatisfying for practical usage.

Figure 1.4: ZigBee based triaxial accelerometers (left) and RFID reader glove with tagged object (right)(Kim et al., 2007)

Apart from using RFID technology for the recognition of ADL, approaches with other technologies have been found in literature. Several of these approaches were based on infrared sensors (Want & Hopper, 1992), (LeBellego et al., 2006). A system based on ultrasonic sound was proposed in (Harter et al., 2002), whereas computer vision technologies were proposed by *Uhrikova et al.* and *Kim et al.* (Uhrikova et al., 2008), (Kim & Medioni, 2008).

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[3] ZigBee is a low-cost, low-power, wireless mesh networking technology (www.zigbee.org)

1.3.2 Use Case dementia

A special use case regarding monitoring of ADL is the support of elderly people diseased with dementia. *“Dementia is a general term describing a group of disorders in which memory and thought processes (cognition) become impaired for a period of at least 6 months“* (MDGuidlines Reed Group, 2010). An early symptom of dementia is impaired memory. Furthermore, new skills and knowledge are difficult to learn and people start losing valuables such as keys or wallets. Usually dementia patients have little or no awareness of memory loss or other abnormalities. A system designed for dementia patients could analyze their ADL pattern and assist them to maintain the standard of living by switching alarms and reminders when it is necessary. Working as an assistive system, it could remind dementia patients of taking their medication, performing hygiene tasks, eating, drinking and interacting with their social environment. All technologies discovered in chapter 1.3.1 show possible solutions for the monitoring of ADL but do not provide opportunities to give feedback for the usage within dementia.

1.4 Background of the current thesis

Population aging is a global phenomenon and has major consequences for all facets of human life, including health and healthcare. *Wootton et al.* suggest that the incidence and prevalence of chronic diseases, such as cardiovascular disease, Chronic Obstructive Pulmonary Disease (COPD), and diabetes, continue to increase as we age (Wooton et al., 2006). Apart from the challenge of the increasing numbers of chronically ill people, there is an acute nursing shortage in many developed countries, including the United States, United Kingdom, Australia, and Canada (Paré et al., 2007).

Meystre points out that telemonitoring is the most promising application for the long-term disease monitoring of patients at home in order to reduce problems due to the increase of chronically ill people (Meystre, 2005). Telemonitoring uses information and communication technology for the transfer of physiological data such as blood pressure, weight, electrocardiographic details, and oxygen saturation from home to healthcare providers (Clark et al., 2007). Telemonitoring provides advantages for patients due to the daily collection of clinical data without the need for face-to-face contact between patients and healthcare providers. Furthermore, benefits for the whole healthcare system are generated. Therapy management can be adapted to the individual requirements and through monitoring of different important health paramaters the physician can identify an undesirable course of the disease. This avoids readmissions to hospitals and extraordinary treatment costs (Kumpusch H., 2009).

In (Morak et al., 2007) a home monitoring concept based on mobile phones and Near Field Communication (NFC) technology was proposed. Thereby, the Keep In Touch (KIT) technology, which allows the collection and forwarding of necessary health data for chronically ill and elderly people, was introduced. KIT ensures the intuitive aquisition of health data by touching the appropriate devices. Mobile phones equipped with NFC technology are becoming patient terminals just by touching the respective objects, which are also equipped with an NFC interface (see Figure 1.5).

Figure 1.5: KeepInTouch (KIT) blood pressure meter and NFC enabled KIT mobile phone

In order to utilize a „Closed Loop Principle“ with the opportunity for physicians to increase the compliance to a therapy, the KIT system was connected to a electronic health record developed by the Austrian Institute of Technology (AIT) (Ebner et al., 2009). Figure 1.6 shows the closed loop principle in healthcare. The collected data is sent to a service center, which is accessible by the physician. The physician can give telemedical advice and improve the treatment if necessary.

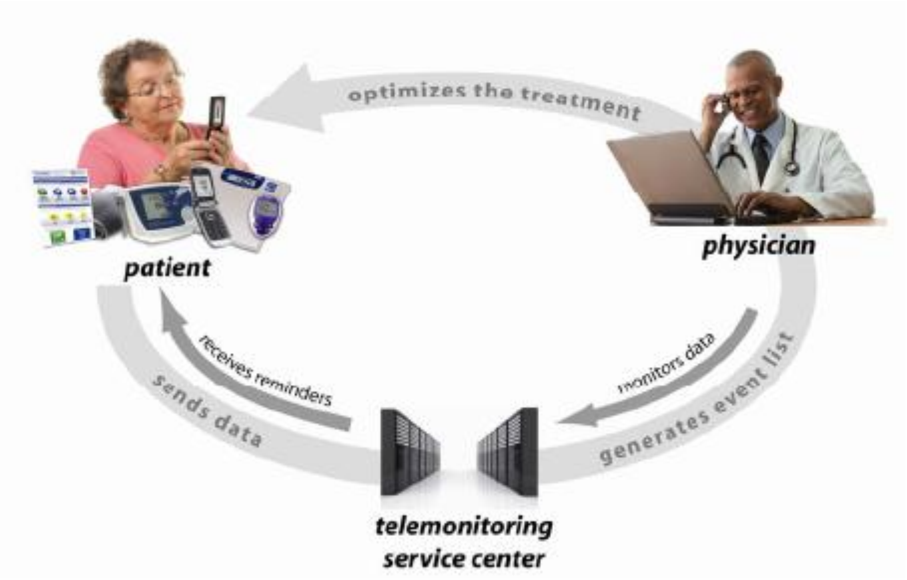

Figure 1.6: Closed loop principle in healthcare

The combination of KIT and Closed Loop Healthcare services results in an applied infrastructure for AAL. On the one hand, data acquisition in the environment of the elderly is possible. On the other hand, it allows the connection to relevant groups of care givers (Dohr et al., 2010). The feasibility of this approach has already been shown in (Drobics et al., 2009) where a system for the medication management of elderly people was introduced and a trial has been conducted.

The KIT technology has already been successfully used in various trials and is supposed to be a promising enabler for future healthcare and AAL developments.

1.5 Objectives of this thesis

A system for monitoring of ADL is the main objective of the current thesis. By taking a look at the state-of-the-art solutions in the context of AAL and telemonitoring of chronically ill people, two important issues have to be considered.

Firstly, a system to support dementia patients with their daily care, as described in chapter 1.3.2, is needed. The problem with the existing technologies is that they do not provide the opportunity to give feedback to the user and are not able to process health parameters such as blood pressure, weight or oxygen saturation. These parameters are important to monitor if dementia patients suffer from a chronic disease.

Secondly, the telemedical therapy management of chronically ill people at home has tremendous advantages for the patient and the healthcare system (see chapter 1.4). However, the proposed KIT technology has not been used in AAL scenarios where monitoring of ADL plays a role.

The following objectives for the current thesis arise from the problems described above. The feasibility for a system that integrates both support of daily care of dementia patients through monitoring of ADL and telemonitoring of chronic diseases should be investigated. Furthermore, a feasibility evaluation of the usage of the KIT technology for monitoring of ADL should be conducted. More precisely, a system that is able to monitor ADL and give visual and acoustic feedback about daily behavior and health status of a dementia patient should be developed. The system should be able to acquire health parameters from medical devices to ensure the front end functionality for telemonitoring purposes. Extensibility should be facilitated in terms of adding new health devices to the developed platform.

2 Methods

In the following, the concept for the integration of telemonitoring and ADL monitoring into an AAL platform is outlined. Starting point of the considerations is the view at the general design of AAL systems. Furthermore, different channels of communication between components in an AAL environment and possible wireless technologies for the implementation are described.

2.1 AAL system

An AAL architecture has to deal with a heterogeneous environment, due to the high variety of technologies of sensors and actuators. AAL systems are divided into three technical layers. There is one hardware layer with research topics in sensors, biosignal processing, wireless networks and interaction mechanisms. The middleware and architecture layer deals with data management, identification, data security and IT integration. A service layer at the top is responsible for business and process models (Kunze et al., 2008). Figure 2.1 depicts a generic overview of a three layer approach to enable communication and connectivity between devices and services in the area of AAL. The chart in Figure 2.1 and the explanations below are taken from the Ambient Assisted Living Roadmap of the AALIANCE[4]-The European Ambient Assisted Living Innovation Platform (Van den Broek et al., 2009).

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[4] www.aaliance.eu

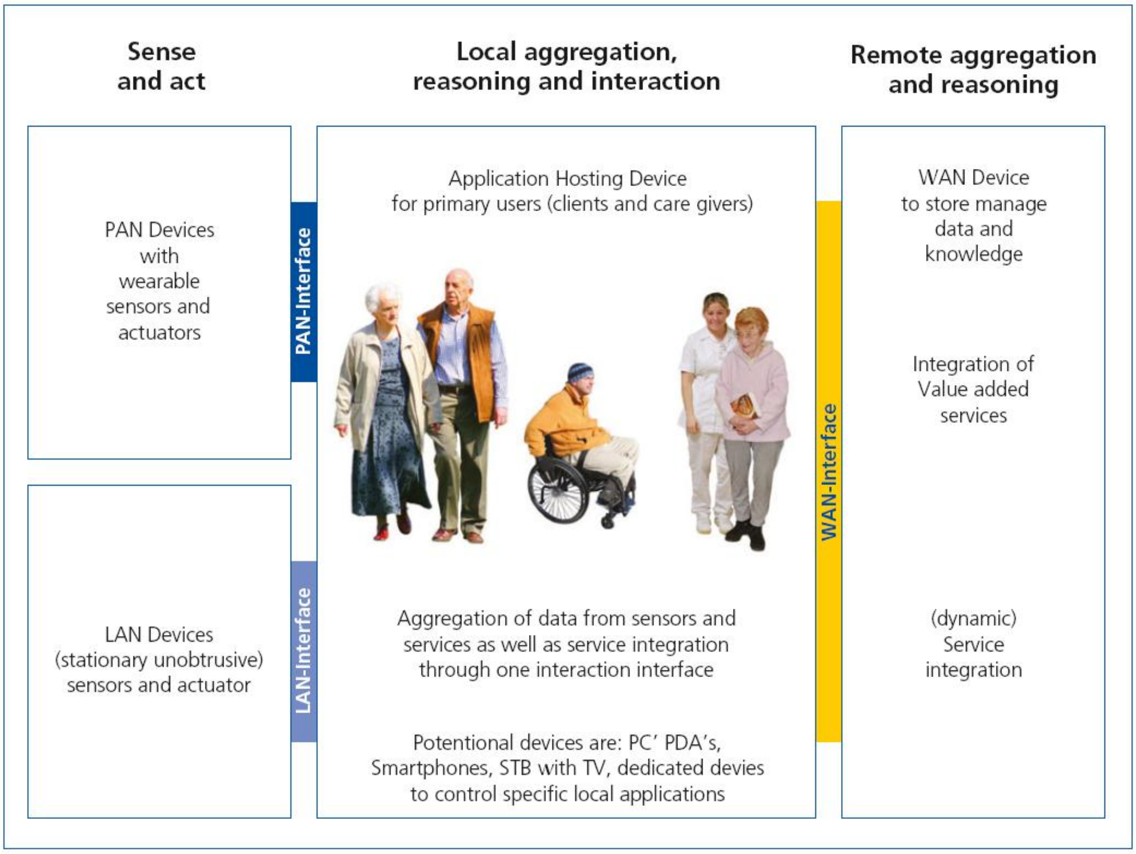

Figure 2.1: Communication and connectivity between devices and services in an AAL architecture; Application Hosting Devices: Personal Computer (PC), Personal Digital Assistant (PDA), Smartphones, Set-Top Box[5] (STB) with Television (TV)

Personal Area Network (PAN) devices collect raw data and provide local processing and aggregation of the collected data. For instance, PAN devices can be blood pressure monitors or scales that deliver vital parameters. Furthermore, they can also be objects in the ambient area, which are equipped with RFID tags making ADL monitoring possible.

The PAN interface is responsible to exchange data between different PAN devices and a host application device. In many AAL use cases this is realized by a secure and wireless connection, to facilitate the exchange of sensitive data (e.g. healthcare data). Local Area Network (LAN) devices are intended to be stationary and may be movable in a room. For example, these can be thermometers or barometers, which provide information about environmental factors.

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[5] A set-top box is a device that turns a signal of an external source into content to display it on the television screen

The application hosting device has several important functions, which include the communication with PAN and LAN devices to collect sensor data and send commands to the actuators. Furthermore, it manages the storage, the aggregation and the reasoning about the data. Additionally, the application hosting device, in the following referred to as home terminal, interacts with the user to present information and manages a remote data management service over a Wide Area Network (WAN) based Internet connection.

Remote data management services in an AAL environment store the collected data and share relevant information with other services. For example, the calculation of ADL profiles and the rule-based feedback about changes of the activity pattern of elderly people can be an issue.

2.2 Channels of communication

The practical part of this thesis focused on the communication and connectivity between PAN and LAN devices and a home terminal in an AAL scenario. The observation of the interfaces described in chapter 2.1 showed that there are four different channels of communication between the different components.

Context based information from RFID Tags

In this setup a device reads data from RFID tags, which are attached to different objects in the ambient area and store context sensitive data. This communication is especially interesting for the monitoring of ADL. Objects could be mugs/glasses or food labels in order to get information about nutrition and drinking. Toilet use could be monitored by arranging of an RFID tag with the flush button. Doors equipped with RFID Tags could detect access to different rooms and care for location information of the subject. When it comes to hygiene, the bath tub could also be equipped with a tag. Another opportunity is the usage of RFID Tags to realize a touch based user interface. Touching RFID tags within a menu card can be used for a simple food ordering solution.

Dynamic information from health devices

In this scenario health devices store the acquired vital parameters after every measurement. Chronically ill persons are requested to send their vital parameters to a telemonitoring station on a regular schedule. They need to somehow easily and intuitively acquire data in order to send it.

Temporary wireless connection between devices

Health devices, which are able to acquire biosignals via a live streaming channel, such as an Electrocardiogram (ECG) recorder does, need a temporary link with the terminal. This ensures the possibility of appropriate data processing at the terminal.

Permanent wireless connection between devices, sensors and objects in the ambient area (not within the scope of this thesis)

Another way of communication in an AAL scenario is the permanent wireless connection. Thereby, the sensors are equipped with a wireless module and permanent power supply. They are able to send data such as room temperature, humidity and other continuously captured parameters to the terminal.

2.3 Wireless technologies in AAL scenarios

Especially to communicate between the hardware layer and the middleware, wireless technologies play an important role in an AAL scenario. The following section gives an overview about important wireless technologies in healthcare and AAL settings.

Bluetooth

Bluetooth is a communication technology that allows wireless connection between devices and is intended to realize communication within a range of 10 to 100m. Bluetooth operates in the Industrial, Scientific, Medical (ISM) frequency band (2.402 GHz to 2.483 GHz). Transmission works packet oriented with a Time Division Multiplexing technique splitting the channel into 625µs slots. (Chevrollier & Golmie, 2005). There are a number of demonstration projects involving the Bluetooth technology for establishing healthcare environments. For example, *Kumpusch* showed a possible solution for the mobile phone based acquisition of electrocardiograms for telemonitoring (Kumpusch et al., 2010).

Bluetooth has been selected by the Continua Health Alliance as a standard for wireless technology in the telehealth sector. Due to moderate power consumption, small size, low cost and integration in mobile phones, Bluetooth was chosen to satisfy the required use cases (Bluetooth Special Interest Group Inc., 2009).

ZigBee

ZigBee is based on the IEEE 802.15.4-2003 standard and intended to be a wireless communication specification simpler and less expensive than other technologies, such as Bluetooth. The name of the brand is originated with reference to the behaviour of honey bees after their return to the beehive[6]. The IEEE 802.15.4-2003 standard supports low-power applications very limited battery consumption requirements and short range operation (10m). The specification comprises the slotted and unslotted variation and describes three different frequency bands. (Chevrollier & Golmie, 2005)

- 1 channel in the (868 to 868.6) MHz band
- 10 channels in the (902 to 928)MHz band
- 16 channels in the (2400 to 2483.5)MHz band

Taken together, ZigBee receives more and more attention in healthcare applications. *Dagtas* proposed a system for real time health monitoring via ZigBee in Smart Homes. ZigBee was used to acquire vital data within the Body Area Network (BAN) as well as transferring data within the Wireless Personal Area Network (WPAN) (Dagtas et al., 2007).

WLAN

Wireless Local Area Network (WLAN) was specified by the IEEE 802.11 group of standards. A WLAN is intended to connect electronic devices to each other, to the Internet and to wired networks which use Ethernet technology. They operate in the 2.4 and 5 GHz radio bands, with some products that contain both bands (dual band) (Wi-Fi Alliance®, 2010).

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[6] http://en.wikipedia.org/wiki/Waggle_dance

Many healthcare applications, such as patient monitoring in nursing homes or hospitals, require reliable monitoring of patients. Often, hospitals already provide infrastructure-oriented wireless networks. *Varshney* demonstrated how WLANs, based on variants of IEEE 802.11, can be used to support patient monitoring in diverse environments. However, he also pointed out that there are many limitations in using WLAN as far as security and multicast support is concerned (Varshney, 2006).

Thus, using WLAN technologies in their originally intended use is the adequate approach by now. In an AAL scenario, WLAN plays a key role in transferring data from data processing modules via the Internet to higher layers within the AAL system architecture.

RFID

RFID is “*a method for uniquely identifying an object using a tag or module that carries a unique ID number, or code. Identification can be made using wireless (RF, or radio-wave) connection, meaning no line-of-sight or physical contact is needed*“ (Maxim Integrated Products, 2010).

One of the most important characteristic of an RFID system is the operating frequency and the resulting range of the system. Basically, there are three different frequency bands: LF (low frequency, 30 kHz … 300 kHz); HF (high frequency, 3 MHz … 30 MHz); UHF (ultra high frequency, 300 MHz … 3 GHz). RFID systems can be active or passive. Within passive RFID systems the transponder is power supplied by the RFID reader, whereas transponders in active systems include a battery to supply the microchip on the RFID tag (Finkenzeller, 2002).

One of the major growth areas of RFID is healthcare. RFID technology enables smart hospitals as it was proposed by *Fuhrer and Guinard*. One possible use case in hospitals is the tracking of equipment, patients, staff and documents. Another possible application area is avoiding thefts of medical equipment. (Fuhrer & Guinard, 2006)

NFC

Near Field Communication (NFC) is a short range wireless technology to exchange data between two devices. Basically an NFC connection is established just by bringing two devices close together. It uses magnetic induction where 2 loop antennas are influencing each other and forming an air-core transformer. NFC operates in the unlicensed frequency band of 13,56Mhz within a short range of typically 5 up to 10 centimeters. Market researchers predicted that that by 2012 20% of all sold mobile phones will be NFC enabled. Mobile phones would become the largest infrastructure for RFID readers worldwide (Wiechert et al., 2006). The benefits of NFC technology for the health sector have already been proven in various studies. For example, NFC technology can be used to acquire data from medical devices in the home environment (Morak et al., 2007). The project *PDR-Eval* (Drobics et al., 2009) used NFC technology to support elderly people in their medication management, and helped to increase the accuracy of medication intake schedules.

2.4 AAL platform overview

The following section shows one possible solution to realize an AAL platform for the acquisition of health data as well as data in the context of ADL. Figure 2.2 gives an outline of the components that were used to handle an AAL use case. The relevant components and interactions, which are within the scope of this thesis, are highlighted.

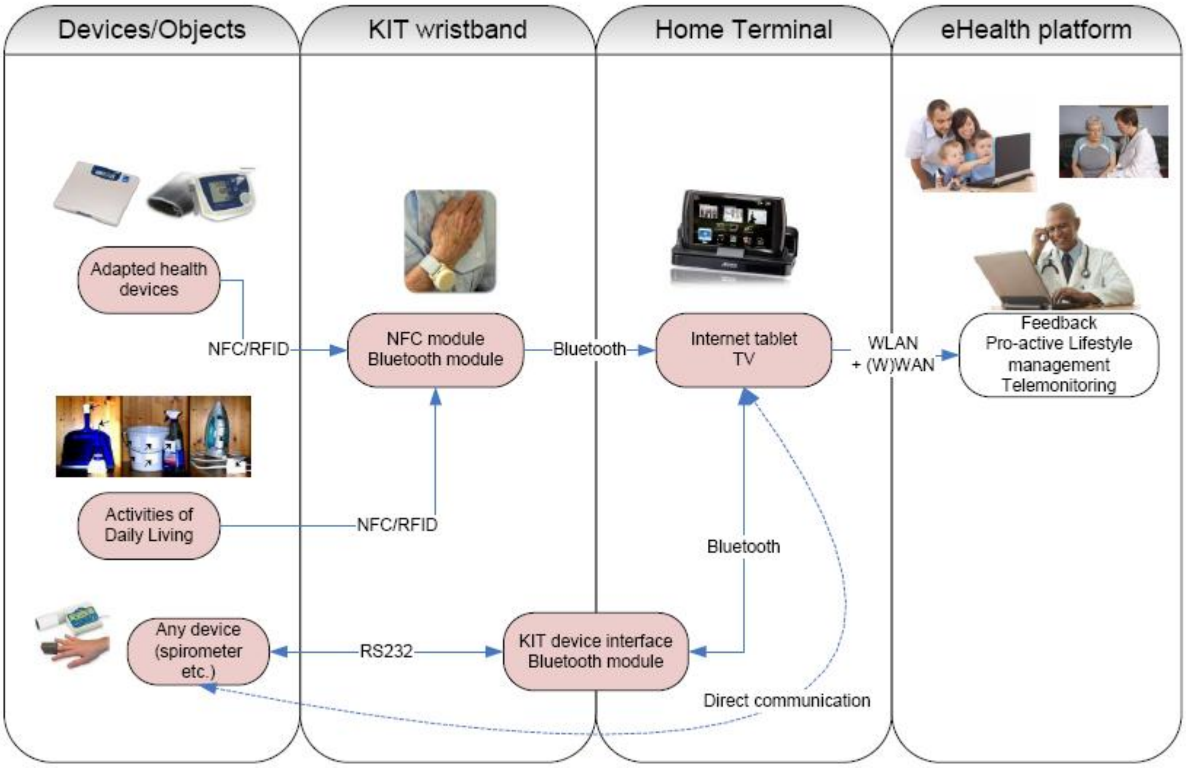

Figure 2.2: Detailed overview of the system that meets the need for AAL use cases. The relevant components and interactions, which are within the scope of this thesis, are highlighted.

To realize the required communication channels between the sensors and the home terminal, this thesis used an approach where a wristband, based on KIT technology, is worn permanently by the elderly person. According to *Fishkin* (Fishkin et al., 2005) a system to detect objects in the ambient area, should be unobtrusive. The user should be unaware that the system is at work. The system should require little maintenance and allow for inexpensive, incremental deployment. *A* wristband satisfies all these constraints being an unobtrusive device, which does not disturb people in their daily routine tasks. *Fishkin* also pointed out that RFID technology is the most ubiquitous approach for tagging objects compared to barcode and computer vision technologies (Fishkin et al., 2005).

In the first development step the KIT wristband, which is illustrated in Figure 2.2, was designed prototypically as a wand. The KIT wand worked as an intermediate section to receive data from different health devices and different objects in the home environment. The wand transmitted these data via a Bluetooth connection to the home terminal. The used technology to acquire data from devices and objects was NFC. NFC technology has already been proved to perform well within the KIT technology of AIT being realized in various studies and projects. Thus, NFC technology was chosen within this thesis to show the feasibility of the KIT wand.

Touching the objects enabled the NFC link and data were transferred. After this touch based trigger, indicated by the user, the KIT wand automatically established a Bluetooth connection with the home terminal realized by a tablet PC.

A tablet PC has a significant number of advantages, which makes it the most suitable device to work as a home terminal for the AAL system. The most important feature is the ability of connecting it to a TV set, which increases the usability and the acceptance. Elderly people are familiar with using the TV and the size of a TV screen can help to overcome optical disabilities. The touch based interface also makes sure that people can easily manage user inputs. Furthermore, integrated WLAN and Bluetooth make it suitable for realizing the required communication channels.

The Archos 5 internet tablet[7] (Archos Inc., Greenwood Village, California, USA) was chosen as the appropriate product for the prototype. Bluetooth connectivity, integrated WLAN and the opportunity to connect the tablet PC to a TV set were

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[7] www.archos.com

crucial features to choose the Archos 5. The operating system running on the Archos 5 was Android[8]. Android is an operating system for mobile devices, which allows developers to write managed code in the Java language.

Bluetooth is an accepted standard for wireless communication. It offers a lot of profiles and is integrated in many off-the-shelf tablet PCs. Thus, it was the best approach to use Bluetooth within the first prototype. However, bad energy performance compared to other communication standards and the need to actively pair devices, have to be considered.

Using the KIT device interface offered the opportunity to connect a various set of devices to the AAL platform. After a Bluetooth link between the KIT device Interface and the home terminal was established, the home terminal was able to communicate directly with the device. A transparent communication channel using the Serial Port Profile (SPP) managed the data transfer.

A user interface, running on the home terminal, interprets the incoming data and gives direct feedback on health status and activities of daily living. The home terminal is placed in an often used room (living room) at home and continuously scans the area for incoming Bluetooth links (idle mode). Through a web connection with the AIT eHealth platform (Ebner et al., 2009) which has already been adopted for the usage in a web-based telemonitoring management environment, a far reaching healthcare loop can be closed. This opportunity involves physicians, family members, care institutions and compliance management systems.

2.4.1 Components

The next sections introduce the components and technologies that were utilized in the technical setup, described above.

KIT device interface

The KIT device interface platform was responsible for the temporary communication between health devices and the home terminal. Especially with devices that deliver a huge amount of data within a short time range, it was necessary to stream data directly to the home terminal, instead of just storing some parameters on an RF-

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[8] www.android.com

ID Tag. To deal with this issue a device interface has been developed. It provides the opportunity to plug in a variety of devices in a plug and play manner. The device interface automatically detected which kind of device has been plugged-in. As soon as the home terminal connected to the Bluetooth module, which is integrated in the KIT device interface, a transparent Bluetooth connection between the device and the home terminal was established. To trigger the start of the Bluetooth connection, the KIT wand sent pairing parameters, acquired through an RFID Tag stuck on the device interface.

KIT wand

The KIT wand was the central unit in the scenario realized in this thesis. It was worn by the elderly person and manages all the possible connections between the modules in the AAL scenario. One main task was the monitoring of ADL by reading data from context based RFID Tags. Another task was the acquiring of dynamic health parameters from adapted health devices such as blood pressure meter or scale. This process was done by touching the objects or devices respectively. Another important responsibility of the KIT wand was sending of the collected data via a Bluetooth connection to the home terminal for further data processing and interpretation of the data.

Home terminal

The home terminal, which was realized by a tablet PC from Archos (see Figure 2.3), is the only visible interface to the user. It processes all the data, which has been acquired by the KIT wand. Furthermore, it is able to interpret data and give feedback to the user in an easily comprehensible way. The home terminal is also responsible for showing reminders and alarms which come up during ADL recognition or telemonitoring of diseases. Through a web-based connection it is possible to get feedback from a physician who is also connected with the eHealth Platform (Ebner et al., 2009).

Figure 2.3: The Archos 5 internet tablet used as home terminal

Adapted BPM/scale/pulse oximeter

In order to make an off-the-shelf blood pressure meter, a pulse oximeter and a scale providing the adequate data for the processing through the KIT wand, they were equipped with an NFC module (Morak et al., 2007) and an RFID tag (Mifare, NXP Semiconductors[9], Eindhoven, Netherlands). After every measurement, the NFC module communicates with the hardware of the health device in order to get the value of the last performed measurement and saves it on the RFID tag. During intuitive touching of the device, the KIT wand obtains the most recently saved data record from the tag.

Figure 2.4: KIT enabled blood pressure monitor (UA-767 Plus NFC, A&D[10],Tokyo,Japan)

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[9] www.nxp.com

[10] www.aandd.jp

Figure 2.5: KIT enabled pulse oximeter MirOxi (MIR - Medical International Research[11], Rome, Italy)

2.5 Evaluation

2.5.1 RFID Technologies

The prototype realized within this thesis is based on the KIT technology. KIT is using NFC technology to intuitively acquire vital parameters by touching devices. To show the feasibility of applying the KIT technology for ADL monitoring, it was used apart from telemonitoring of chronic diseases. Since NFC technology has a limited operating range of a few centimeters, it is not the best approach to use it for ADL recognition. The operating range is the maximum distance an RFID reader can either write or read data from the tag. ADL monitoring should work unobtrusive without the user engaging actively with the data acquisition process. The evaluation of different RFID technologies is essential, to find out the best approach for ADL monitoring. To evaluate the different RFID frequency ranges, the following setup was utilized and all measurements were performed in the RFID Center of TAGnology RFID GmbH[12].

Low Frequency System

In order to measure the behavior of LF RFID systems, the TAGindustry LF 125kHz (Figure 2.6) (TAGnology RFID GmbH., Voitsberg, Austria) first was used to obtain an objective overview about the possibilities of a LF system regarding maximum reading distance.

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[11] www.spirometry.com

[12] www.tagnology.com

Figure 2.6: TAGindustry LF 125kHz reader from TAGnology

The device reads 125kHz read-only tags that comply with the EM400x or EM410x standard. The read-only tags were responding with their serial number when they are successfully read. The minimal distance was evaluated in this setup.

To measure the frequency behavior of a LF system that is influenced by different materials, a series of measurements was performed. The equipment for the following tests included the IberWave RTS200.RFID Test Set (S/N 0002.0057) and the Software tool RTS Tag Analyzer from IberWave[13] (Iberwave Ingeniería SLL, Madrid, Spain), all provided by TAGnology.

Figure 2.7 illustrates the measurement setup with the IberWave hardware and the specific reader antenna.

Figure 2.7: IberWave RTS200 RFID Test Set with reader antenna

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[13] www.iberwave.com

High Frequency System

For measurements of HF RFID technology, the same equipment as with the LF measurements was used, except of changing the LF reader antenna into a HF antenna and changing the appropriate parameters in the RTS Tag Analyzer software.

Ultra High Frequency System

To find out the performance of UHF systems, influenced by different materials, some more results have been produced. At the beginning a set of different transponders was evaluated in order to obtain the tag with the highest transponder reflection power at a given setup. The tag was not attached to any material and placed directly on the reader antenna. Figure 2.8 gives an overview of the tested transponders.

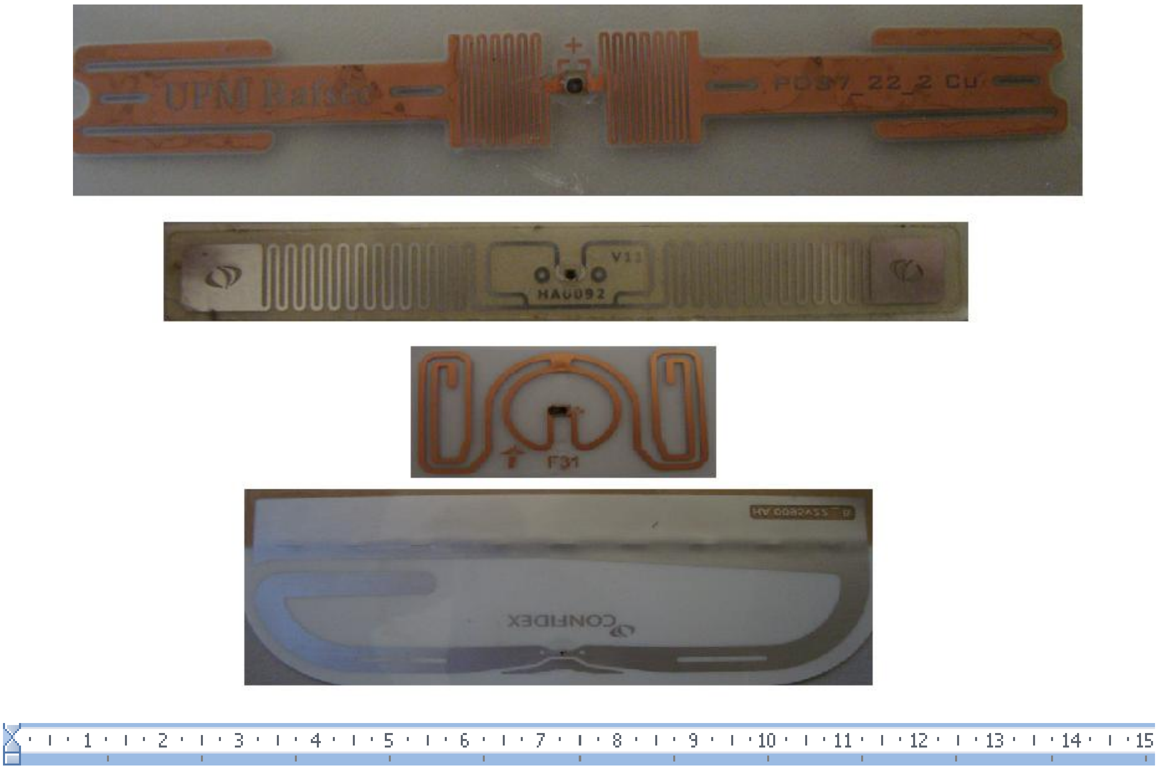

Figure 2.8: Repertory of UHF tansponders tested with the IberWave RFID Test hardware

2.5.2 Energy performance

Energy consumption is a main criterion for the usability and performance, because the KIT wand is switched on permanently, when in use. As it is equipped with a rechargeable Lithium Ion battery, it is necessary to keep the energy consumption low in order to keep the operational time between charging high. The evaluation of the prototype included electrical current measurements of the KIT wand prototype, which showed the current flow within the different states of the KIT wand. The current was measured with the Agilent technologies DS01012A[14] oscilloscope (Agilent Technologies, Santa Clara, California, USA) by voltage measurement on a 1 Ohm resistor. Figure 2.9 shows the principal measurement circuit.

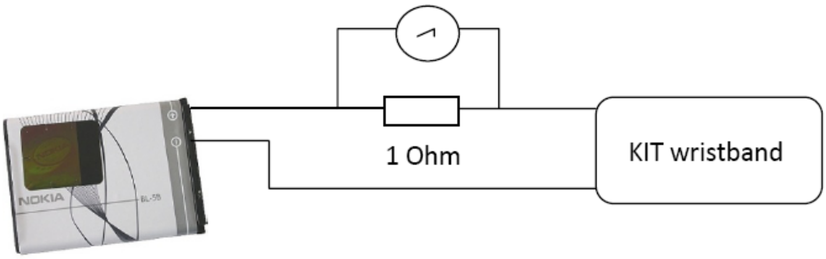

Figure 2.9: Principal circuit for current consumption measurement of the KIT wand

2.5.3 Feasibility

The following sections introduce the test methods that have been performed with the prototype of this thesis. Firstly, an NFC range test was utilized. Secondly, the feasibility of the KIT wand for the recognition of ADL and the acquisition of health data was inspected. Finally, the maximum Bluetooth range of the prototype was determined.

NFC range

Within this experiment, the reading range of the NFC module on the KIT wand was examined. The following test setup was utilized. Beginning at a distance of ten centimeters the tag was placed above the KIT wand and brought closer to the RFID

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[14] www.agilent.com

tag with every measurement. The maximum reading distance of the NFC module results from the first successful acquisition of data from the tag. Figure 2.10 gives an overview of the test setup.

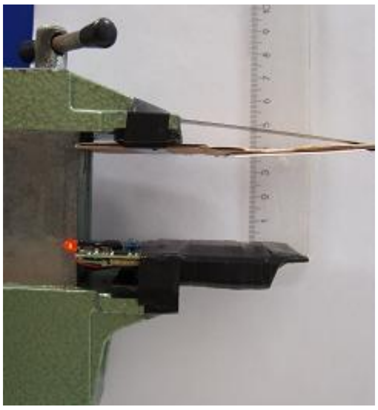

Figure 2.10: NFC range test setup: KIT wand parallel to RFID tag

Furthermore, the KIT wand was placed in different angles to the RFID tag. This was to obtain the maximum NFC range depending on different angles between the KIT wand and the RFID tag. Figure 2.11 outlines the test scenario.

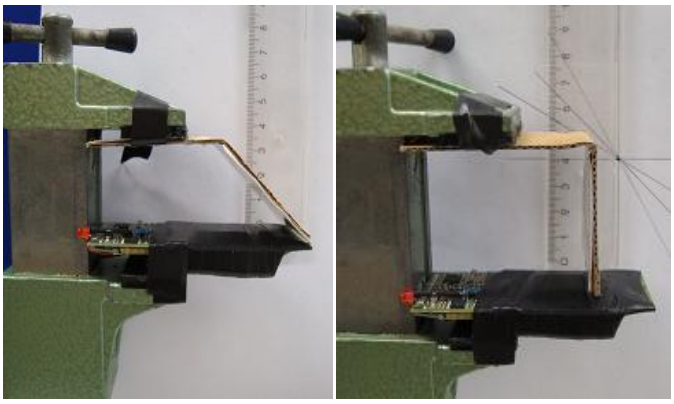

Figure 2.11: NFC range test setup: KIT wand in different angles to RFID tag

Performing ADL tasks

To show the feasibility of the developed prototype, a test environment similar to a real application scenario has been utilized. A standard living area was prepared for the usability tests, which are described in the next sections. Therefore, the home terminal was placed at an easy accessible position in the living/dining room next to the TV set. The knobs of a dishwasher and a cupboard, the remote control, the entrance door, as well as a kettle full of water were equipped with configured RFID tags. Figure 2.12 shows the test environment for the feasibility test. Figure 2.13 outlines the adapted objects and devices in the test environment.

Figure 2.12: Test environment for the feasibility test of the KIT wand

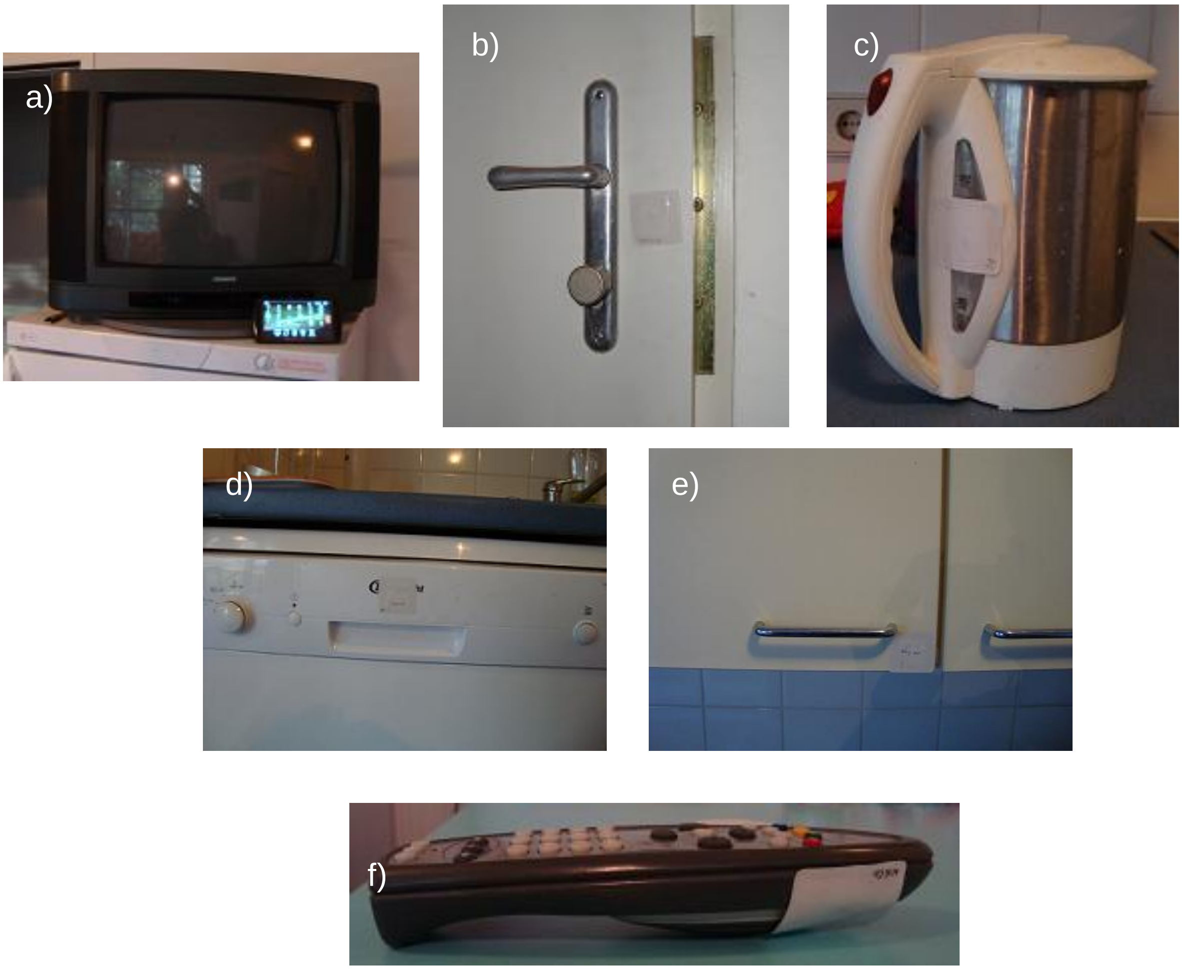

Figure 2.13: Adapted objects in the test environment: a) Home terminal next to TV set, b) entrance door, c) kettle, d) dish washer, e) cupboard, f) remote control

To show the feasibility of the KIT wand while performing ADL tasks, five test persons were equipped with the KIT wand. Therefore, it was attached on their wrist through a bag. Figure 2.14 shows the KIT wand attached to the wrist.

Figure 2.14: KIT wand attached on the wrist

The test persons were asked to do the following tasks while wearing the KIT wand:

1. Open the dishwasher and take out some plates
2. Open the cupboard and put the plates in it
3. Close the cupboard
4. Close the dishwasher
5. Take the kettle and fill a glass of water
6. Watching TV (using the remote control)
7. Leave the room through the entrance door

Part one of this feasibility test was to show, if the events are recognized by the KIT wand. This was examined through the red LED on the KIT wand, which stopped blinking when processing read data and again started blinking after successful operation. The second part of this feasibility test was to show, if the collected data was sent to the home terminal via Bluetooth. Therefore, the software application on the home terminal was running and the recognized events were shown as a text message on the screen.

Acquisition of health data

In order to show the feasibility of the acquisition of health data from devices, the pulse oximeter MirOxi, the adapted blood pressure meter and the scale (see chapter 2.4.1) were used. The MirOxi, and the scale were connected to a KIT box, which was developed by AIT to enable them for NFC functionality. Five test persons were asked to perform the following tasks, while wearing the KIT wand on their wrist:

1. A) Turn on the MirOxi
   B) Put on the fingerclip sensor
   C) Start a measurement through the green button on the KIT box connected to the MirOxi
   D) After the measurement take off the fingerclip
   E) Touch the KIT box with the KIT wand

2. A) Turn on the blood pressure meter
   B) Start a measurement (press button START)
   C) Touch the device with the KIT wand
3. A) Turn on the scale
   B) Perform a weight measurement
   C) Touch the scale’s KIT box with the KIT wand

A successful acquisition of the appropriate data was examined through a verification of the text messages on the home terminal application after data have been sent via Bluetooth.

Bluetooth range

The Bluetooth range of the developed prototype was examined through the following test. Hereby, an RFID tag and the KIT wand were taken to different places within the test environment and data acquisition was performed by touching the tag with the KIT wand. To find out the maximum range, data acquisition was also performed outside the room where the home terminal was placed. Figure 2.15 illustrates the floor plan of the test environment and the spots, where data acquisition was performed.

Figure 2.15: Floor plan of the test environment

3 Results

3.1 *Prototype*

The prototype realized within this thesis, was able to support two different communication scenarios. Firstly, intuitive data acquisition from health devices and monitoring of ADL were performed through the developed KIT wand and data were transferred via Bluetooth to the home terminal. Secondly, the KIT wand was used as a trigger to initialize a communication between the KIT device interface and the home terminal.

Figure 3.1 outlines the interaction diagram and data flows between the adapted health devices, the KIT wand and the home terminal. The interaction between the components was based on wireless technologies (NFC, Bluetooth). Interaction 1) and 2) dealt with the establishment of a connection between KIT enabled health devices and object tags through the KIT wand. Interactions 3), 4) and 5) dealt with the establishment of a Bluetooth connection between the KIT wand and the home terminal respectively.

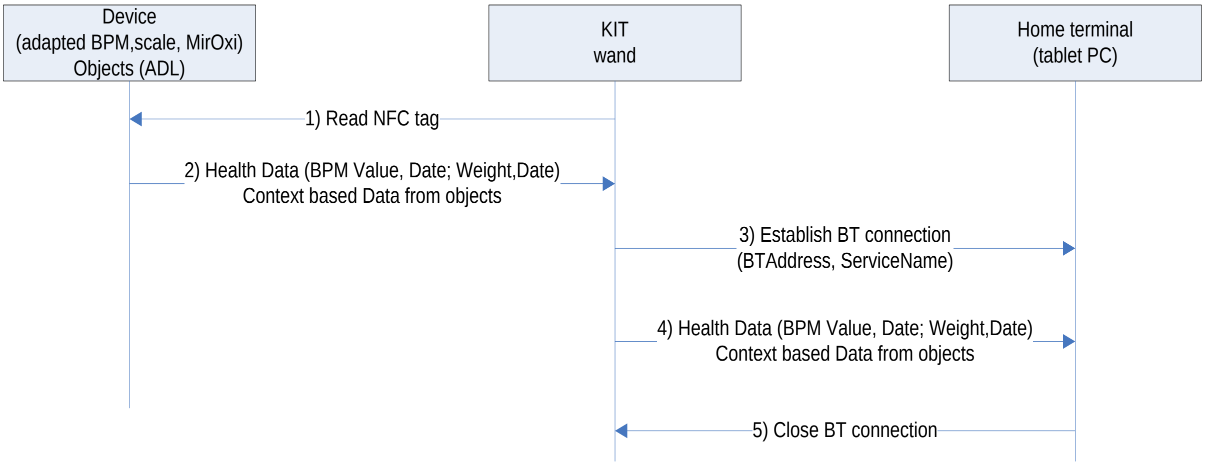

Figure 3.1: Interaction diagram showing the data exchange between devices, KIT wand and home terminal

Figure 3.2 shows the establishment of a point-to-point Bluetooth communication between the KIT device interface and the home terminal. This link was established by using the KIT wand as a trigger that provided the home terminal with the required connection parameters.

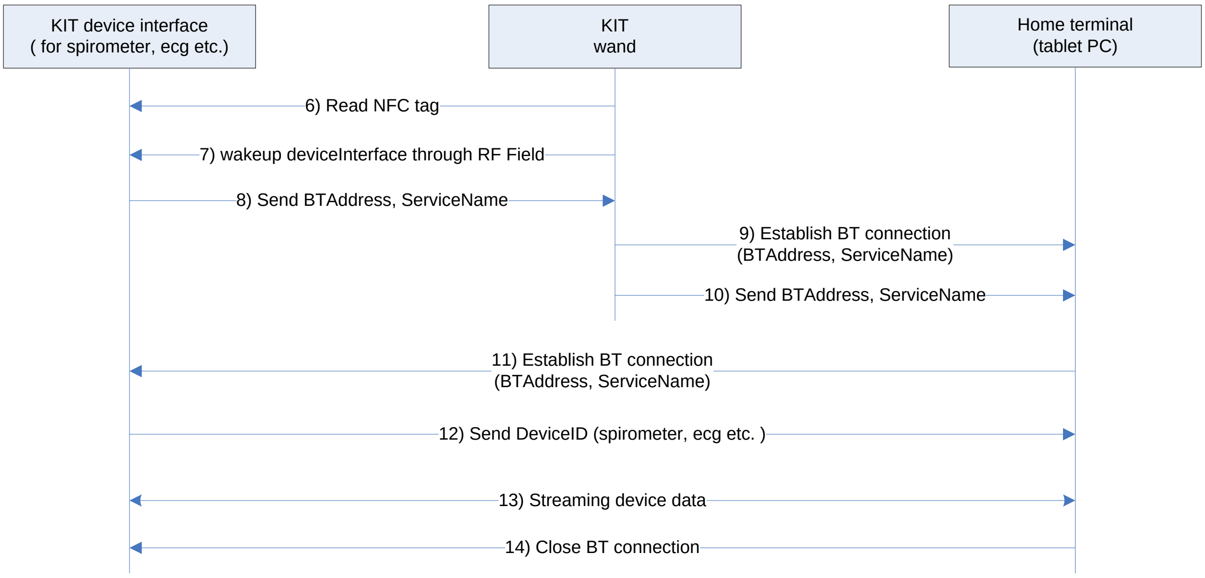

Figure 3.2: Interaction diagram showing the data exchange between KIT device interface, KIT wand and home terminal

3.1.1 KIT wand

A KIT module for the communication between the home terminal and health devices as well as object tags in the home environment was developed prototypically. This module can be integrated into a wristband, to ensure an easy and unobtrusive handling. Figure 3.3 shows a block diagram of the different components of the KIT wand. The NFC/RFID module was responsible for acquiring data from different objects and health devices by reading data from the RFID tags. The microcontroller MSP430F123 (Texas Instruments[15], Dallas, Texas, USA) worked as a central processing unit, which allowed dataflow between the NFC/RFID module and the Bluetooth module BNC4 (Amber Wireless[16], Köln, Germany). After a tag was read, the Bluetooth module tried to establish a connection with the home terminal and sent data via the secure Bluetooth channel.

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[15] www.ti.com

[16] www.amber-wireless.de

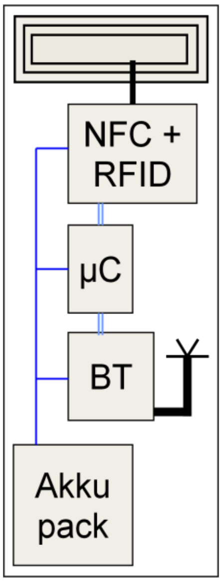

Figure 3.3: Block diagram that shows the components integrated in the KIT wand

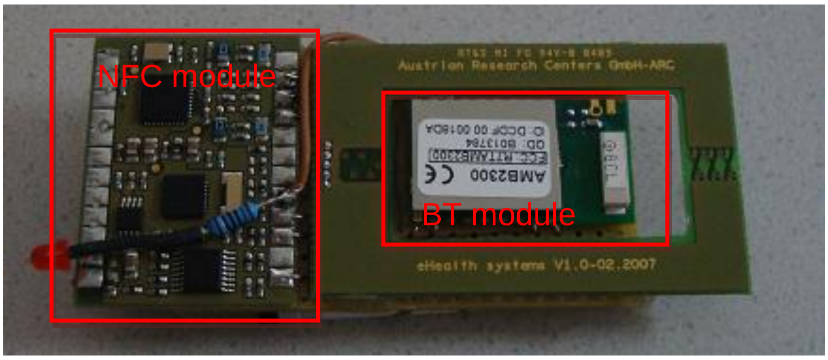

Figure 3.4: KIT wand prototype

In order to ensure the communication between the different modules on the KIT wand, a time oriented flow control was implemented on the microcontroller. At the beginning the controller jumped in low power mode (LPM) and the connected Bluetooth- and NFC modules were not activated. After a certain time (200ms) the controller woke up and scanned for RFID Tags. The data was read after a Tag was found and saved in the controller's memory.

The next step was to initialize a Bluetooth connection. Thereby, the Bluetooth module tried to connect with the master (home terminal) by establishing a default connection. The default connection was initially configured on the KIT wand so that a connection only with the home terminal was established. If there was no connection available at the moment, a minutes counter was started and the current timestamp (number of minutes since last unsuccessful try) was saved. This allowed handling of use cases, where there was no Bluetooth connection available although Tag data were acquired. The next time when the home terminal was reachable through Bluetooth, the data was sent with all records containing also timestamp information. Thus, the home terminal could evaluate the timestamps to determine when exactly an event occurred. This was important regarding the monitoring of ADL. To create a precise ADL profile one must know exactly at what time an activity was performed. The essential steps of this workflow are depicted in Figure 3.5.

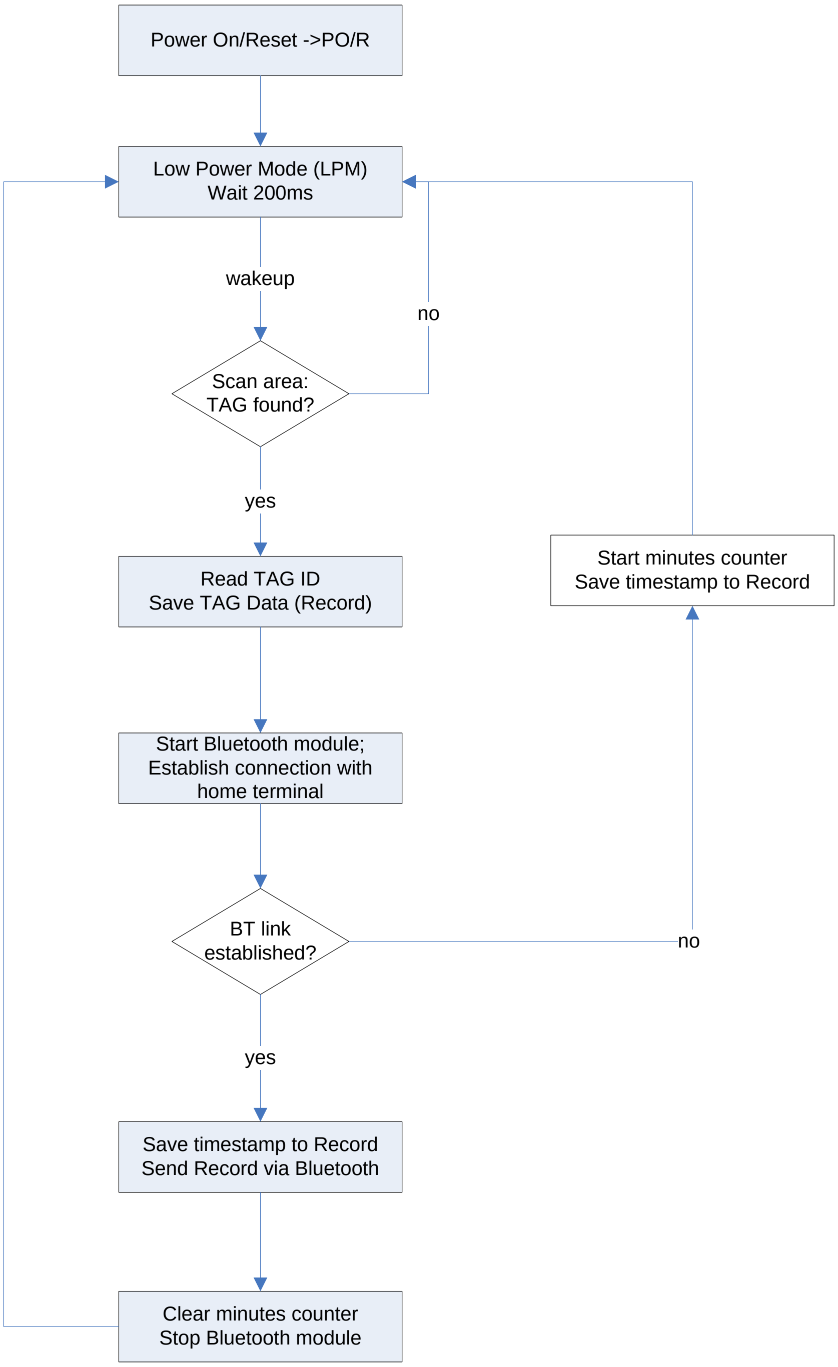

Figure 3.5: µController MSP430 flow control diagram on the KIT wand

3.1.2 KIT device interface

For the easy integration of further devices into the AAL platform, a KIT device interface, which is able to communicate with any connected device and the home terminal via a direct Bluetooth link, was developed. Figure 3.6 shows the components, which were embedded in the KIT device interface. The RFID Tag had to provide Bluetooth pairing information for the KIT wand, which transmitted the data through Bluetooth to the home terminal.

The home terminal was responsible for establishing of a Bluetooth link with the KIT device interface. The RF field detector woke up the µC from the LPM, if it detected an RF field.

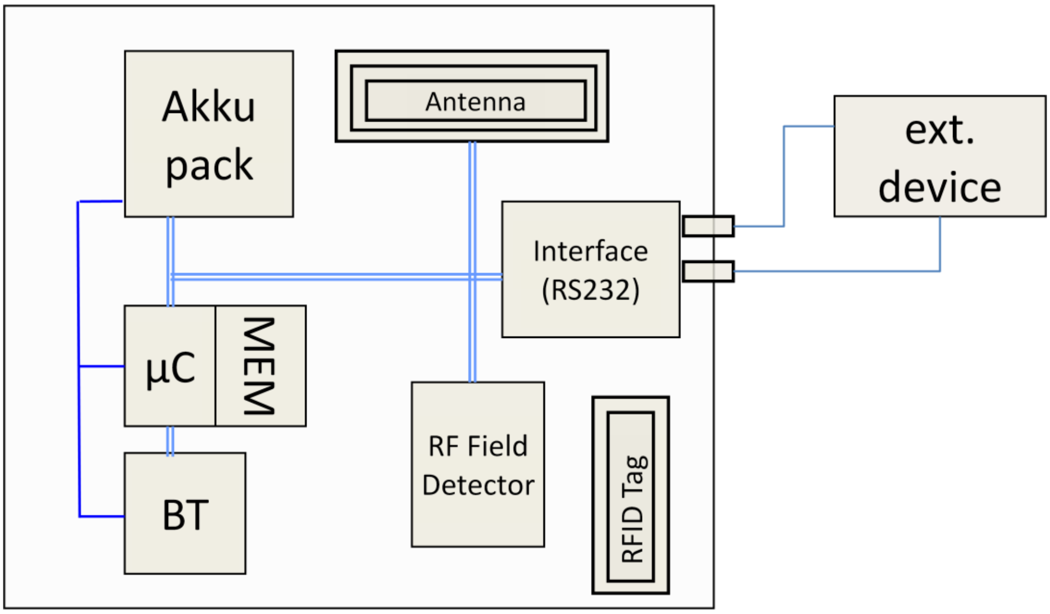

Figure 3.6 : Block diagram of the KIT device Interface

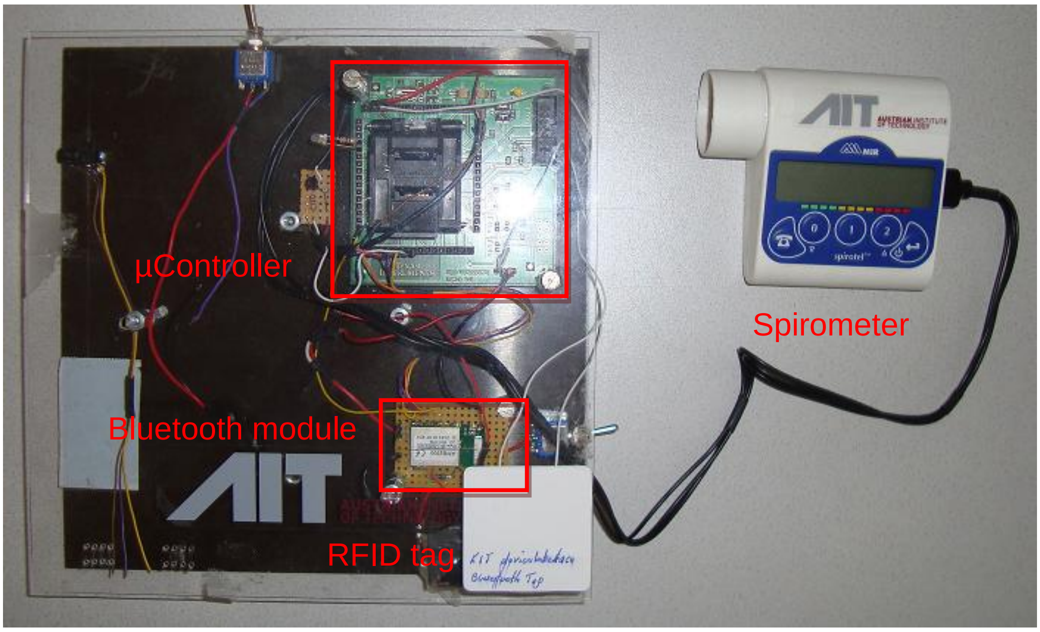

Figure 3.7: KIT device Interface with µController, Bluetooth module, RFID tag and the connected spirometer

The microcontroller waited in the LPM until an RF field was detected. This happened when the KIT wand touched the RFID tag at the KIT device interface to read Bluetooth specific data. Reading an RFID Tag generated an RF field which was detected by the integrated field detector. After waking up, the Bluetooth module started and was awaiting an incoming Bluetooth link for a time period of 10 seconds. If there was no Bluetooth link established within this time period, the controller entered the LPM again.

If a Bluetooth connection was established, the KIT device interface sent the specific device ID and the Bluetooth module worked in the *transparent mode*. All data was streamed directly to the connected device, using the *Serial Port Profile (SPP).* The end of transfer (EOT) command signalized the completion of the communication, which stopped the Bluetooth module and put the controller in the initial state (LPM).

For a detailed flow control of the µC program see Figure 3.8

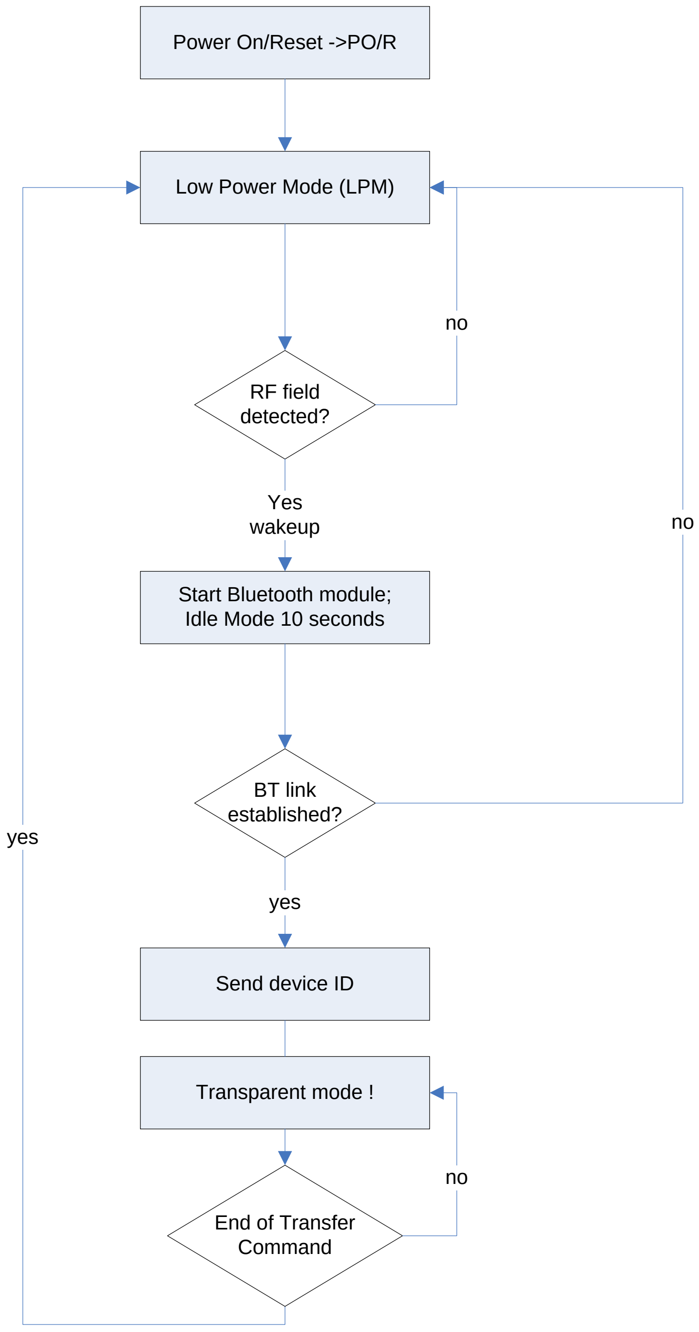

Figure 3.8 : µController flow diagram on the KIT device Interface

3.1.3 Android software application

The software, implemented on the internet tablet, integrated three core modules:

- Bluetooth communication
- Data handling
- Visualization

Bluetooth communication

This module implemented functions, which were responsible for the establishment of connections as well as communication between the home terminal, the KIT wand and the KIT device interface. The software was listening for incoming Bluetooth links from the KIT stick. The home terminal handled the data depending on the data sent via the Bluetooth link. The Bluetooth Communication module was also responsible for the link establishment with the KIT device interface to handle direct communication with medical devices.

Data Handling

The Data Handling module comprised functions for the handling of incoming data. The included TagParser class, was able to distinguish between data coming from an object tag, a medical device or the KIT device interface tag. The module also implemented a DeviceParser class, which offered functions to directly communicate with a medical device connected to the KIT device interface. A StorageManager class, which was not yet implemented, may provide functions to save data and make it available for further ADL profile calculations.

Visualization

This module was responsible for the graphical visualization of measurement results and feedback screens. A high end graphical user interface was not within the scope of this thesis. Therefore, the Visualization module was only implemented on a low level with the possibility to show events in text form.

3.2 Evaluation

3.2.1 RFID Technologies

The following section shows the results of the performed measurements, which provide information about the behavior of different RFID systems.

The green Light Emitting Diode (LED) on the TAGindustry reader indicates whether a serial number successfully has been read. Figure 3.9 shows the maximum reading distance of the evaluated LF reader at different access angles.

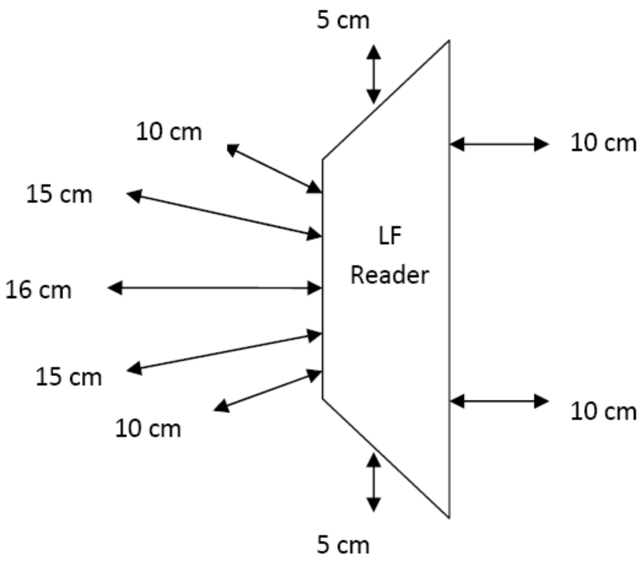

Figure 3.9: Maximum reading distance of LF reader at different angles (see **Figure 2.6** for the picture of the LF reader)

A total of three different models of LF tags were compared in order to get the LF tag with the maximum transponder response signal. Figure 3.10 shows the three tag formats which basically differ in the antenna diameter.

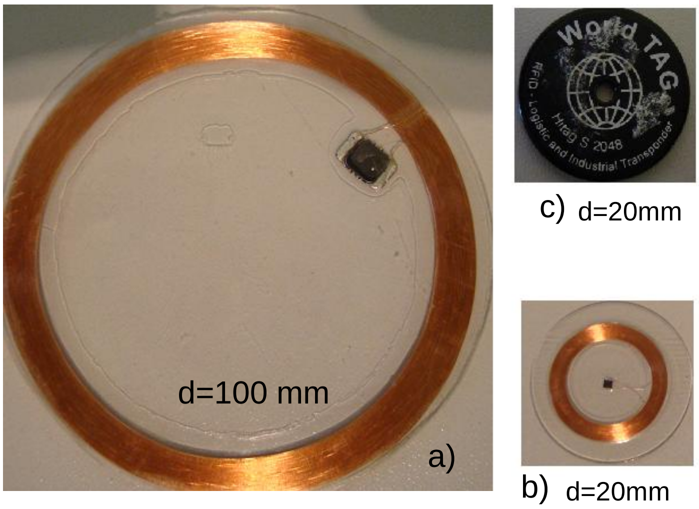

Figure 3.10: Different LF RFID Tags (a) Clear Disc Hitag S2048 100mm , b) Clear Disc Hitag S2048 20mm, c) WORLD TAG Hitag 20 mm (Sokymat Identification[17],Granges, Switzerland))

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[17] www.cyntag.com

Figure 3.11 shows the transponder signal of the Clear Disc Hitag S2048 100mm transponder with an antenna power of -23.161 dBm at resonance frequency.

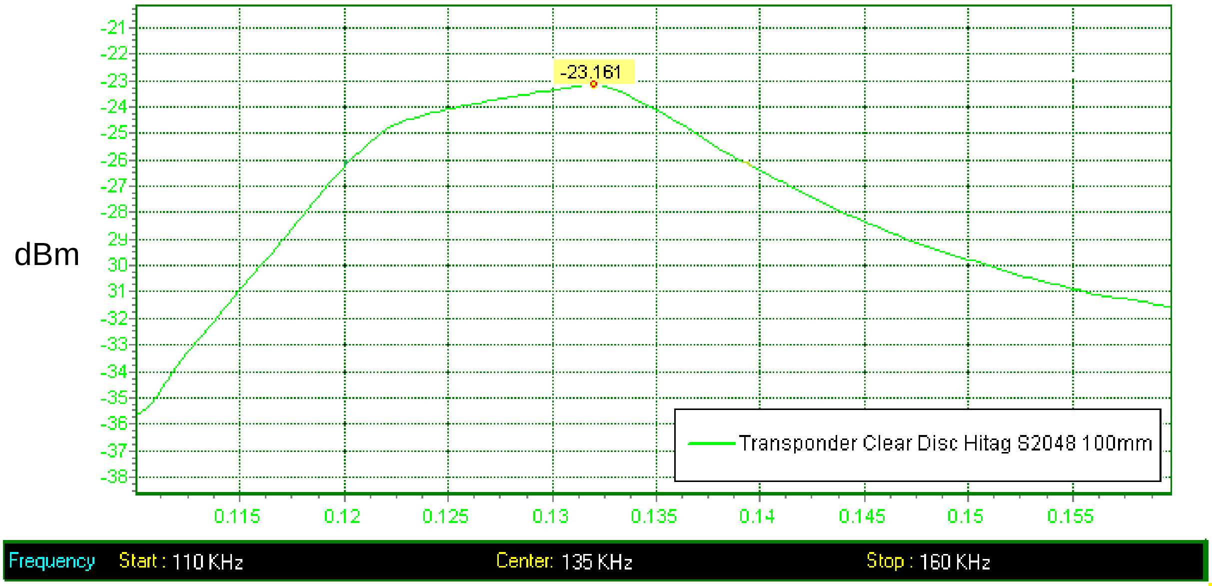

Figure 3.11: LF transponder signal with resonance frequency at 132kHz

In order to evaluate the performance of this transponder if it is attached to different materials such as body tissue or metal, the following measurements had been performed. All results show a comparison of the transponder without the tested material and with the influence of the material.

The green plot in Figure 3.12 shows the transponder signal without interfering with any other material than air. The yellow plot was measured while bringing the hand between the reader antenna and the transponder.

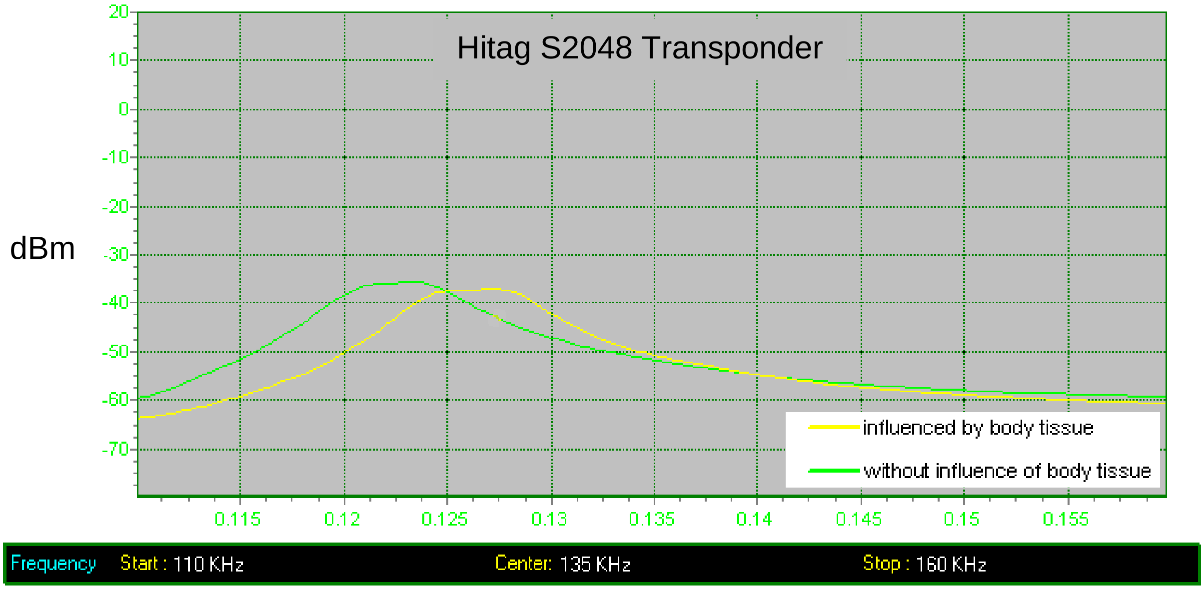

Figure 3.12: LF transponder signal with and without body tissue

The comparison of the two signals showed that there is a small and negligible shift of the resonance frequency, due to the influence of the body tissue. This was practical evidence that LF systems easily penetrate body tissue and do not cause a significant change of transponder characteristic.

When attaching the transponder to a metallic material, the change in the frequency-power diagram was significant. Figure 3.13 shows the effect.

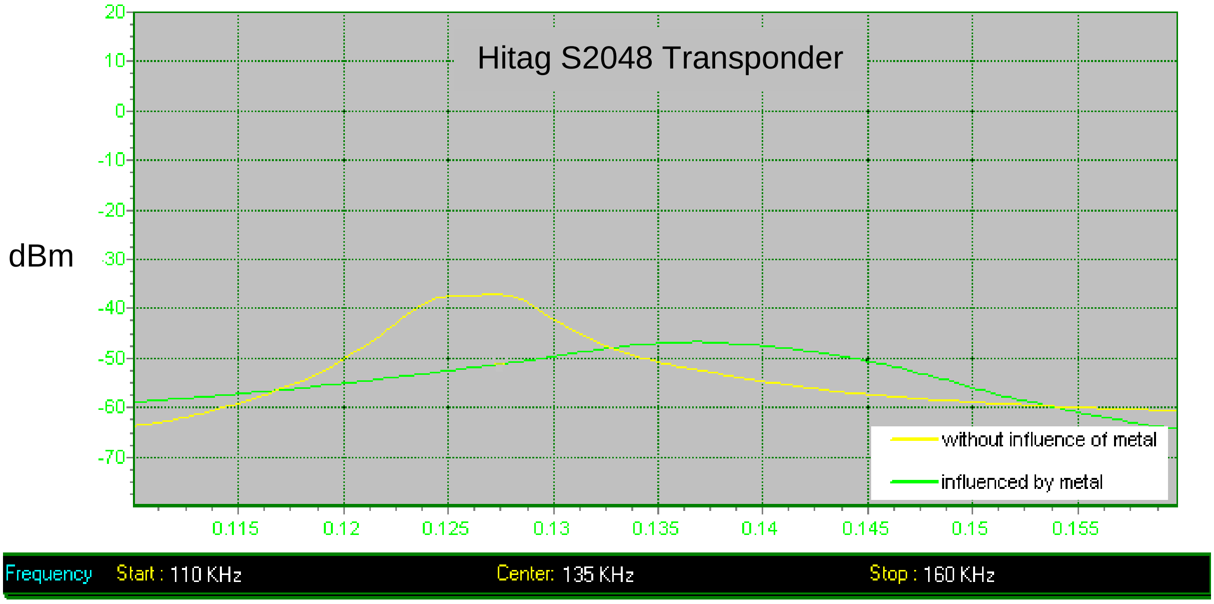

Figure 3.13: LF transponder signal with and without metal

The green plot shows the transponder signal of the LF tag attached to the metal, and it demonstrates a significant reduction of the amplitude as well as a change of the resonance frequency. This demonstrated that metal is changing the behavior of LF systems, which was mentioned in the theoretical section above. If the LF reader is optimized for the standardized frequency of 125kHz and the transponder resonance frequency is slightly shifted because of material effects, it causes a lower reading distance due to frequency mismatch of reader and transponder.

High frequency system

The transponder was realized by an I CODE SLI Standard Label (ISO 15693). Figure 3.14 demonstrates the results of the behavior of a HF transponder influenced by body tissue.

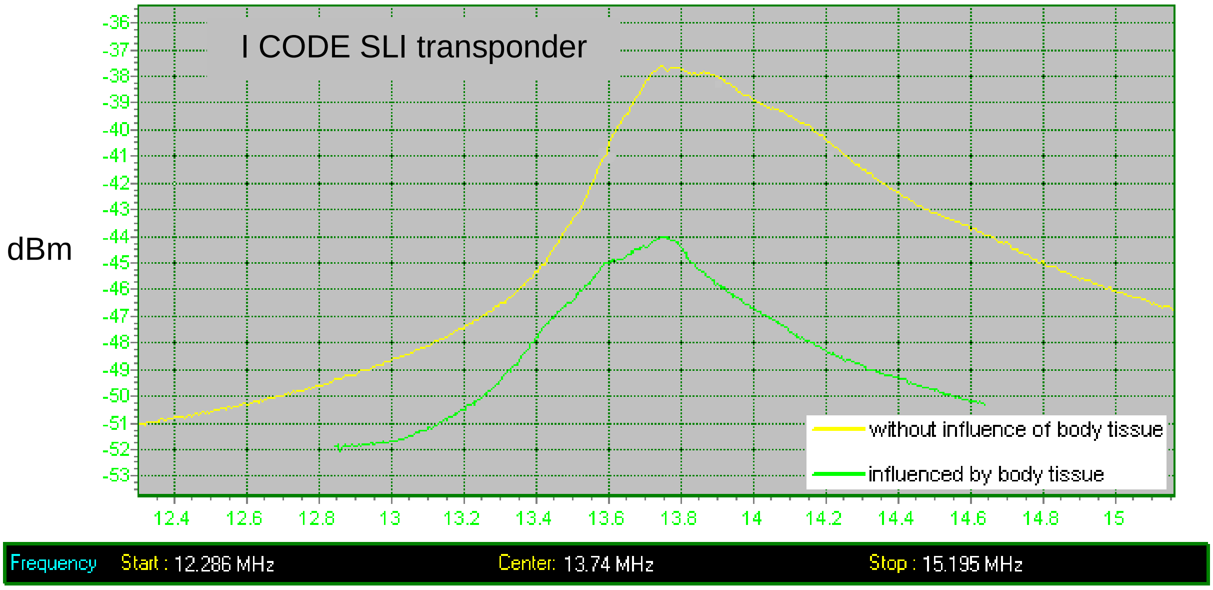

Figure 3.14: Comparison of transponder signal of a I CODE SLI Standard Label with and without the influence of body tissue

The shift of the resonance frequency between the green plot (measurement affected by body tissue) and the yellow plot is negligible. However, there is a significant lower reflection power, which again causes a lower reading distance.

In order to receive information about the influence of other materials on a HF system, some more measurements had been performed. Figure 3.15 shows the influence of Polymethylmethacrylate (PMMA), which is an acrylic glass often used as a light or shatter-resistant alternative to glass (Wikipedia, 2010).

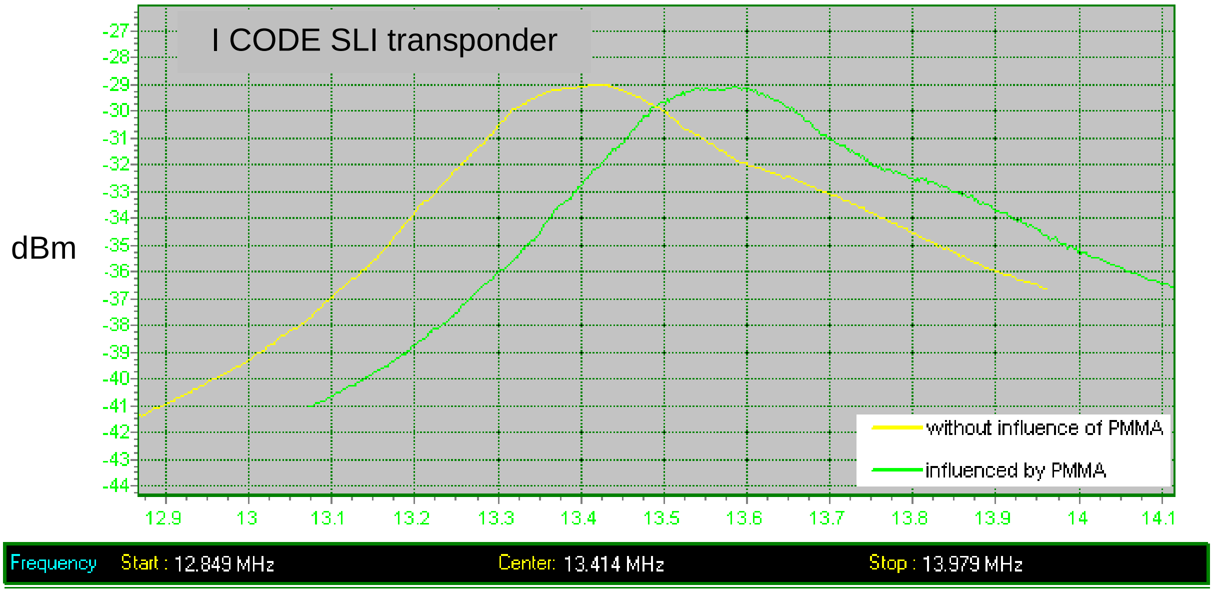

Figure 3.15: Comparison of transponder signal of a I CODE SLI Standard Label with and without the influence of PMMA

Figure 3.16 shows the results of the transponder behavior, when attaching it to a glass of water.

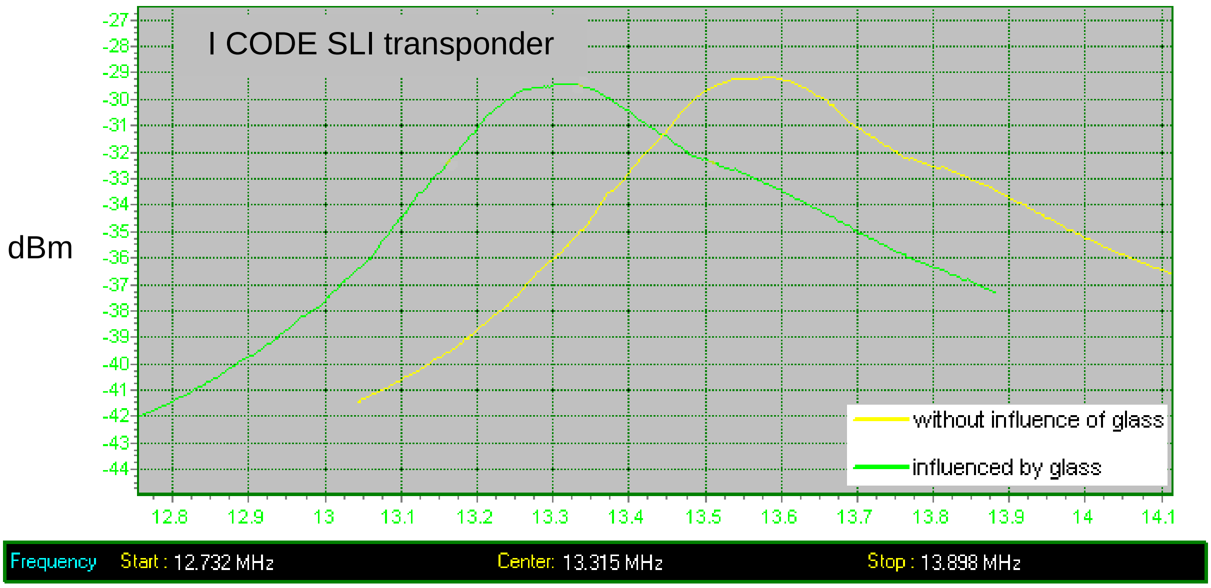

Figure 3.16: Comparison of transponder Signal of a I CODE SLI Standard label attached on a glass of water and behavior without the influence of other materials

In both figures Figure 3.15 and Figure 3.16 the frequency shift between green and yellow plot was quantifiable. In contrast, the attenuation of the reflection power was not significant in this case. It can be proposed that different materials have a negative impact on the HF signal, which correlates with the theoretical considerations in the methods part of this thesis.

Ultra High Frequency system

To make statements about the behavior of metals in an UHF environment, the tag with the highest response amplitude was placed at a metallic material and a resonance frequency test was performed with the RTS200. RFID Test Set (IberWave). Figure 3.17 shows the results.

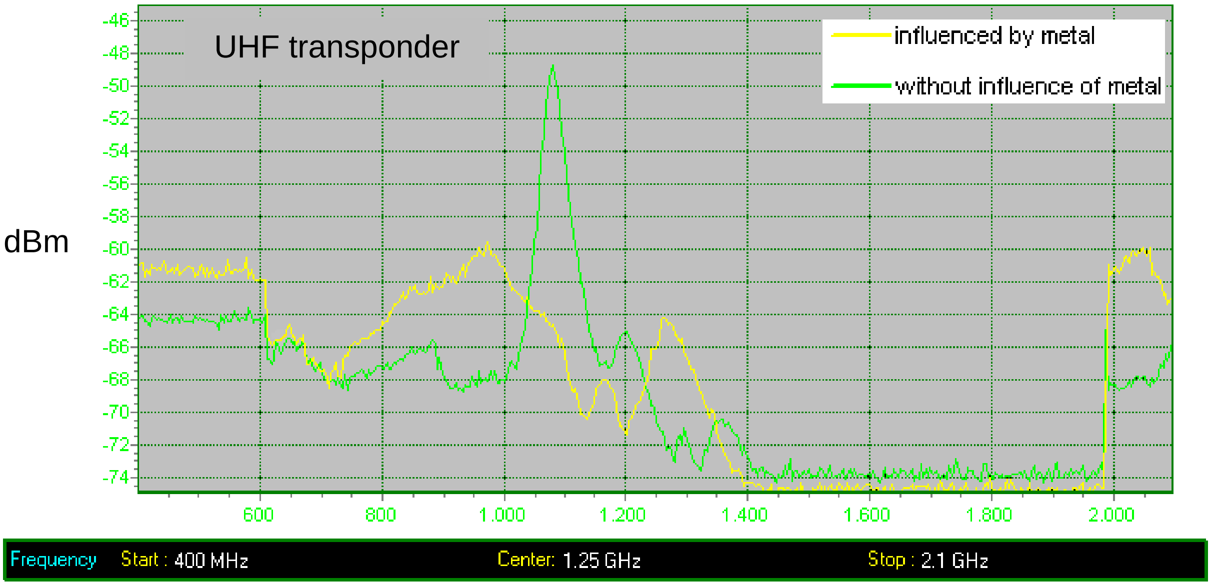

Figure 3.17: Influence of metal in an UHF environment, the green plot shows the transponder behavior without metal whereas the yellow plot demonstrates the behavior of the UHF tag placed on a metallic surface

The transponder characteristic diagram (green plot) shows the resonance frequency at 1.075 Ghz with a small bandwith in this frequency region. Considering the yellow signal trace, it is obvious that the influence of metal on this transponder was devastating since there is an identifiable blurred signal with an undefined resonance frequency.

Figure 3.18 outlines a comparison of transponder signals of a plain UHF tag and a tag, attached to a glass of water. The diagram shows a resonance frequency shift from 1.075 GHz to 875 MHz, due to the change of the ambient material. This outcome has to be considered when it comes to transponder and reader design for the use in AAL scenarios where ADL has to be monitored.

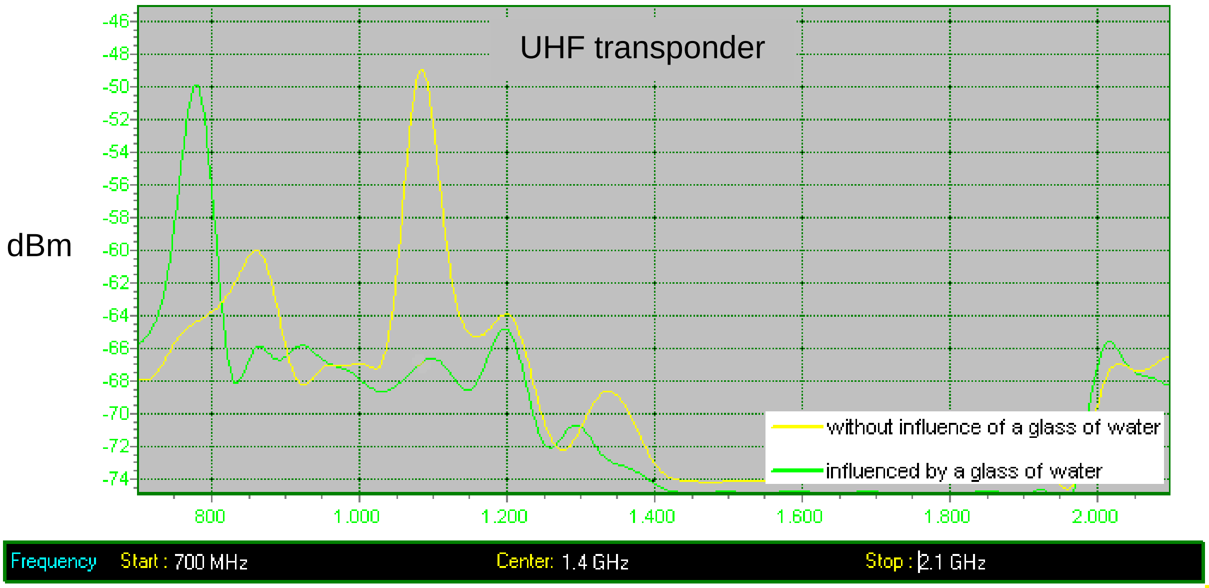

Figure 3.18: Difference of the signal traces of a UHF transponder measured plain (yellow) and in contact with a glass of water (green)

3.2.2 Energy performance

There are different modes to consider, when it comes to energy performance and current consumption of the KIT wand prototype. Table 3.1 gives an overview of the different modes and shows the related current consumption.

Operating mode	**Current consumption (I)** **[mA]**	**Time interval (t)** **[ms]**	**Electric charge Q=I*t** **[mAs]**
Idle	<1	200	<0.2
Initializing	17	165	2.805
Tag scanning/reading	125	10 250 (if tag is present)	1.25 31.25
Data transmission over Bluetooth channel	62	3000	186

Table 3.1: Overview of the different operating modes of KIT wand with related current consumption

In the following section the results of the current measurements within the operating modes are shown in detail.

Idle cycle – scanning area with absence of an RFID tag

In this mode, the KIT wand was periodically scanning its environment for RFID tags. The PN531 chip on the KIT wand hardware module was responsible for the detection of tags and must be switched on. In the current setting the PN531 chip was only switched on every 200ms in order to save energy but still make it possible to detect tags by bringing the KIT wand close to them within a short time interval. The hardware needed 175ms to switch on the field, which are needed for tag detection and returning the µController to its LPM. Figure 3.19 shows the duty cycle of the KIT wand in the idle mode.

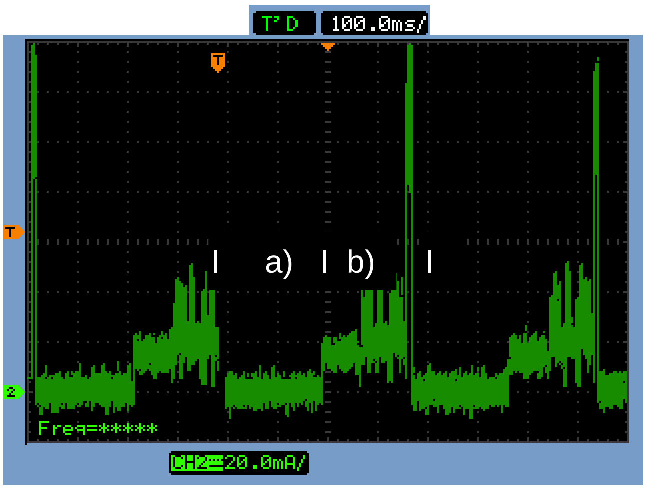

Figure 3.19: Duty cycle of KIT stick prototype in idle mode

Section a) illustrates the current consumption while being in the low power mode, which is less than 1 mA. Section b) shows the current consumption needed by the PN531 NFC chip (17mA) for initializing. Furthermore, reading the area for tags consumed 125mA for a short time interval of 10ms.The signal noise occurred due to the measurement circuit with the oscilloscope and would not occur during normal operation.

Operating cycle - Tag reading and Bluetooth transmission

After a tag was detected and successfully read, the KIT wand switched on the Bluetooth module and tried to establish a Bluetooth connection with the home terminal. The Bluetooth module automatically connected to its default link after it was switched on. Figure 3.20 shows the current consumption in *tag reading and Bluetooth establishment* mode of the KIT wand.

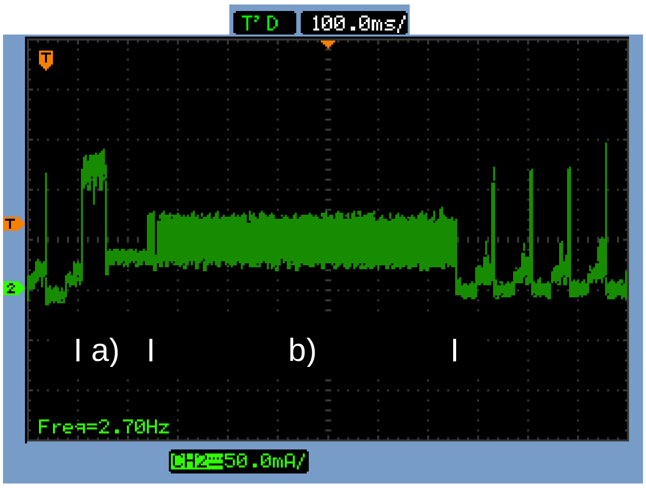

Figure 3.20: KIT wand current consumption in tag reading mode

Section a) displays the current flow while reading a tag. This caused a current of 125mA for the time of 250ms, which was needed to read all data from the tag. In section b) for the time of 3 seconds a current of 62mA occurred. This was the time for data transfer via Bluetooth. The current of 62mA corresponds to the data sheet information about the Bluetooth module, which has a typical current consumption of 65mA.

3.2.3 Feasibility

After the prototypical implementation, the KIT wand was evaluated in terms of NFC range, Bluetooth range, and feasibility for ADL monitoring and intuitive acquisition of health parameters. The following sections show the results of the feasibility test of the prototype.

NFC range

The maximum distance where a tag was read successfully by the KIT wand, located parallel to the tag, was at 3.5 centimeters. Furthermore, different angles between KIT wand and RFID tag were inspected. The results of this experiment showed that the maximum reading distance decreased, due to changes of the angle. Table 3.2 and the related diagram in Figure 3.21 show an overview of the conducted results concerning the NFC range.

Angle between KIT wand and RFID tag [degrees]	**Maximum reading distance [cm]**
0	3.5
30	3
45	2.9
60	2.7
90	2

Table 3.2: Results of NFC range test; KIT wand in different angles to RFID tag

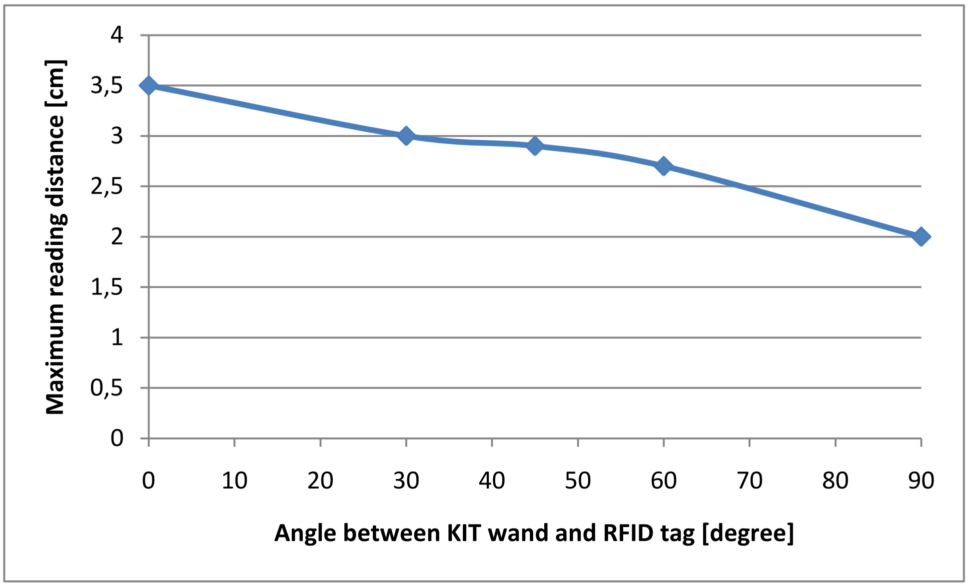

Figure 3.21: Diagram showing the relation between maximum reading distance and angle between KIT wand and RFID tag

Performing ADL tasks

Performing ADL tasks was the next feasibility test conducted with the KIT wand. Five test persons (2 female, mean age of 23,2 ±2,2 years) were equipped with the KIT wand and had to perform certain tasks in order to show the successful data processing of KIT wand and the home terminal. Table 3.3 outlines the results of this test. The events “Open dishwasher”, “Open cupboard” and “Use kettle” were performed successful in 80 percent of all conducted tests. “Close cupboard” and “Close dishwasher” performed successful in 100 percent of the tests. Bluetooth transfer of “Use remote control” and “Open door” was successful in 80 percent, although KIT wand data processing was successful in 100 percent of all conducted tests.

Test person	**Open dishwasher**	**Open cupboard**	**Close cupboard**	**Close dishwasher**	**Use kettle**	**Use remote ctrl.**	**Open door**
Nr.1	passed	passed	passed	passed	passed	passed	passed
	passed	passed	passed	passed	passed	failed	failed
Nr.2	passed	passed	passed	passed	passed	passed	passed
	passed	passed	passed	passed	passed	passed	passed
Nr.3	passed	failed	passed	passed	passed	passed	passed
	passed	/	passed	passed	passed	passed	passed
Nr.4	passed	passed	passed	passed	failed	passed	passed
	passed	passed	passed	passed	/	passed	passed
Nr.5	failed	passed	passed	passed	passed	passed	passed
	/	passed	passed	passed	passed	passed	passed
Success [%]	80	80	100	100	80	100	100
	80	80	100	100	80	80	80

KIT wand data processing
Bluetooth transfer

Table 3.3: Results of performing ADL tasks with the KIT wand

Acquisition of health data

The test persons were asked to use all three adapted health devices (MirOxi, scale, blood pressure meter, see chapter 2.4.1), perform measurements and acquire data by touching. The results of this usability test are depicted in Table 3.4. Data acquisition with the MirOxi and the scale performed successful in 80 percent and data acquisition with the blood pressure meter in 100 percent of all conducted tests.

Test person	**Data acquisition with**		
	MirOxi	**Scale**	**Blood pressure meter**
Nr.1	passed	passed	passed
Nr.2	passed	passed	passed
Nr.3	passed	failed	passed
Nr.4	passed	passed	passed
Nr.5	failed	passed	passed
Success [%]	**80**	**80**	**100**

Table 3.4: Results of acquisition of health data with the KIT wand

Bluetooth range

The results of the maximum Bluetooth range test within the home environment (shown in chapter 2.5.3, Figure 2.12) demonstrated that connection of the home terminal to all measurement spots was possible. In order to find out maximum ratings, the prototype was tested in a bigger office building complex. The maximum Bluetooth range without any walls or objects between KIT wand and home terminal was 45 meters. Furthermore, the influence of walls was tested. Bluetooth transfer through two plasterboard walls was feasible over 8 meters. One concrete wall and one plasterboard wall decreased the maximum reading distance to 6,5 meters. Bluetooth transfer through three walls failed.

4 Discussion

A prototype for the intuitive acquisition of vital parameters and the unobtrusive monitoring of Activities of Daily Living was developed. A platform for easy integration of further health devices and objects in the ambient area and the possibility of communicating with higher layers of an AAL architecture was realized. Furthermore, an Android software application to collect the acquired data was implemented.

The NFC based KIT wand was proven feasible for the concurrent acquisition of health data from KIT enabled devices and the recognition of ADL through objects equipped with RFID tags. The Android software application on the Archos 5 internet tablet was proven feasible for the collection of data from the KIT wand via a Bluetooth connection.

In the following, a critical eye is cast on the current thesis. The practical usage of the system for dementia patients is discussed. Furthermore, the energy performance of the prototype is discussed, and optimization strategies are presented. Thereafter, the results of the evaluation of the prototype and different RFID systems are reviewed and conclusions for future developments are drawn. Finally, future prospects are given.

4.1 Practical usage of the system for dementia patients

User acceptance, usability and costs are crucial factors when bringing technological solutions to healthcare. Assistive systems draw always a fine line between acceptance and total rejection caused by too much interference on daily living. Apart from the user acceptance, the practical usage of the system for dementia patients is a crucial point. Dementia is a complex disease with different symptoms and peculiarities. This makes it difficult for a system to perform well for a broad range of dementia stages. The system developed and presented within this thesis was designed to overcome problems which occur as a consequence of mild forms of dementia. People with a mild form of dementia live independent at home but sometimes need reminders and assistive feedback in order to maintain a safe and comfortable life. Thus, an assistive system could remind people to do routine tasks such as hygiene, interacting with their social environment or turning off the oven after cooking meals. The problem is that no studies have been performed where the practical usage on dementia patients is shown. Future work on the current prototype is to set up a trial to determine the user acceptance and the practical usage of the system. It has to be investigated where the limits of the proposed systems are concerning different dementia stadiums. The studies should address if a dementia patient can handle the feedback given through the home terminal and to which extent the system can replace the presence of a caregiver.

4.2 Optimizing energy performance

The KIT wand, as described in chapter 3.1.1, is intended to be switched on permanently in order to detect RFID tags when they are in the ambient area. Thus, energy consumption of the KIT wand is high. The estimated battery life of the current KIT wand prototype is around a few days, when using a 3,7V Li-Ion cell with 1000mAh. The battery has to be recharged every week which increases the costs and the amount of maintenance. Therefore, solutions to optimize the energy performance of the prototype have to be considered.

One possible solution to overcome the energy performance is changing the permanent scanning for tags to a triggered approach. When taking a look at ADL monitoring, it is obvious that the interaction with different objects in the ambient area is a possible trigger to switch on the KIT wand. Future developments could use ultrasonic sensors. These can recognize the presence of objects and subsequently enable the process for scanning of tags which needs the highest amount of energy as it is described in chapter 3.2.2. Ultrasonic sensors were already used in a similar approach proposed by *Ettelet* for mobile robotic assistants for health or homecare applications, to recognize obstacles. (Ettelet et al., 1998)

Another trigger for bringing the KIT wand into service can be the recognition of specific arm or finger movements. Within this approach the integration of accelerometers plays an important role. Recognizing a person’s hand palm moving in a specific pattern could be an indicator for the usage of an object in the ambient area. The problem hereby is that not many daily activities are performed with specific arm or hand gestures and it would be difficult to distinguish between normal movement of the arm and the movement due to executing a specific activity.

Apart from the possibilities to trigger the operation of the KIT wand, other technologies that consume less power have to be considered. ZigBee technology, described in chapter 2.3, is targeted to control applications with low data transfer rates and low energy consumption. For the usage in the permanently switched on KIT wand, ZigBee would be suitable. Another low power wireless technology would be *Bluetooth low energy,* which is the hallmark feature of the Bluetooth Core Specification Version 4.0 (Bluetooth Special Interest Group Inc., 2010) . At the moment there are no end-user devices with Bluetooth V4.0 available on the market, since the specification of Bluetooth low energy was just completed in early 2010.

4.3 Feasibility of the prototype

A series of feasibility tests were performed with the prototype, designed and developed within this thesis (see results in chapter 3.2.3). The first test, which examined the maximum reading distance of the NFC module on the KIT wand, showed a maximum range of 3.5 centimeters in parallel position to an RFID tag. Reading an RFID tag perpendicular to the KIT wand decreased the maximum reading distance to 2 centimeters. Thus, using the KIT wand prototype in the following tests was limited to distance and angle to the tagged objects. The test persons obtained exact instructions how to use the objects and the KIT wand in order to ensure a correct data acquisition.

The first feasibility test was to show the KIT wand's ability to recognize ADL tasks. The results of test person Nr. 1 (see Table 3.3), show an unsuccessful Bluetooth transfer during “Use remote control” and “Open door”. Due to an incorrect data transfer within “Use remote control”, the home terminal was in an undefined state and was not able to process any further data. This result demonstrated that Bluetooth technology is affected by instabilities, which can disturb precise operation of devices. The unsuccessful events of test person Nr.3, Nr.4 and Nr. 5 resulted due to incorrect handling of the KIT wand. The test persons did not touch the attached RFID tags correctly, which caused a loss of ADL events.

Considering the results of the acquisition of health data with the KIT wand, it turned out that the prototype performed as expected (see Table 3.4). The failed data processing during data acquisition with the MirOxi and the scale through test person Nr.3 and Nr. 5 appeared again through wrong handling of the KIT wand prototype.

The acquisition of health data is a conscious activity. The patients are expected to touch the health devices with the KIT wand in order to transfer data. Thus, the loss of data due to incorrect handling of the KIT wand could be avoided through an acoustic alarm or a short vibrating of the KIT wand. This would signalize a patient that the action was performed correctly and data are transferred. The KIT wand only has to give this feedback if the person is acquiring health data. Within ADL recognition, which should be unobtrusive, there is no feedback necessary after an ADL task is performed. A future version of the KIT wand should be able to handle this issue.

The examination of the maximum Bluetooth range showed that within the test environment all measurement spots could be reached through Bluetooth. The problem with Bluetooth distance measurements is that local circumstances such as walls or doors massively influence the range. That makes it difficult to determine an exact range within a real test environment. The limits of the Bluetooth range were tested in an office building, bigger than the test environment, introduced in chapter 2.5.3. The test showed that walls within a building disturb the Bluetooth signal and reduce the maximum Bluetooth range.

Taken together, the feasibility of the KIT wand prototype for the acquisition of health data as well as for the recognition of ADL was proven. However, the maximum reading distance of 3.5 centimeters limits the handling of the KIT wand worn on the wrist. To ensure an unobtrusive data acquisition and to improve the monitoring of ADL a higher NFC reading distance would be advantageous.

4.4 RFID Technology

An evaluation of different RFID frequencies was conducted within this thesis. The focus of this evaluation was to determine which technology is the most adequate solution to use for ADL monitoring. Two technical factors, which are significant for the adaptability of RFID systems in an ADL monitoring scenario, were tested. Firstly, the maximum tag range of an LF system, which can be seen in chapter 3.2.1, was verified. Secondly, the influence of different materials on the behavior of the LF, HF and UHF systems was inspected.

The results show that an off-the-shelf LF reader is able to detect and read an RFID tag from a maximum distance of 16 cm at a specific angle. This points out that the reading distance of LF systems is higher than the reading distance of NFC technology, which is based on HF technology. Regarding the information of chapter 2.3, NFC has a maximum reading distance of 5 up to 10 cm. The KIT wand prototype, realized within this thesis, handles a maximum reading range of 3.5 cm (see chapter 3.2.3). As far as tag range is concerning, using LF technology would be an improvement of the current prototype.

An important issue in supplying objects with RFID tags is the influence of the object material on the frequency behavior. Bad matched reader circuits cause a poor reading range due to changes of the transponder's resonance frequency. One can see that there is only a small influence of body tissue on the behavior of a LF system. However, in HF and UHF systems the presence of body tissue causes a significant reduction of reflection power, which leads to a lower reading range. Metallic surfaces reduce the ability to read tags in all considered frequency ranges. The results of the measurements show that different materials have a deep impact on the behavior of RFID systems and strongly have to be considered when designing RFID applications.

Taken together, the usage of an LF system for the implementation of ADL monitoring on the KIT wand would be the best approach regarding tag range and influence of materials. However, one must not forget other important factors such as energy consumption. The chosen technology has to fit the required energy balance, which has to be examined for further developments of the prototype. Another important factor is the tag size. Different objects in the home environment have different shapes and sizes. Therefore, the appropriate RFID technology has to make sure that tag size and shape is in an applicable region. Furthermore, costs of tags play an important role in order to keep the costs of the overall system as low as possible.

4.5 Future prospects

The prototype realized within this thesis offers a solution for the home care of an elderly and chronically ill person. Thinking of future developments and usage of the proposed technology for telemonitoring and recognition of ADL opens space for other scenarios. The current use case is that a patient is in possession of one single

KIT wand and one home terminal which is installed in his/her living room. Instead of using one KIT wand in one household, a multi user approach in a care institution or a hospital is imaginable. Within home care institutions all residents could be equipped with KIT wands, integrated in wristbands, and their daily activity pattern could be monitored. This could give information about changes of cognitive abilities and health status.

Another possible approach is to use the system for logging of activities of nursing staff. Home care institutions have to document care services. For this, nurses could be equipped with KIT wands, which allow the monitoring of several tasks they do while servicing a patient. The documentation effort could be reduced and nursing staff could be reminded if they have forgotten one or more important tasks. In all the multi user scenarios described above each KIT wand would send a unique identifier in order to relate the acquired data with the corresponding patient. The KIT wand would be responsible for identity management, because it is involved in all communication scenarios in the developed system. This ensures that every event can be correlated with the appropriate user.

In the following, a mobile version of the system apart from the stationary operation in someone’s home or in institutions is discussed. Thinking of chronically ill people on vacation, it is crucial that daily acquiring of health data has to continue in order to maintain therapy management. A mobile version of the system proposed within this thesis would ensure this requirement. The KIT wand itself would have to send the acquired data through a WAN based Internet connection (see chapter 2.1) without the support of the home terminal. This leads to a KIT wand that provides the appropriate interfaces, which is discussed in the next section.

Further future application areas of the presented system can be generated when using the home terminal for other purposes. Due to the connectivity with a TV set, the home terminal opens the opportunity for giving feedback to the user. For example, it could be used for personal fitness training. Special software on the Archos 5 internet tablet could provide visual and acoustic instructions to do daily exercises. This could help with rehabilitation and weight reduction. In the context of AAL the home terminal could be an interface for social contacts via video streaming of conference calls. Friends or family members would be able to talk and interact with their relatives without being physically there.

Another possible application for the system would be fall detection. A fall is the biggest fear of elderly people who live alone. The KIT wand could be adapted with accelerometers, which detect longer inactivity. The home terminal can manage emergency calls if a fall was detected.

Taken together, there are tremendous opportunities for the future development of the prototype, as realized for the present thesis.

4.6 Future KIT wand

To overcome the problems discussed above an overview of different possible upgrades of the KIT wand is described in the following.

Firstly, the KIT wand would have to be equipped with an external flash memory. Described in chapter 3.1.1, the KIT wand saves the current data record together with a timestamp, if a Bluetooth connection is impossible. The internal memory of the KIT wand would exceed the maximum capacity after approximately 10 read objects, if no Bluetooth connection with the home terminal is possible. An external memory would ensure a higher capacity and no events would be missed.

Secondly, integrating a GSM module into the KIT wand would ensure direct connectivity with a WAN based Internet connection without the intermediate section through the home terminal. This would allow usage in mobile scenarios when there is no home terminal available.

Thirdly, the appropriate RFID technology according to the evaluation of different technologies has to be developed and integrated into the KIT wand. Due to the results in chapter 3.2.1, the influence of different materials on the behavior of different RFID technologies has to be considered. Therefore, the RFID reader antenna and matching circuit would have to be optimized for human body tissue, because the KIT wand is in direct contact with the user’s arm. Apart from the redesign of the RFID reader, the specific design of transponders, which are attached on different objects, is an important issue. To optimize the reading range of the KIT wand, transponder antennas should be designed according to the material on which they are going to be attached. The design for an RFID transponder on a metallic surface would look different than on a Poly Vinyl Chloride (PVC) surface.

5 Conclusion

Technologies in the context of AAL are becoming more and more important to ensure a longer independent life for elderly people in their homes. Furthermore, due to the high prevalence of chronic diseases in elderly people, telemedical services play an important role for the patients and the healthcare system.

The aims of this thesis were to show the feasibility for a system that both enables users to intuitively acquire vital parameters for telemonitoring of chronic diseases and monitors activities of daily living for care support of dementia patients. Through the development of an NFC based KIT wand the intuitive acquisition of health parameters was taken in to account. Thus, monitoring of the health status of chronically ill people can be reached. Furthermore, the KIT wand was able to recognize ADL of elderly people through interaction with objects in the home environment that were equipped with RFID tags. Additionally the connection of the KIT wand with a home terminal realized by a tablet PC enabled feedback opportunity for dementia patients in order to assist them in their daily routine tasks. The results of this thesis show that telemedical services combined with AAL technologies give opportunities to counteract healthcare and ageing related future problems.

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