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DESIGN, DEVELOPMENT AND EVALUATION OF A WIRELESS MULTIUSER AND MULTIMODAL TELEHEALTH TERMINAL

Diploma thesis

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Ich danke allen.

ABSTRACT

Background: Wireless technologies play an important role in applications dealing with telemonitoring, Ambient Assisted Living (AAL) and fitness. Technologies such as WiFi, Bluetooth and Near Field Communication (NFC) have already been utilized for monitoring purposes in AAL and telemonitoring. ANT+ and ZigBee offer ideal protocols to be used in the AAL setting too. To cope with these requirements AAL has to combine products from different market segments, offered by different manufacturers, which need to work together. Currently most of these products are stand-alone solutions and do not offer interoperability. In the future they should work together or have a common interface.

Methods: To address the needs in the field of telemonitoring and AAL, a multimodal wireless Application Hosting Device (AHD) has been designed. Based on this design a prototype has been developed that can collect various user data. Several wireless communication technologies were used to acquire vital signs from home monitoring devices, sport and fitness data and environmental data. Development and implementation were focused on usability and interoperability aspects using Bluetooth, ANT+ and ZigBee technology for data acquisition and NFC for user identification. The prototype was evaluated in terms of feasibility, performance and usability for monitoring in a real home environment.

Results: The AHD was evaluated for three weeks with two independent user groups. The prototypically developed AHD was proven to be feasible for the multimodal data acquisition. Data acquisition was successful. The usability test indicated that the patient terminal was well accepted by the users. Multiple users could be monitored with one device set.

Conclusion: The results show that a single point of data collection may be feasible to serve several eHealth applications, i.e. telemonitoring, AAL, environmental monitoring as well as sport and fitness tracking. Because of the fact that the AHD has been evaluated neither in a clinical setting nor on an appropriate user group, further trials have to be conducted.

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LIST OF ABBREVIATIONS

AAL	Ambient Assisted Living
AES	Advanced Encryption Standard
AHD	Application Hosting Device
API	Application Programming Interface
ASK	Amplitude Shift Keying
BAN	Body Area Network
BLE	Bluetooth Low Energy
BPM	Blood Pressure Monitor
CCID	Chip Card Interface Device
CHA	Continua Health Alliance
CHF	Chronic Heart Failure
CSMA-CA	Carrier Sense Multiple Access-Collision Avoidance
DSSS	Direct Sequence Spread Spectrum
ECG	Electrocardiography
EMC	Electromagnetic Compatibility
E2E	End-to-End
FHSS	Frequency-Hopping Spread Spectrum
GFSK	Gaussian Frequency Shift Keying
GUI	Graphical User Interface
HDP	Health Device Protocol
HRN	Health Reporting Network
ICT	Information and Communication Technology
IoT	Internet of Things
ISM	Industrial, Scientific and Medical
J2ME	Java 2 Micro Edition
KIT	Keep in Touch
LAN	Local Area Network
MITM	Man-in-the-Middle
MOBITEL	MOBIle TELemonitoring
NFC	Near Field Communication
NFC-SEC	Near Field Communication Security Standards
NYHA	New York Heart Association
PAN	Personal Area Network
PC/SC	Personal Computer/Smart Card
RFID	Radio-Frequency Identification
SIG	Special Interest Group
SpO$_2$	Oxygensaturation
SSP	Simple Secure Pairing
TCX	Training Center XML
TDD	Time Division Duplex
UID	Unique Identifier
WAN	Wireless Area Network
WAP	Wireless Application Protocol
WPAN	Wireless Personal Area Network
XML	eXtensible Markup Language

STATEMENT OF ORIGINALITY

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"Hereby I faithfully declare that I have independently composed this diploma thesis and that no other than the indicated aids and sources have been used. Every external source used is referenced in the bibliography. All phrases, which were obtained literally from external sources, are marked. This thesis has not been presented to any other examination board and has not been submitted for publication elsewhere."

Graz, April 17, 2012

(SEDAT AKYILDIZ)

CHAPTER 1

INTRODUCTION

The demographic trend shows a rising proportion of elderly people in the coming decades. Our society is aging continuously and will continue to do so due to decreasing birth rates and death rates. While the number of young people is falling, the number of people over 65 in the EU is rising rapidly. In 2050 the number of people over 65 is predicted to rise the most by 58 million, while the population between 15 and 64 is estimated to fall by 48 million in the EU. Together with an aging society, the prevalence of chronic diseases like heart failure, diabetes II, high blood pressure and obesity is increasing [6].

> *Chronic diseases are diseases of long duration and generally slow progression. Chronic diseases, such as heart disease, stroke, cancer, chronic respiratory diseases and diabetes, are by far the leading cause of mortality in the world, representing 63% of all deaths [7].*

Patients suffering from these diseases need special care. It is these patients in particular, who add significant costs to the health care system due to frequent and long hospitalisations.

The problems of care and assistance to chronically ill people are becoming more and more important from a social and economic point of view. Permanent monitoring is needed to treat chronic diseases adequately, but periodical visits are neither comfortable for the patient nor for the doctor or caregiver. The challenges of demographic change cannot be approached with traditional concepts due to lack of workforce in care and cure. Today there are still four people in employment for every retired person. By 2025 this ratio is predicted to drop to three to one and to only two to one by 2050 [8].

The approach must be to make the promise of Information and Communication Technologies (ICT) a reality. ICT can play an important role in care and cure of people with chronic illnesses. Telemonitoring is a viable alternative to regular visits. Among other purposes, the aim of telemonitoring is to prevent hospitalisations through early detection of disease worsening followed by immediate intervention. Using ICT, patients are virtually linked with their caregivers to provide their vital signs on a daily basis and to receive treatment instructions in case of worsening [9].

1.1 Telemonitoring

Telemonitoring, which is also known as remote patient monitoring [10] or home monitoring, is defined as the use of information and communication technology to monitor patients' clinical status [11]. Telemonitoring deals with the transfer of physiological data such as blood pressure, weight, electrocardiographic (ECG) details and oxygen saturation (SpO_2) from home to healthcare providers [12]. Special telecare devices are now used in conjunction with a telecommunication system (telephone line, cable networks, broadband technology, mobile communication technology) to acquire and transmit patient data to physicians' offices in order to evaluate the patients' health status once or several times a day or even by continuous monitoring. Telemonitoring can alleviate the access to care for patients as it allows the collection of clinical data without the need for face-to-face contact between patients and healthcare providers [11].

Telemonitoring for patients with chronic diseases provides advantages not only for the patients but for the healthcare system as well. It allows the continuous monitoring of the health status and consequently therapy management, which is adapted to the individual requirements of every patient.
The process of telemonitoring is shown in figure 1.1, which can be described as a 'closed loop'. One actor is the patient entering health and lifestyle data into the system. A telemonitoring service center can store patients' data for viewing later or for a patient's health record. Changes of vital parameter are detected via pre- processing algorithms to alarm caregivers. A physician, nurse or health care center staff then connects to the telemonitoring service to view the data, give feedback or optimize the treatment thus closing the loop.

Through the monitoring of different important health parameters, namely weight, blood pressure, heart rate, medication and wellbeing, the attending doctor can quickly identify a possible undesirable course of the disease. A monitoring system tailored to the needs of the patient saves time and costs. This enables the physician to initiate counteractive measures in due time. Thus, readmissions to the hospital, emergency cases and extraordinary treatment costs can be reduced.

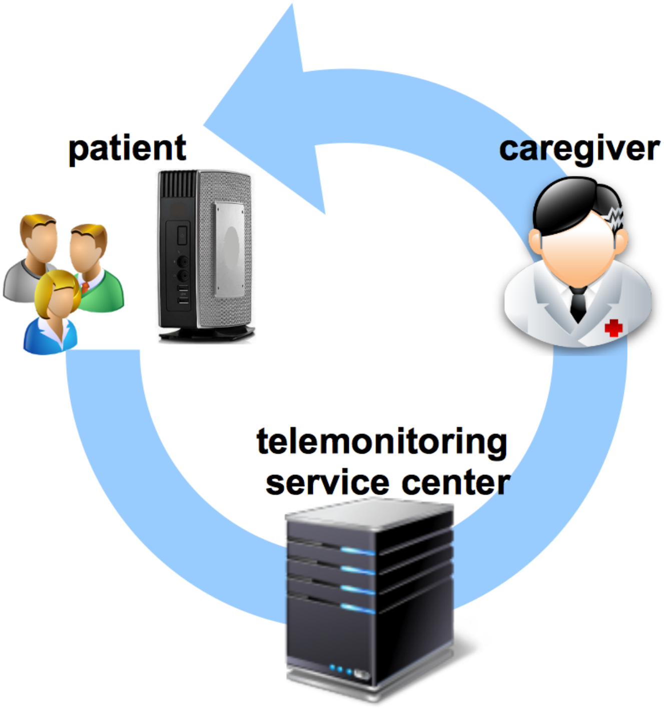

Figure 1.1. 'Closed loop principle' in healthcare. The data collected by the patient is sent to a telemonitoring service center, which is accessible by the attending physician. The physician monitors the health status and may change the treatment, if necessary.

1.2 Chronic Heart Failure (CHF)

CHF is frequently named as one of the major epidemics of the 21^{st} century [13] and affects people mainly around the age of 75. CHF is generally defined as the inability of the heart to supply sufficient blood flow to meet the needs of the body. CHF can cause a number of symptoms such as fluid accumulation which may lead to pulmonary congestion and peripheral oedema. Other symptoms are dyspnoea and fatigue, which may limit exercise tolerance. It is defined as a complex clinical syndrome that can result from any structural or functional cardiac disorder that impairs the ability of the ventricle to fill with or eject blood [14].

Over time, conditions such as narrowed arteries (coronary artery disease) or high blood pressure gradually leave the heart too weak or stiff to fill and pump efficiently. Tight control over medication, a lifestyle change and tight monitoring are the first steps to treat heart failure. The goals of treating heart failure are to decrease the likelihood of disease progression (decrease mortality and the need of hospitalisation) and to improve quality of life. The stages of heart failure are classified by the New York Heart Association (NYHA) into different stages from I-IV according to the degree of the symptoms [1].

Table 1.1. New York Heart Association Classification [1]

NYHA class	Symptoms
I	Patients with cardiac disease but no symptoms and without limitation in ordinary physical activity.
II	Patients with cardiac disease resulting in mild symptoms and slight limitation during physical activity. They are comfortable at rest.
III	Patients with cardiac disease resulting in noticeable limitation of physical activity.
IV	Patients with cardiac disease resulting with severe limitations. Inability to carry on any physical activity without discomfort.

CHF causes a high readmission rate and the prevalence is increasing [15]. There are two reasons for the upward trend in CHF prevalence: Firstly the aging of the population which is responsible for an increased prevalence of arterial hypertension and coronary artery disease and of the resulting left ventricular dysfunction. The second reason is the higher survival rate of acute cardiac patients after a heart attack due to the efficiency of intensive care procedures [16].

Today CHF patients with acute decompensation are often being hospitalised. During their stay at the hospital, those patients are treated with an oral therapy regime according to international guidelines. CHF therapy management is often very complex including administration of interacting drugs depending on the current health status of the patient [17]. However, those patients are discharged from hospital when their health status returns to a stable condition and are being trained in self-administration of the CHF therapy management at home. To prevent heart failure from worsening, patients should keep their blood pressure low so that the heart can pump effectively without extra stress. Patients should check their fluid status by weighing themselves daily to avoid fluid retention.

Because of the complexity of CHF self-management and a lack of communication between patients and doctors during the therapy process, it is hardly surprising that patients' compliance to the given therapy management is often poor. This results in a high rate of rehospitalisations within 6 months after discharge and a poor quality of life [18].

Hence, conventional methods (i.e. patient education and training) must be enhanced to increase the quality and the outcome of CHF therapy and self-management. New strategies are needed to support patients in CHF self-management and to guide them through the therapy management process in order to achieve the best possible health status at home.

The concept of heart failure treatment has changed dramatically within the last years. Prior to the late 1980s, cardiac enlargement, decreased left ventricular systolic function and heart failure were considered absolute or relative contraindications to exercise training. Exercise and physical activity is a treatment area being completely readdressed. Previous treatment strategies involved restriction of physical activity and bed rest [19].

Rest was considered to be beneficial due to increased blood flow and enhanced urine output. Patients were advised to avoid exercise, however prolonged inactivity can lead to skeletal muscle atrophy, venous thrombosis, pulmonary embolism and decubitus. The concept of exercise training in heart failure patients first developed in the 1980s and is now a well established treatment. Exercise gives partial relief of symptoms such as muscle weakness, sleep disturbance and improves NYHA class. Patients with heart failure experience progressive disability and decline in health-related quality of life. Exercise training is an effective treatment to improve quality of life, as patients become more comfortable performing tasks of daily living. Such a response is associated with more independence, less chronic illness behavior and less depression. However, any recommendation for exercise training should be adapted to each heart failure patient and his condition individually [19].

CHF patients are also influenced by ambient effects such as weather. Bhaskaran et al. [20] reviewed 19 studies, a number of these studies suggested that ambient outdoor temperatures have a short-term effect on overall mortality. Periods of extreme cold or heat have also been associated with mortality peaks. Evidence suggests that cardiovascular effects of differences in ambient may contribute to the increased mortality risk. Many studies have shown that hospital admissions for heart disease increase monotonically with average temperature on the day of and the day before admission [21], [22], [20].

Many studies have shown increased cardiovascular diseases mortality both with cold [23] and hot [24], [25], [26] outdoor temperatures.

1.3 State of the art

In the following section an overview of existing telemonitoring systems will be given.

In a German clinical study ('Partnership for the heart'[1], 2010), 710 patients were equipped with medical devices over a minimum period of 12 months. The telemonitoring system used portable devices to monitor the activity, ECG + SpO_2, blood pressure and body weight. The devices were connected to a personal digital assistant via Bluetooth that sent automated encrypted messages via cell phones to the telemonitoring service center. The primary end point was death from any cause. The first secondary end point centered a composite of cardiovascular death and hospitalisation for heart failure. At least 70% of the patients were compliant with the daily data transfer to the telemonitoring data center and had no break in information transfer for >30 days [27].

In an Austrian trial named 'MOBIle TELemonitoring in heart failure patients (MOBITEL, 2009)' patients with a recent episode of acute decompensation were randomized to a telemonitoring or control group. One group received pharmacological treatment (control group), the other received pharmacological treatment with telemedical surveillance. Patients in the telemonitoring group were equipped with a mobile phone based patient terminal, digital weighting scales and a fully automated blood pressure monitors (BPM). Patients in the telemonitoring group were asked to send physiological parameters using Wireless Application Protocol (WAP) on the mobile phone. If values exceeded the individual set limits, the physician was sent an alert email. Primary endpoint was either hospitalisation or death. The study showed that 18 control group patients reached primary endpoint (17 hospitalisations, 1 death) compared to telemonitoring group patients (11 hospitalisations, 0 deaths) risk of hospitalisations could be reduced. Hospitalised telemonitoring patients had a significantly shorter stay (median 6.5 days) compared with control group (median 10.0 days). Several studies have been conducted which show, that telemonitoring has the potential to improve outcomes in the treatment. The preliminary results of this study indicate that telemedical interventions can contribute to the prevention of an undesirable course of disease.

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[1] www.partnership-for-the-heart.de

Based on these results a telemonitoring system called Elicard[2] was developed to monitor CHF patients. Elicard is a heart failure telemonitoring system developed by Austrian Institute of Technology (AIT) which is already in use at the Elisabethinen hospital in Linz, Austria to monitor a significant number of patients successfully.

It is a system based on a mobile phone as an Application Hosting Device (AHD), collecting the patients health data via Near Field Communication (NFC). Being a portable patient terminal, a mobile phone allows patients not to be bond to a specific location to take their measurements, which can boost their quality of life. NFC offers a safe data transmission due to its limited operation range. With a nominal reach of a few centimeters and the limitation to two communication partners the 'Keep in Touch (KIT)' paradigm is given. When a NFC enabled mobile phone and a NFC enabled health device are brought together they pair automatically and begin to transmit data.

Figure 1.2 a) shows the KIT system with a blood pressure meter and NFC enabled mobile phone. The communication is established by bringing the devices close together. After the data (blood pressure and heart rate) are collected, they are sent to a telemonitoring service center automatically. No manual interaction (data entry via key pad) on the mobile phone is required.

Figure 1.2 b) shows the Elicard dialog book, which uses passive Radio-Frequency identification (RFID) tags. By touching the tags with the mobile phone, the patient can give information about his medication intake and wellbeing. In order to realise a 'Closed loop principle' with the opportunity for physicians to increase the compliance to a therapy, the KIT system is connected to a remote therapy management system developed by the AIT [9].

a) b)

Figure 1.2. 'Keep in Touch' technology

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[2] www.elicard.at

The process for the acquisition and transmission is as follows:

1. Measure blood pressure as usual
2. Touch the smart card with the mobile phone
3. Touch the blood pressure monitor to collect data
4. Touch the smart card again to signal that the data acquisition has been finished

Data acquisition and transmission needs usually less than three minutes and is done without a single keystroke [9].

Three key components for the smooth routine operation of the system in daily use were identified. They mainly concern the interaction between participants of the system (caregiver and patients) and the system itself. The main points are defined by [9]:

1. Usability and secure data acquisition methods for the patient:
   The main requirement for the use of the system is an easy, secure and consistent monitoring of the designated vital parameters (blood pressure, pulse and body weight) as well as subjective parameters like well-being and medication intake. The patient needs a system that can collect vital parameters from medical devices as well as answers to questions about their well-being and medication. The data should be collected without overburdening the patient with data input. The age of the main patient group is essential.

2. Ability to monitor the medication:
   The ability to monitor the dose of medication is important for the therapy. The caregiver can respond to changing symptoms by varying the dosage of the medication.

3. Pre-processing algorithm:
   Early detection of changes in vital parameters is a key component of the system, therefore there is a need of pre-processing in order to determine if a patient is still in the predefined thresholds. An entry is added to the eventlist, if a value exceed the thresholds.

The Pre-processing algorithm creates entries, which are reported, in the following three events.

- Exceedance of limit value: Every new measured value is compared to the set thresholds, a violation automatically creates an entry in the event list. Filtering algorithms ensure that not every violation is reported i.e. overstepping of the blood pressure values is only reported when it happens several times, a weight gain of >2kg/2days is reported or the patient reports a bad wellbeing.
- Failure to take measurements: If the patient fails to take and send measurements for several days, the patient is classified as overdue and reminded via a text message.
- Weekly checkups: If none of the situations mentioned previously cases occur, every patient is assigned to the 'weekly checkup' category to be checked by the physician.

1.4 Challenge of the thesis

Mobile phones have been given the most important role when it comes to logging health data. In Morak et al. (2007) [28], the authors proposed a home monitoring concept based on mobile phones and NFC technology. It was for this reason, that the KIT technology was introduced, which allows the collection and forwarding of health data for chronically ill and elderly people. KIT ensures the intuitive data acquisition by touching the particular devices. Mobile phones equipped with NFC technology become patient terminals, simply by touching the medical devices or objects equipped with an NFC interface. Multiple platforms have made it unaffordable in terms of costs and development time to support such applications on the newest mobile handsets. Another reason is that because some patients are not free to move they can be monitored with a stationary data collecting hub, also known as AHD. Technology can be a resource for the elderly if the users perceive a device or system as being helpful and not stigmatizing or too complex. Technology acceptance not only depends on the needs and attitudes of older people but also on their age, gender, experience of life and health conditions [29].

Elderly people are confronted with complex systems which require a lot of training and sometimes do not work properly if not used in the correct manner. Besides multimorbidity, cognitive functions begin to decrease with age, so usability is an important issue. If a device, for example a mobile phone which has a primary function to phone somebody, is used for some other purpose, older patients sometimes react with refusal and mistrust [30].

1.5 Wireless technologies, standards and interoperability

Wireless technologies play an important role in applications dealing with telemonitoring, AAL and fitness. Technologies such as WiFi, Bluetooth and NFC have already been utilized for monitoring purposes in AAL and telemonitoring. ANT+ and ZigBee offer ideal protocols to be used in the AAL setting too.

These technologies can be utilized to offer solutions to increase autonomy, better symptom control and healthcare for elderly people. Telemonitoring can be used to control sudden degenerations in the patient's health. The idea of AAL is also linked to Ambient Intelligence which refers to electronic environments that are sensitive and responsive to the presence of people. Such a system ideally consists of many invisible, unobtrusive devices that monitor the patient's area of life. Sensors incorporated into appliances and furniture would recognize the user and adapt to the users' needs [31].

Next to AAL and telemonitoring the field of fitness and sports is an area of application for sensing and monitoring as well as wireless transmission of vital signs. Physical exercise is important as it can contribute positively to maintain a healthy lifestyle. Tracking activity and analysing data is becoming easier for the end-user. Fitness systems provide a range of training tools from online analysis to fitness equipment. Such systems can be employed easily to monitor daily activity.

Standardisation is a prerequisite for a broad deployment and use of ICT in eHealth, it triggers and enables new businesses. The ICT standards community is characterised by a large number of standards bodies, ranging from basic communication standards to the content standard. ICT standardisation is already a big issue and standardisation in AAL technologies is also rapidly evolving in order to achieve the necessary interoperability [32].

The Continua Health Alliance (CHA) - an industry-driven global consortium - has taken the lead and established design guidelines and a product certification process for medical devices and infrastructure connecting them. In Continua's view the market will be driven by different trends, the healthcare will be driven by the needs of the consumer and the individual's home will function as a hub.

To cope with these requirements AAL has to combine products from different market segments, offered by different manufacturers, which need to work together. Currently most of these products are stand-alone solutions and do not offer interoperability. In the future they should work together or have a common interface. The following market segments could be relevant for AAL:

- medical devices
- home automation and control
- environment monitoring systems
- fitness and sports equipment

Currently, most of them have different standards, different data exchange protocols and different terminology. A future system for AAL could be based on a combination of all technologies to provide the best care as possible for the patients [31]. Monitoring systems available up to now use only one or two of the mentioned wireless technologies [33], [34], [35].

1.6 Interoperability Levels

According to Broek [31] the following levels of interoperability are to be considered.

Physical or environmental interoperability to ensure that products fit together and fit into the environment related to the connectors as well as considering Electromagnetic Compatibility (EMC) regulations and wireless communication protocols for transmissions.

Technical or syntactically interoperability refers to the safe and secure transmission of data. The focus of technical interoperability lies in the conveyance of data, not in its meaning. It incorporates the transmission and reception of information that can be used by a person, for instance the encryption and decryption to ensure a secure transmission or the use of a 'check digit' to verify the integrity.

Semantic interoperability allows meaningful exchange of data between the systems and the service and in so doing ensures the mutual understanding of each systems data. It is the ability to understand data that is shared between systems.

Process interoperability is a concept that has been identified as a requirement for successful system implementation into actual work settings. It deals with methods for optimal integration of computer systems into actual work settings of humans. Explicit user role specification, useful, friendly and efficient human-machine interface and data presentation/flow supports the work setting.

The first two levels are well understood but an agreement on standards and development effort is still required. The last two levels still need a lot of research.

Four types of standards can be distinguished:

- official standards which are mandatory to use
- voluntary standards
- proprietary standards defined by the industry
- open standards

The CHA has selected three domains (aging independently, chronic disease management, health and wellness) to establish an ecosystem of interoperable personal health systems. Continua wants to approach the interoperability problems by developing design guidelines based on existing standards to enable device manufacturers to build interoperable sensors, home networks, telehealth platforms and health services. Furthermore, the CHA intends to establish a product certification program with a consumer recognisable logo, promising the interoperability between certified products. Products are tested against interoperability guidelines and reference systems.

Cost savings for health care providers and consumers can be realized differently depending on the use case [36]. Different working groups are responsible for different activities in the consortium and therefore have different responsibilities. These are technical, use case, market, regulatory, test and certification. There are also working groups for lobbying in the European Union, Japan, Latin America and the United States [37]. Requirements ranging from marketing, through technical aspects to business models are decided in those working groups [38].

1.7 Internet of Things (IoT) for AAL

The IoT is a concept in which the virtual world of information technology integrates seamlessly with the real world of things. The real world becomes more accessible through computers and networked devices in business as well as in everyday scenarios. Thanks to the recent advances of miniaturization and the falling costs for RFID, sensor networks, NFC, wireless communication, technologies and applications, the IoT has suddenly become relevant for industry and end-users. Detection of the physical status of things through sensors, together with collection and processing of detailed data allows immediate response to changes in the real world. This fully interactive and responsive network yields immense potential [39].

The idea of IoT originates from the following innovations in ICT [40]:

- Ubiquitous Communications
- Pervasive Computing
- Ambient Intelligence

A new dimension is being added to the world of ICT: from connectivity anytime and anyplace for anyone, there is now connectivity for anything. AAL has a strong bond to 'Ambient Intelligence', which is a leading IoT technology. Safety and wellbeing can be increased with the help of smart objects. The monitoring of chronic diseases (health), alarm and reminder systems (safety) are just few applications [40].

1.8 AAL use case

A special use case regarding AAL is an elderly, computer illiterate couple. At least one person in this household is chronically ill (e.g. CHF) and is monitoring his/her vital parameters (weight, blood pressure) for therapy optimization. Activity parameters are collected to determine the patient's heart failure status according NYHA classification from I to IV. The patient is meteorosensitive, so environmental data are collected to give feedback to the patient about weather conditions.

In this use case, multiple devices should transmit their data to an AHD placed in the center of this household. The AHD should be able to collect data from one or more persons living in that household as well as environmental data. This data should be routed through the internet to the telemonitoring service center.

1.9 Objective of the thesis

The objective of this thesis is to design an AHD, based on a broad range of wireless interfaces that are well established in the eHealth market.

The basic idea is to separate the assignments of a mobile phone for telemonitoring into two paths. Path one would be to build up a platform to collect health, sports and fitness and environment data and transmit them to a data center. In path two feedback and trend data can be received and visualized for a Graphical User Interface (GUI). Path two can now be any PC, tablet or mobile handset, without the need of specific interfaces.

A user interface in path one is not needed but possible, for usability reasons remote maintenance of the system is preferred. With the use of wireless communication technologies personal health, sports and fitness and environment data should be collected by different sensors transmitted to the system automatically. Various wireless communication technologies should be identified in this thesis and applied to their best use.

The system is intended for a seamless integration into the patient's life without changing his/her daily routine or giving him/her the feeling of using technology. A prototype of this AHD should be developed to act as an experimental platform in telehealth and AAL applications ranging from patient monitoring and sports tracking to home sensing and control. Home devices for body weight and blood pressure should be used to track the vital data from the patient.

Bluetooth is often used for medical devices because saving power in not an issue. ANT+ is used for sports and fitness devices, where saving power is an issue and devices need to live on a coin cell battery. In a smart home environment ZigBee seems to be the best solution as a communication protocol due to its ability to create large wireless sensor networks.

Based on a minicomputer or netbook the basic idea of the 'KIT case' (shown in Figure 1.3) should be prototyped. The AHD should have interfaces to the following technologies:

- NFC for user identification and configuration
- Bluetooth to connect to health devices with Health Device Protocol (HDP)
- ANT+ to connect to sports and fitness devices
- ZigBee to collect environmental data
- WiFi, Ethernet or integrated mobile network link to transmit data to the telemonitoring service center

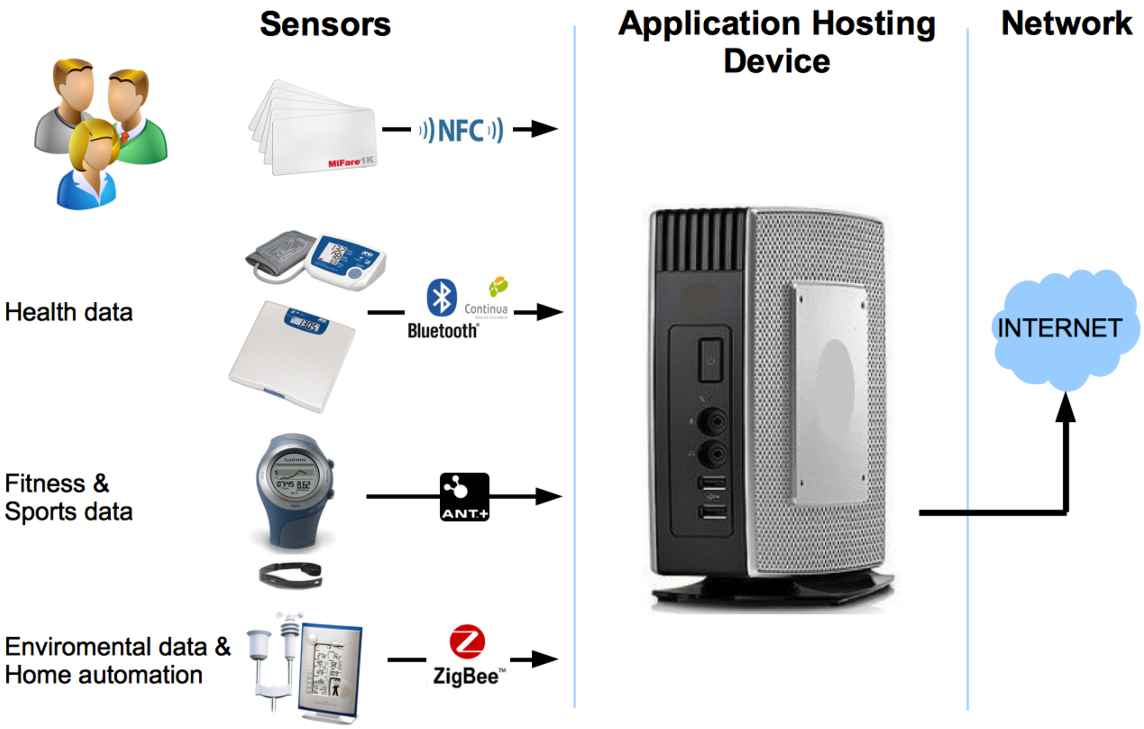

Figure 1.3. System overview of the desired AHD

CHAPTER 2

METHODS

In this section, the concept for developing a multiuser and multimodal AHD will be discussed.

Communication with health, sports and fitness and home automation and control devices require a wide spectrum of communication protocols. The technology to collect information about the user's health status, his/her fitness and wellbeing and the environment does already exist. The idea was to develop a system to collect all this data in one place so that the information can be shared effectively. At the beginning of the masters thesis a market research was made to determine if such systems already exist. The results are presented in chapter 3 of this thesis.

2.1 Wireless standards

In telemonitoring, AAL and fitness applications wireless technologies play an important role. Telemonitoring and AAL applications have already used technologies such as WiFi, Bluetooth and NFC for monitoring. ANT+ and ZigBee offer ideal protocols to be used in the telemonitoring and AAL setting too. In the following sections the various wireless protocols are introduced. The wireless protocols were compared respective to their range, data rate, field of application, energy consumption, setup process (pairing) and security. The results are presented in Chapter 2.2.

2.1.1 Bluetooth

The IEEE 802.15.1 standard is the basis for the Bluetooth wireless communication technology. The Bluetooth SIG is a proprietary open wireless technology standard for exchanging data over short distances using the Industrial, Scientific and Medical (ISM) band from 2400 to 2480MHz in which unlicensed devices are permitted to communicate, creating personal area networks (PANs).

Bluetooth uses frequency-hopping spread spectrum (FHSS), which chops the data and transmits it on up to 79 bands, each of 1MHz. Bluetooth is a packet-based protocol with a master-slave structure. One master can communicate with up to 7 slaves in a piconet, all of which share the master's clock. Being a slave of more than one master is challenging. The specification is vague about the required behaviour in scatternets[3].

The technology operates with three different classes of devices: Class 1, class 2 and class 3 where the range is about 100 meters, 10 meters and 1 meter respectively. Figure 2.1 shows the Bluetooth power classes.

Table 2.1. Power classes of Bluetooth[4]

Power Class	**Maximum Output Power (P$_{MAX}$)**	**Range**	**Minimum Output Power**[5]
1	100 mW (20 dBm)	100 meters	1 mW (0 dBm)
2	2.5 mW (4 dBm)	10 meters	0.25 mW (-6 dBm)
3	1 mW	up to a few meters	N/A

Bluetooth specifications, which are defined by the Bluetooth Special Interest Group (SIG), state that all versions of Bluetooth are designed for downward compatibility. Todays state of the art standard is Bluetooth v4.0, a specification released in December 2009. In Bluetooth v4.0 the Low Energy (BLE) protocol is implemented which allows devices to establish a connection within less 5ms and maintain it to a distance up to 100m. Currently only the MacBook Air, Mac mini and iPhone4S have implemented, dongles with the 4.0 specification will enter market in 2012.

Although Bluetooth v2.1+EDR was used for the practical part of this master thesis, Bluetooth v4.0 will permit Low Energy protocol enabling devices to operate for months or even years on a coin-cell battery. This creates new opportunities for sports fitness device developers to work with Bluetooth. Currently the power consumption of Bluetooth limits battery lifetime, so the focus has been on ANT+ to collect patient activity data and ZigBee to collect environment data.

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[3] A scatternet is a number of connected piconets. A piconet is formed between two or more Bluetooth enabled devices.

[4] www.bluetooth.org/Technical/Specifications/adopted.htm

[5] Minimum output power at maximum power setting

Bluetooth has been selected by the CHA as a standard for wireless technology in the eHealth sector. Bluetooth has defined the HDP specifications to meet the needs of the medical community. It is designed in order to exchange data wirelessly between a medical device and a corresponding terminal device [3]. The components utilized in the HDP are shown in figure 2.1.

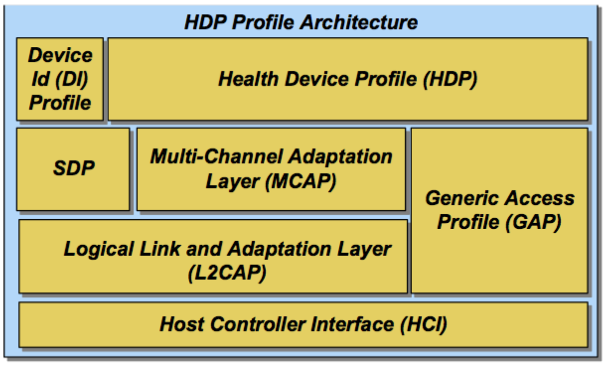

Figure 2.1. Health Device Profile Architecture [3]; SDP-Service Discovery Protocol

HDP provides two roles - sink and source. A source is a small device, which acts as the transmitter of the medical data such as a weighing scale, blood pressure monitor etc. The sink is a device, which acts as the receiver of the medical data for instance a computer, mobile phone etc.

To allow the combination of several sensors, HDP allows the synchronization of signals using the Bluetooth master clock. HDP does not define the data format and data content. The Bluetooth SIG mandates for HDP the usage of the IEEE 11073-20601 for data exchange between HDP devices and the IEEE 11703-104xx device specification. IEEE 11073-20601 defines the data exchange protocol and IEEE 11703-104xx defines the data format including size and coding of all data exchanged between HDP devices. Figure 2.2 shows the architecture of a Bluetooth device with IEEE-11073-20601, Device specifications with IEEE-11073 (-104xx) and IEEE-11703-00103 Personal Health Device Communication specifications [4].

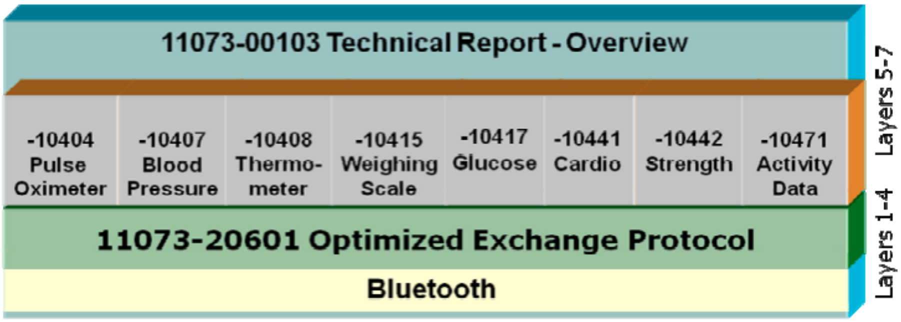

Figure 2.2. Devices with HDP [4]

The length of transmitted data is in most cases 896 bytes for transmission and 224 bytes for reception. The communication happens between HDP Agents (source) and HDP Managers (sink). Both Agent and Manager can start a data transmission.

2.1.2 ANT+

ANT+ is a 2.4GHz wireless networking protocol and embedded system solution specifically designed for wireless sensor networks that require ultra low power. ANT+ is today the de facto standard for ultra-low power wireless connectivity in sports fitness equipment. It is supported by a wide range of ANT+ profiles enabling multi-vendor interoperability. The first cell phones with built-in ANT+ support were launched in 2011. Currently only the Sony X8 & X10 have a built in ANT+ antenna. ANT+ offers the following benefits:

- Extraordinary battery lifetimes - up to years from coin cell batteries
- Small size - enabling small sensors to be developed
- Multi-vendor interoperability - connectivity to existing ANT+ sensors and hubs

All ANT+ networks are built up of nodes. A node can be anything from a simple sensor, to a collection unit, for example a watch or computer. Unique to ANT+ is that the setup of each ANT+ channel is independent from all the other ANT+ channels in the network, including other channels in the same node. This means that one ANT+ node can act as a master on one ANT+ channel while being a slave to another. Since there is no 'network master' in ANT+, the network can solely be configured to the needs of the node. This gives the flexibility in adjusting ANT+ channel parameters like data rate and latency versus power consumption, so the network is as complex as it needs to be at any given time.

The primary parameters which two ANT+ nodes use to identify each other form the channel ID. Once an ANT+ channel is established, the channel ID parameters are set. It is possible to set only the device type of the masters you want to link up with. If a new master is found to match the device type, the slave will connect and store the unknown parts of the channel ID. In areas with a high density of ANT+ networks like a sports centre proximity search helps to find the right master [41], [42], [43].

2.1.3 ZigBee

ZigBee was designed to meet the needs of a low-cost, low-power sensor network. It is based on the IEEE 802.15.4 standard, which is a communication standard for wireless networks specifying the two lowest layers of the OSI reference model. The ZigBee technology is intended to be simpler and cheaper than other Wireless Personal Area Networks (WPAN) such as Bluetooth. It is targeted at applications that require low-data rate, long battery life and secure networking. It is best suited for periodic data acquisition. It is operating on the worldwide license free ISM band at 2.4GHz, 915MHz in America and 868MHz in Europe [2].

Table 2.2. ZigBee specifications [2]

Frequency	Number of channels	Data rate
2.4 GHz	16	250 kbit/s
915 MHz	10	40 kbit/s
868 MHz	1	20 kbit/s

ZigBee battery powered devices can sleep for hours or even days, reducing battery consumption to a minimum. Once associated with a network, a ZigBee node can reactivate and communicate with other ZigBee devices and return to sleep in 30ms. ZigBee implements the Carrier Sense Multiple Access-Collision Avoidance (CSMA-CA) protocol, which reduces interference with other users [2]. ZigBee has been chosen from the CHA for communication with sensors in the home environment.

2.1.4 Near Field Communication

NFC is a short-range communication technology for wireless information exchange. It is based on RFID and contactless smart card technologies. NFC uses magnetic inductive coupling in order to transmit data. NFC allows bidirectional communication between two devices (like Bluetooth). Both devices can initiate data transmission. In addition to the communication between two coequal devices (peer-to-peer communication) NFC supports the access to passive RFID transponders and contactless smart cards like Mifare (NXP Semiconductors[6], Eindhoven, Netherlands) and FeliCa (Sony[7], Tokyo, Japan) as well as the emulation of these kinds of RFID transponders [28].

In October 2011 the NFC-Forum[8] and CHA announced that they will work together to establish a system of personal health and wellness. The two organisations are presently exchanging technical informations to embed NFC as a standard wireless technology in the CHA.

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[6] www.nxp.com

[7] www.sony.com

[8] www.nfc-forum.org

2.2 Comparison of wireless technologies

Different applications require different characteristics in terms of data rate, range, energy consumption and mobility. Different wireless technologies exist to satisfy this needs.

2.2.1 Range and data rate

Depending on the field of application, data rates for wireless services span from very few bits per second to several gigabit per second. Figure 2.3 shows all used wireless communication protocols in this thesis regarding data rate and range.

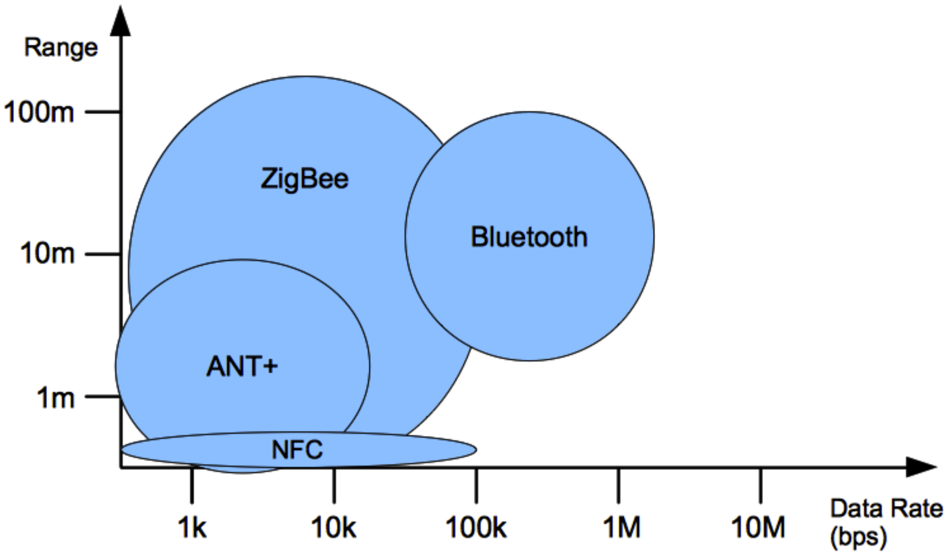

Figure 2.3. Comparison of wireless communication protocols: Data rate versus range for various protocols.

2.2.2 Field of application

Applications of NFC include: sharing personal and business contacts, transfer media and documents, pair electronic devices, mobile payment and ticketing.

Applications of Bluetooth include: consumer electronics, industrial applications, home automation and medical applications.

Applications of ANT+ include: primarily data transfer for sports and wellness applications.

Applications of ZigBee include: light control systems, environmental and agricultural monitoring, consumer electronics, energy management and comfort functions, automatic meter reading systems, industrial applications, and alarm and security systems.

2.2.3 Energy consumption

Energy consumption is a crucial aspect to the field of wireless technology. Most wireless devices have to manage network communication using batteries (rechargeable or one-way). Sensor nodes can be placed where power lines are often not available. Energy consumption can be determined by the distance and data rate. Limiting data rates and decreasing distances between transmitter and receiver saves energy. The set up time plays a huge role in the energy performance.

NFC requires compared to other wireless technologies such as Bluetooth, ANT+ and ZigBee lower power (<15mA to read). However when NFC works with an unpowered device (e.g. smartcard) the NFC power consumption is greater because the RFID tags need to be powered by the reading devices through the electromagnetic field.

Bluetooth power consumption depends on its class and version. Table 2.1 illustrates the different Bluetooth classes and their power consumption. The Bluetooth core specification version 4.0 includes the BLE protocol stack. BLE requires up to 15mA to transmit and receive data. ANT+ needs up to 35mA for transmission and reception. ZigBee consumes up to 150mA for transmission, making it the largest power consumer when active. However, power consumption on average is low, because ZigBee nodes sleep most of the time. This results in a long battery life.

2.2.4 Pairing

Pairing wireless devices may prove to be difficult as every technology has its own pairing mechanisms, which require different steps to be followed by the user. In comparison to other technologies, NFC technology does not require any pairing to exchange data, while others can take quite an effort and time.

Bluetooth technology requires that the devices are set to visible, a manual scan, selection of target device and entering of a PIN code. If the pairing process is successful, both devices store a pairing link in their pairing tables.

When ANT+ is enabled on the receiver and the transceiver is in close proximity, the terminal will send a request to pair. The user has to approve the connection by pressing a button on the ANT+ transceiver device.

Once a ZigBee device has discovered another device within communication range offering compatible services, it can set up a pairing link in order to begin communication. Again the pairing information is saved in a pairing table.

2.2.5 Security

NFC itself cannot provide protection against 'eavesdropping' or data manipulation. NFC is not prone to Man-in-the-Middle (MITM)[9] attack, therefore establishing a secure channel is the solution.
NFC security standards (NFC-SEC) defines a protocol stack that enables application independent and state of the art encryption functions on the data link layer. A key exchange scheme (Elliptic Curve Diffie-Hellman), is used to establish a shared secret between these devices. The shared secret is then be used to create a secure communication channel [44].

With Bluetooth v2.1 Secure Simple Pairing (SSP) was introduced. The four association models used in SSP are the following [45]:

- **Just works:** No user interaction is required with this method of pairing. No MITM protection is provided.
- **Numeric comparison:** A 6-digit number is displayed on the screen of one device where it has to be accepted. Secure against MITM attacks, assuming the comparison is done properly by the user.
- **Passkey entry:** The user enters a 6 digit number shown on one device. MITM protection is provided.

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[9] MITM is a form of eavesdropping where the attacker makes independent connections with the victims and relays messages between them, making them believe they are talking to each other directly.

- **Out of band:** This method supports other wireless technologies for pairing (e.g. NFC). Pairing is done via Bluetooth when devices are brought close together (few cm). This method provides protection against MITM attacks.

ANT+ is a proprietary standard offering an Advanced Encryption Standard 128 (AES) encryption and decryption.

ZigBee uses device encryption with unique link keys shared between each pair of devices. There are three key types in ZigBee. *A master key is a long-term security key between two devices. The second key type is link key, which provides security on a specific link between two devices. Finally, a network key provides security in the network* [46].

Table 2.3 shows a comparison of various wireless technologies regarding their frequency, modulation, media access control, range, data rate, setup time and network topology.

Table 2.3. Comparison of wireless communication protocols

	Bluetooth	**Bluetooth Low Energy**	**NFC**	**ANT+**	**ZigBee**
Standardisation Body	Bluetooth SIG	Bluetooth SIG	ISO/IEC	ANT Alliance	ZigBee Alliance
Frequency	2.4-2.5GHz	2.4-2.5GHz	13.56MHz	2.4-2.5GHz	2.4GHz (worldwide) 868MHz (Europe) 915MHz (America)
Modulation	FHSS	FHSS	ASK	GFSK	DSSS
Media access control	TDD	TDD	N/A	N/A	CSMA/CA
Range	100m (class1)	50m	0.2m	N/A	70-100m
Data rate	1-3 Mbit/s	200 kbit/s	424 kbit/s	20 kbit/s	250 kbit/s
Set-up time	<6s	<6ms	<0.1s	5.2ms-2s	N/A
Network topology	Star	Star	Point-to-point	Point-to-multipoint	Ad-hoc

2.3 Design of an AHD

An AHD, described in chapter 1.9 should be developed to serve the use case described in chapter 1.8.

This AHD supports a broad range of wireless body area, personal area and local area network technologies (PAN/BAN/LAN) to acquire a variety of sensor data. The process of data acquisition has to work autonomously without any user interaction. Thus, RFID and NFC technology is intended for authentication or configuration.

Bluetooth is used as PAN interface to connect medical sensor devices such as blood pressure monitors and body weight scales. Using the IEEE 11073:20601 protocol on top of the Bluetooth stack as realised by the Bluetooth HDP allows to connect medical devices certified by the CHA.

ANT+ is the interface technology of choice for fitness and sports devices. As it operates at a low energy level it is intended for use in wearable sensors.

ZigBee is used in the context of home automation or control. It allows communicating with sensors and actors to collect environmental data or even to control the electrical equipment.

Use of these standard wireless technologies guarantees high interoperability through a broad range of interfaces and hence flexible extension of the system. In order to communicate with a back-end system for synchronizing the acquired data, an Internet connection is needed. This can be realised by simply adding a mobile Internet modem or in the case of a given infrastructure, by using WiFi connection. Figure 2.4 shows an overview of the intended concept.

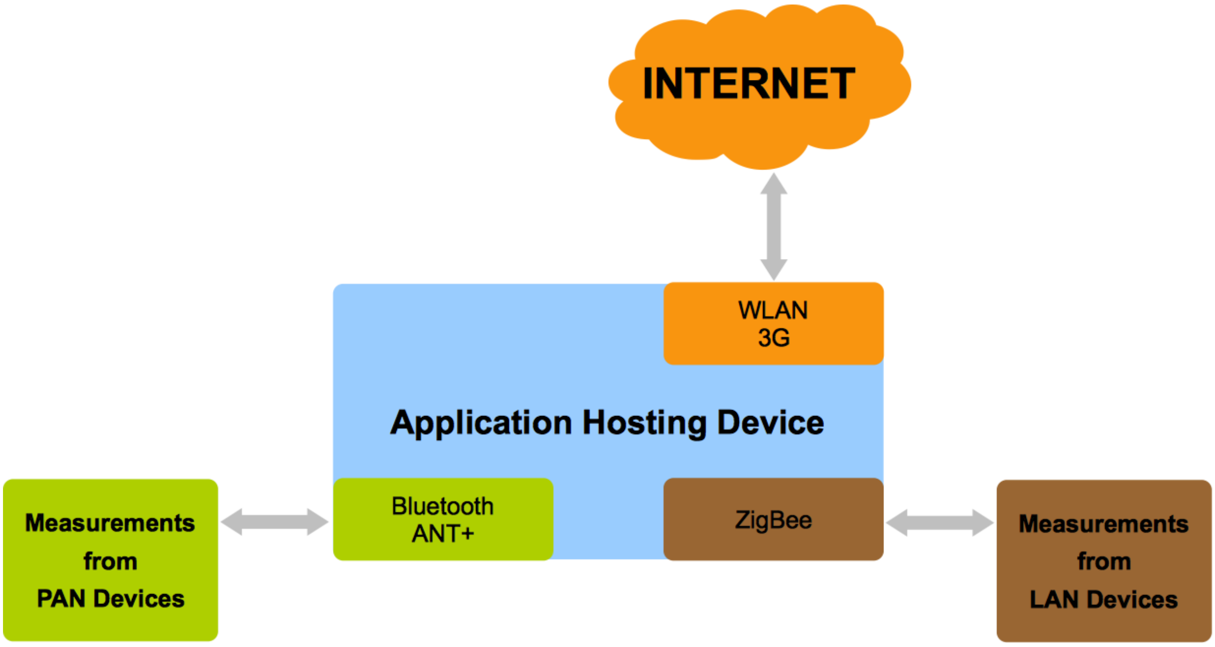

Figure 2.4. Overview of the concept

2.3.1 CHA Reference Topology

The CHA provides design guidelines defining interoperability for the PAN, LAN and WAN interfaces, which enables end-to-end (E2E) interoperability. The E2E architecture is the basis for the interoperability design guidelines, which provides terminology and structure for these guidelines. The architecture distinguishes different interface and reference device classes. In figure 2.5 an overview of the CHA Reference Model is shown. Depending on the communication needs, Continua identifies the following interfaces:

- Personal Area Network (PAN) for communication around a person. Currently, Continua has selected: Bluetooth and USB.
- Local Area Network (LAN) for communication at a location for example with home automation sensors or environmental monitoring. ZigBee has been selected for this purpose.
- Wide Area Network (WAN) Interface for communication from home / office facility to back-end service providers and the Health Reporting Network (HRN)

The AHD can serve interfaces to PAN Devices, LAN Devices and WAN Devices. The AHD can be connected to a HRN Device over the HRN Interface.

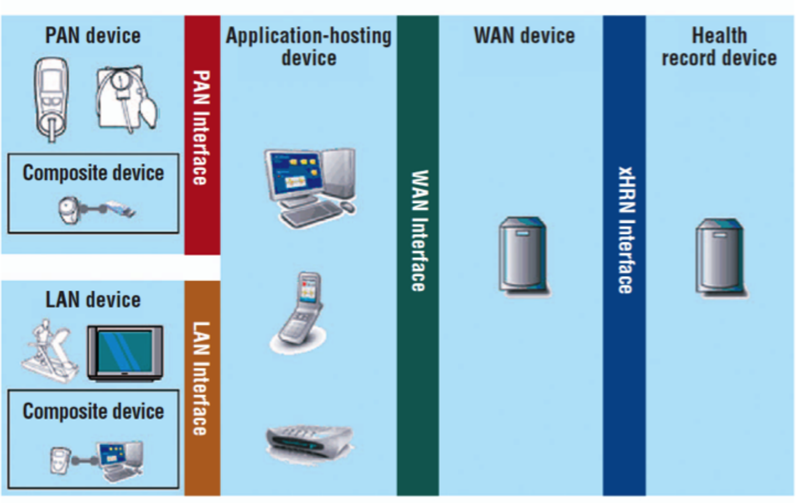

Figure 2.5. Continua Reference Topology [5]

The mission of the CHA is to establish an ecosystem of interoperable personal health systems that empower people and organizations to manage their health and wellness better. Its focus is on:

- Managing chronic diseases
- Aging independently
- Health & Wellness

2.4 Development of a prototype

The work towards creating an AHD acting as a wireless hub will be discussed in this chapter. The AHD was developed prototypically. Figure 2.6 shows a concept of the designed prototype. The core of this experimental platform was represented by an embedded microcontroller system based on x86 architecture with four USB sockets to connect the following dongles:

- NFC smart card reader
- Bluetooth dongle
- ANT+ dongle
- ZigBee dongle

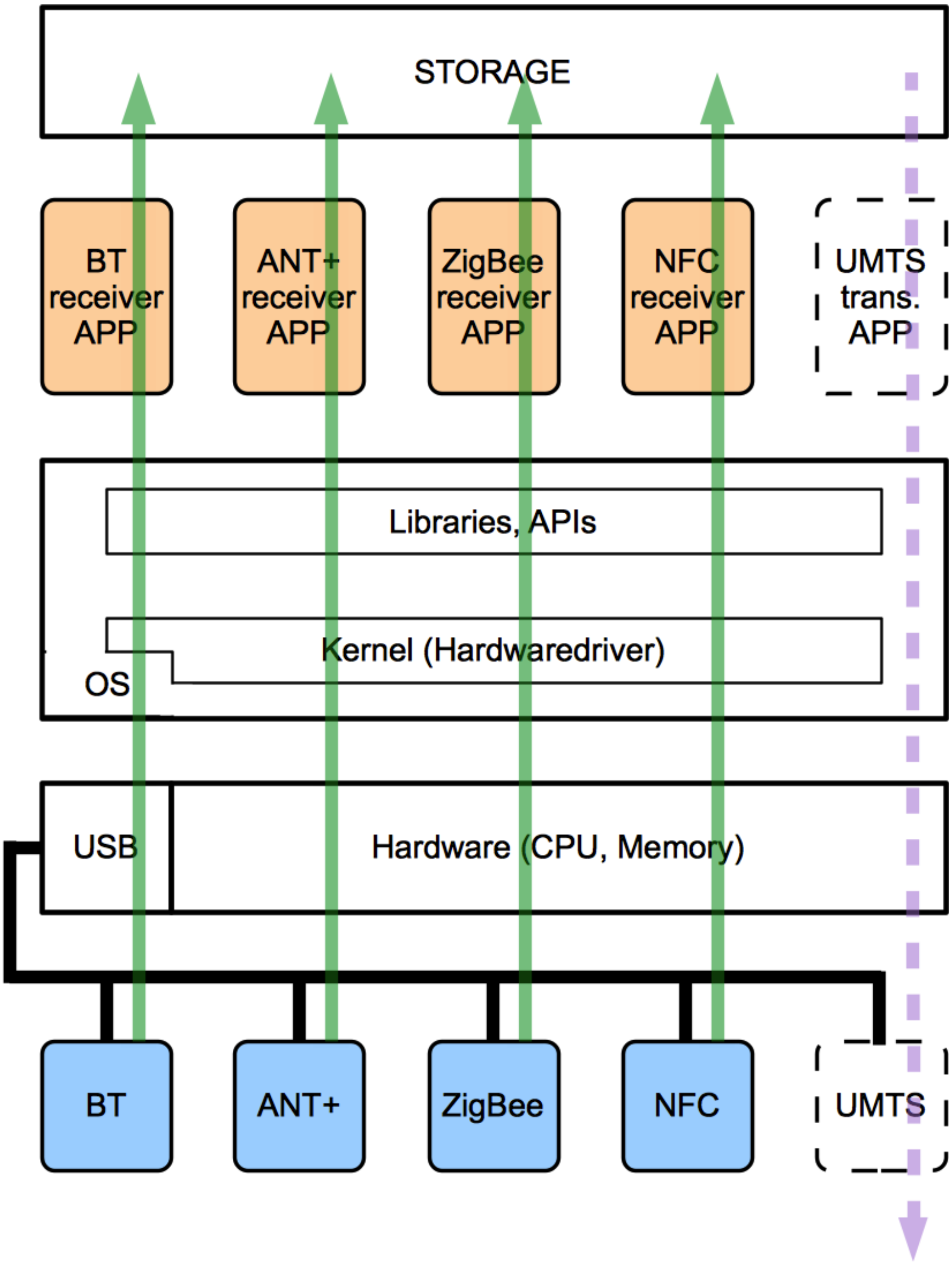

Figure 2.6. Concept of the desired system

In order to ease the software development process for a LINUX operating system (Ubuntu 11.04, Canonical Ltd, London, UK) a Netbook computer was used for this prototype. Several applications and services running on the hub were deployed to collect all data from the dongles and to store them locally.

2.4.1 Bluetooth interface for medical device interrogation

A Bluetooth V2.1 Class 1 USB dongle (bazoo 27211, Vivanco AG, Ahrensburg, Germany) was used as the interface. The USB dongle offers data rates up to 3 Mbit/s, with a range up to 100 meters. It is supporting the needed Bluetooth profiles to exchange data with health devices.

To communicate with health devices the open source IEEE 11073:20601 stack library Antidote was used. The IEEE 11073:20601 protocol stack is a standard stack aimed at medical and health devices. Both CHA and Bluetooth HDP use this as their standard application protocol. As well as the library, Antidote contains a full health service application based on D-Bus. This service allows applications to access health devices via D-Bus. Figure 2.7 shows how health data is read via Bluetooth.

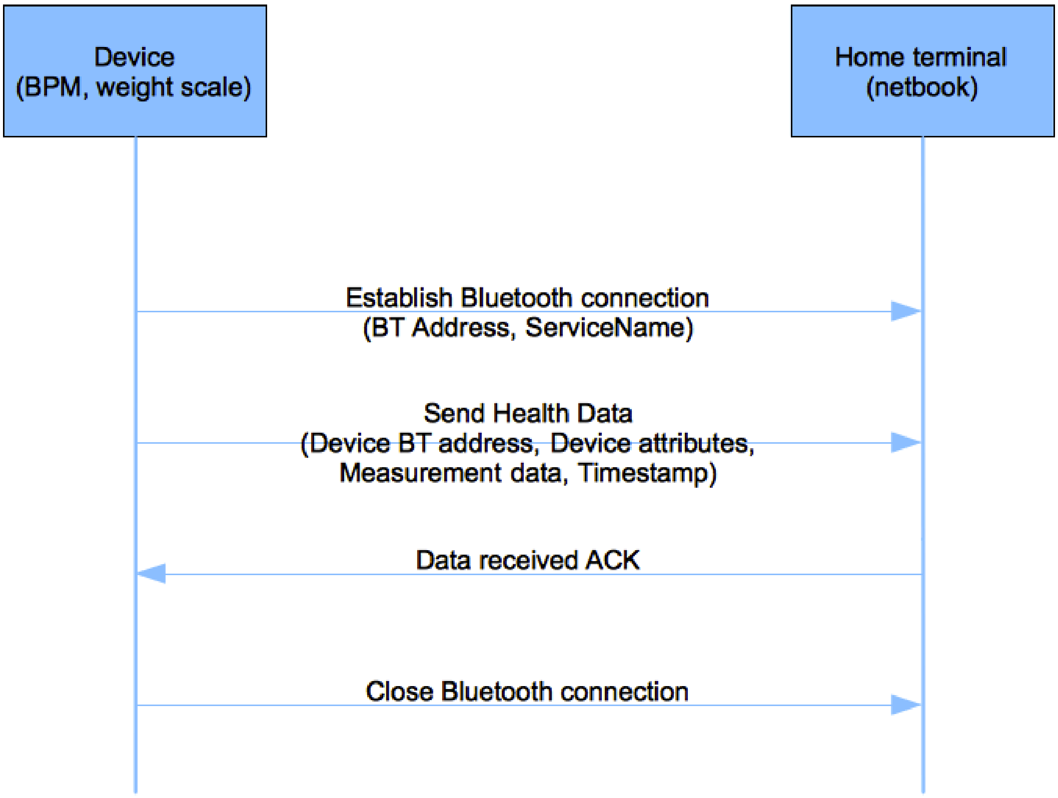

Figure 2.7. Interaction of the health care application with the devices

The Antidote library offers also an Application Programming Interface (API). The API was used to develop an application to communicate with medical devices using the Continua HDP. Dependencies to work with this API are the following:

- Kernel 2.6.36 or newer
- BlueZ (Version 4.80 or newer) - BlueZ provides support for core Bluetooth layers and protocols (such as HDP)[10]
- D-Bus (Version 1.4.0 or newer)

The data acquired by the AHD should have a standardised format to obtain interoperability. A suitable standard is eXtensible Markup Language (XML) that defines the rules of encoding in a format that is both human-readable and machine-readable. Many APIs have been developed to use and process XML data. Medical data received from the Continua enabled devices was received in XML format.

2.4.2 ANT+ Interface for sport device interrogation

A Garmin ANT+ USB dongle (ANT+ USB stick, Garmin, Olathe, Kansas USA) was used to communicate with a ANT+ compatible sport and fitness device such as a sport watch for runners. It offered the best solution to collect data from ANT+ enabled devices such as a tracking device.

The garmin-forerunner-tools package (0.10-3, Ubuntu) was used to read in the users' activity data from the used sport devices. The package contains a tool to sync data to and from Garmin GPS devices. It supports downloading track data, including information about runs. The application is running in the background once the devices are paired after system boot up. The code was modified to poll every second for the paired device in the ambiance. The user has to confirm data transmission by touching the sports watch, then the data interrogated by the application by means of the USB dongle. Figure 2.8 shows the ANT+ data acquisition process.

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[10] www.bluez.org

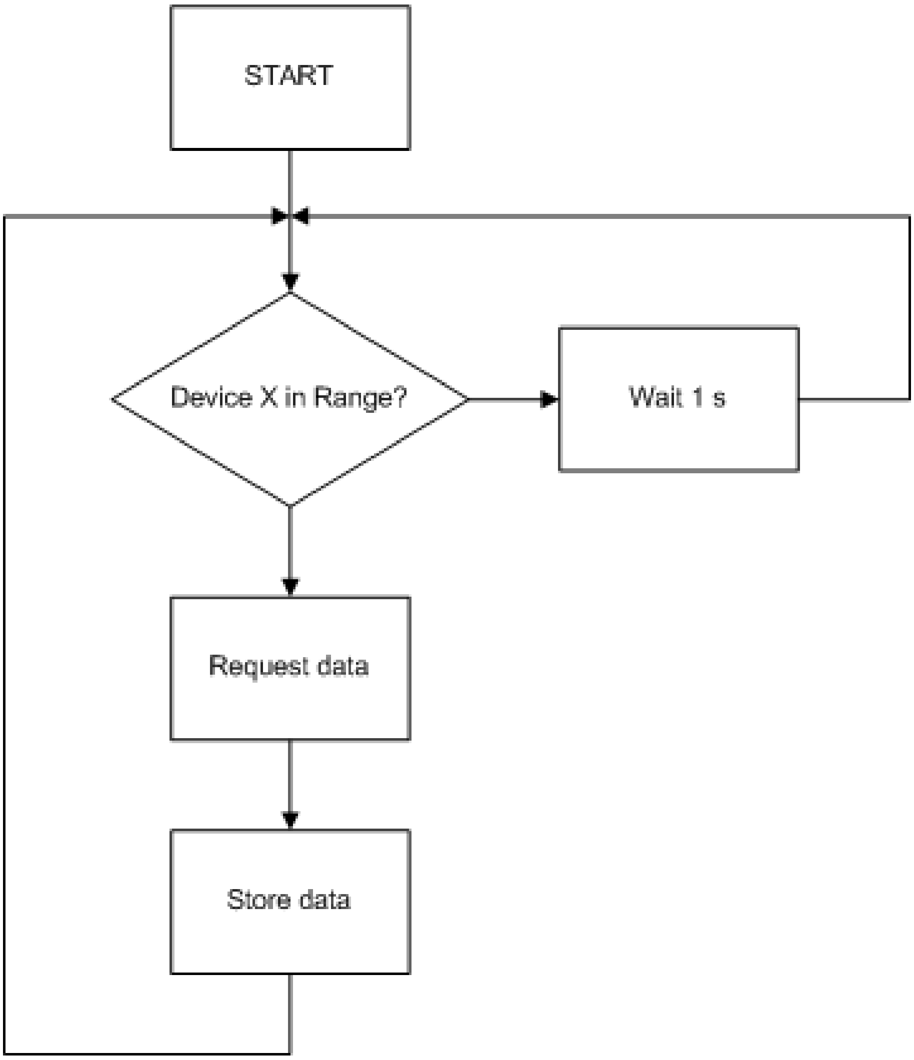

Figure 2.8. Flowchart of the software to collect data from ANT+ enabled devices

The Training Center XML (TCX) format was employed as the transfer format, TCX is a data exchange format introduced in 2007 as part of Garmin's Training Center product. The XML treats a track as an Activity rather than simply a series of GPS points. TCX provides standards for transferring heart rate, running cadence, bicycle cadence and calories in the detailed track.

2.4.3 ZigBee Interface for environmental sensors

A development board with a ZigBee based wireless transceiver[11] (eZ430-RF2500, Texas Instruments, Dallas, TX) was utilized in order to receive environmental data. The eZ430-RF2500 is a USB-based development tool. It uses the MSP430F2274, a 10 bit micro-controller and CC2500 2.4 GHz wireless transceiver. Figure 2.9 shows the ZigBee radio transceiver of the development tool with the free input pins.

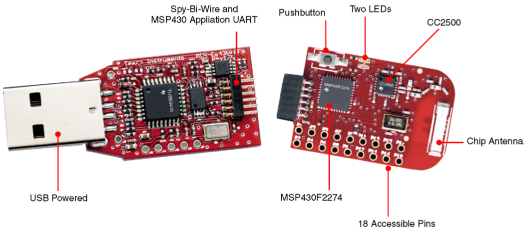

Figure 2.9. Texas Instruments RF Development Tools

A firmware to acquire data from the transceiver and send it to the USB port was developed. Code Composer Studio (Code Composer Studio v4 Core Edition, Texas Instruments, Dallas, Texas, USA) was utilized to code and debug the application.

Figure 2.10 shows the structure of developed software. The transceiver itself measures the ambient room temperature and sends it to the USB port. The transceiver can also send the received data from a sensor node to the USB. The received data are then stored locally for further calculations and/or visualizations.

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[11] www.ti.com/tool/ez430-rf2500

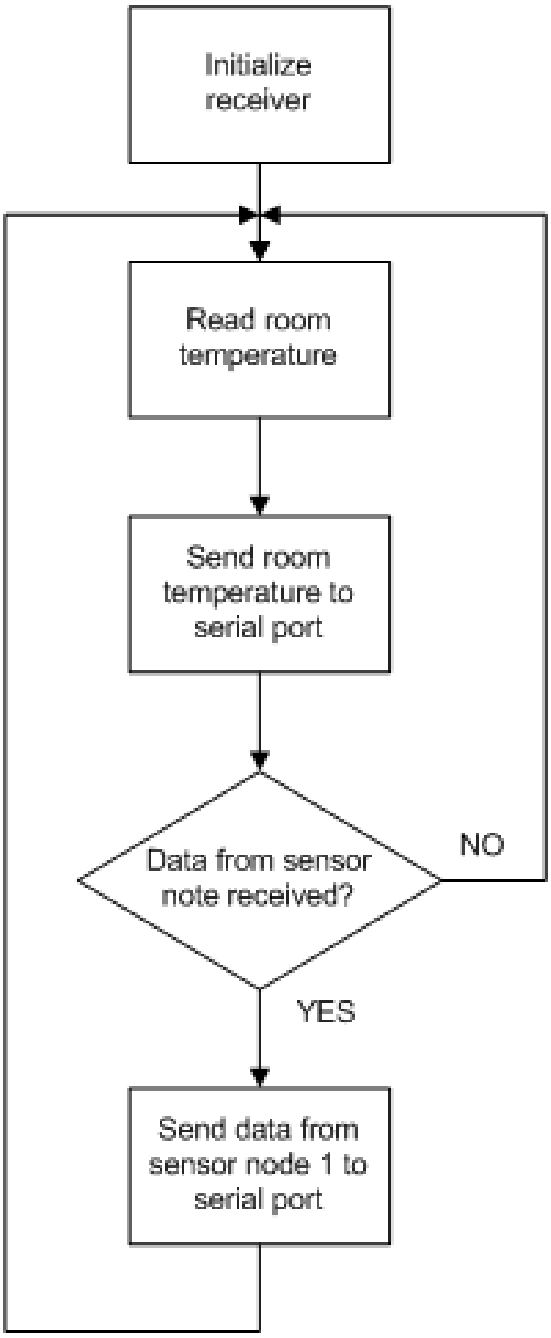

Figure 2.10. Flowchart of the firmware running on the embedded ZigBee receiver

Data from the environment monitoring board and the smart card reader were sent in ’txt’ format.

2.4.4 NFC Interface for user authentication

A Smart Card Reader (ACR122U, Advanced Card Systems Ltd.[12], Hong Kong) was used for user authentication (Figure 2.11). The ACR122U is a contactless smart card reader based on the 13,56MHz RFID technology, compliant with the Chip Card Interface Device (CCID) and Personal Computer/Smart Card (PC/SC) specifications. It supports Mifare®, ISO 14443 Type A and B, FeliCa and all 4 types of NFC (ISO/IEC 18092) tags specified by the NFC-Forum. It follows the ISO 14443 and ISO 18902 standards. It has an access speed of up to 424kbs and a proximity distance of up to 5 cm, depending on the tag type in us [47].

Figure 2.11. Smart card reader (ACR122U, Advanced Card Solutions Ltd., Hong Kong)

The open source library for NFC libnfc, which was released under the GNU Lesser General Public License was used to communicate with the smart card reader and to read the data of cards placed on it. The library supports various NFC hardware devices. The prerequisites to embed libnfc into Ubuntu are libusb, pcsc-lite and libccid.

An application read and store the Unique Identifier (UID) of an RFID card placed onto the reader was developed in C. Data were stored in a log file. Figure 2.12 illustrates the user authentication process with the NFC reader.

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[12] www.acs.com.hk

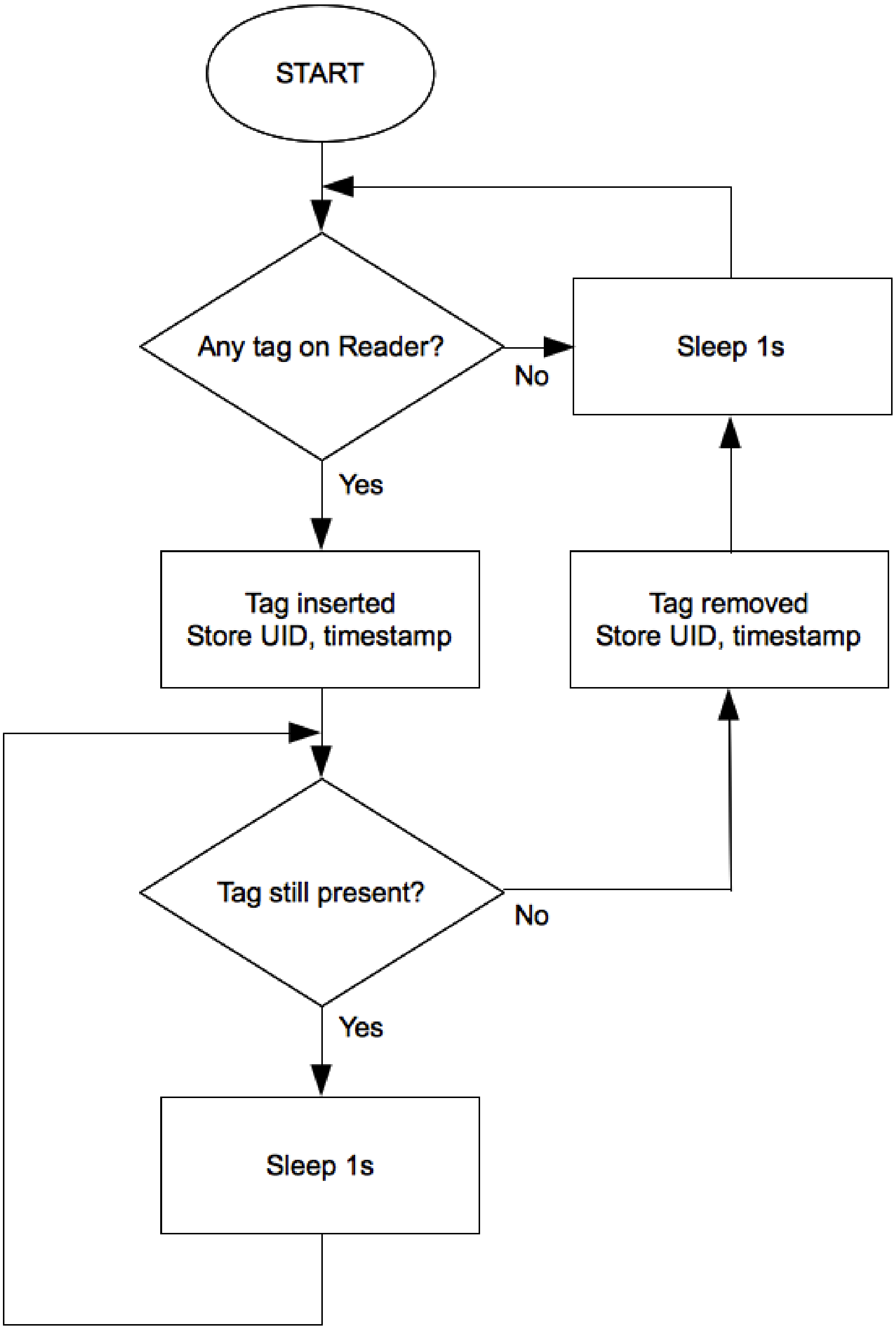

Figure 2.12. Flowchart of user authentication

2.4.5 Development of an environmental data sensor

To measure temperature, humidity, illuminance and ambient air pressure an add-on board with appropriate sensors was developed and linked to the target board of the ZigBee development kit from Texas Instruments (Figure 2.13).

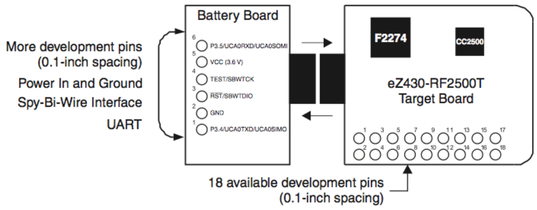

Figure 2.13. Texas Instruments ZigBee target board

The schematic of the added board to sense humidity, luminance, ambient air pressure can be seen in figure 2.14. The firmware of this wireless sensor prototype was developed for the purpose of acquiring and sending these data to the AHD periodically. Code Composer Studio (Code Composer Studio v4 Core Edition, Texas Instruments, Dallas, Texas, USA) was used to code and debug the application and download it to the target boards.

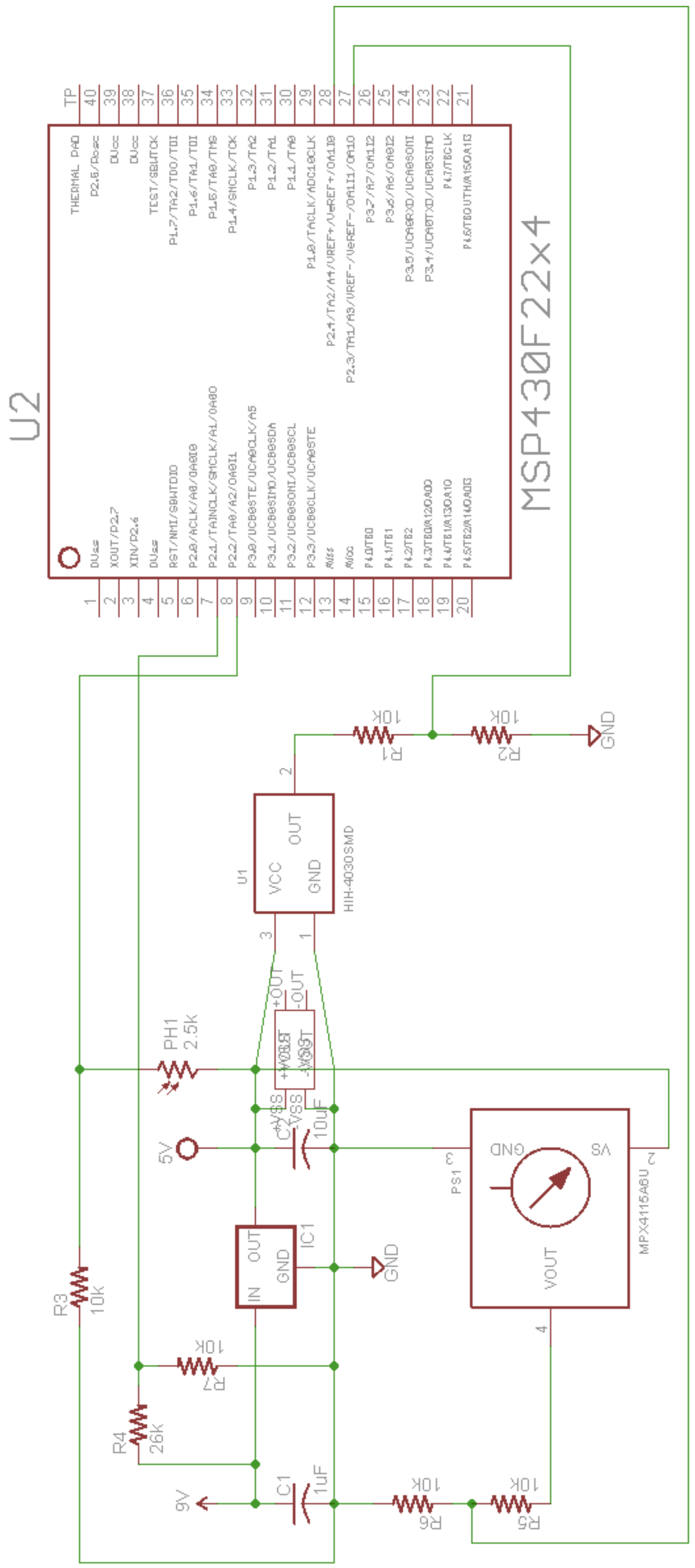

Figure 2.14. Schematic of the added circuit

Figure 2.15 shows the developed software. A sensor node software was developed to measure temperature from the build in temperature sensor, humidity from a humidity sensor (HIH-4030-001, Honeywell, Morristown, New Jersey, USA). The ambient air pressure (MPXA4100A6U 20-105kPa, Freescale, Austin, Texas, USA) and luminance with a photoconductive cell (VT 83, Perkin Elmer Optoelectronics, Waltham, Massachusetts, USA) were also recorded.

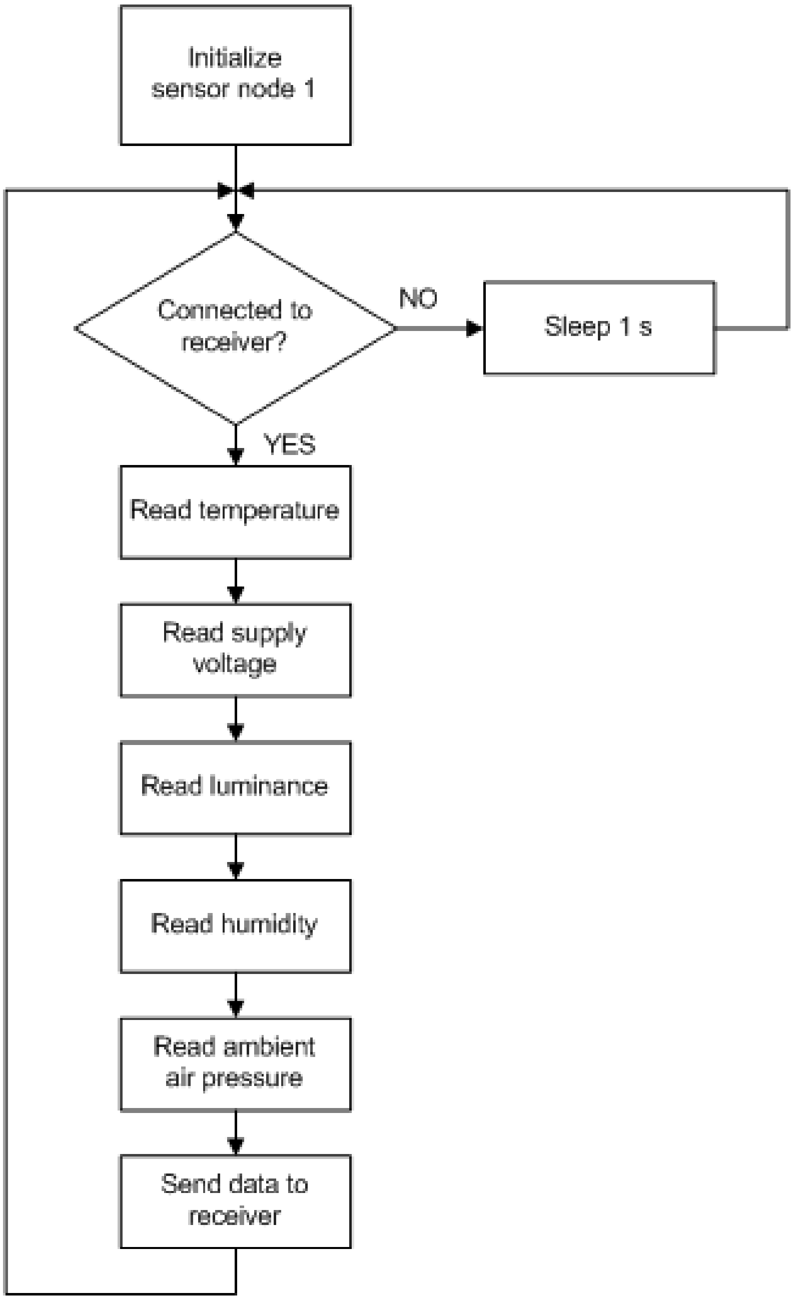

Figure 2.15. Flowchart of the firmware running on the embedded ZigBee transceiver

Figure 2.16 shows the realised board can be seen. A 9V block battery was used a source in case a power supply was not available.

Figure 2.16. Prototype of the wireless sensor node to measure temperature, humidity, ambient air pressure and luminance

2.5 Setting

The next sections describe the components that were utilized in this thesis. In the following section an overview of the setting of the developed AHD and all the devices will be given. The evaluation of the AHD will be described in chapter 3.3.

2.5.0.1 Prototype hardware

The AHD was the central unit realised in this thesis. A netbook (Acer Aspire One, Taipeh, Taiwan) (see figure 2.17) was used for that purpose. The AHD was also responsible for the identification of the user. The dongles were connected through USB interfaces by means of a USB hub.

Figure 2.17. The Acer Aspire One was used as an AHD with Bluetooth, ZigBee, ANT+ dongle and NFC card reader

2.5.0.2 User ID Token

Users were given Mifare identity cards for the trial period to identify themselves to the system. Mifare 1k cards (Figure 2.18) which offer contactless data and energy transmission with a data transfer rate of 106kbs were employed for the identification of the user. Mifare was designed by Phillips[13] according to ISO/IEC 14443A. An intelligent anti collision function allows more than one card to operate simultaneously in the field. The algorithm selects each card individually and ensures the data transmission is executed correctly with each card, so that data corruption or interference from other cards does not occur. For this purpose only the UID number of the card was read in order to identify the patient using the system need to be real[48].

Figure 2.18. User ID tokens, Mifare 1k cards

2.5.0.3 Weight scale and blood pressure meter

For the purpose of medical data acquisition, a blood pressure meter (UA-767PBT-C, A&D Medical, Tokyo, Japan) and a body weight scale (UC-321PBT-C, A&D Medical, Tokyo, Japan) were used (Figure 2.19). These devices were linked to the AHD using Bluetooth link supporting the HDP. If was necessary to pair the devices to the AHD once whilst setting up the system. The data were transmitted to the hub automatically.

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[13] www.philips.com

Figure 2.19. Weight scale (UC-321PBT-C, A&D Medical, Tokyo, Japan) and blood pressure monitor (UA-767PBT-C, A&D Medical, Tokyo, Japan)

Pairing PBT-C Series Device

The PBT-C series devices are designed to be connected only with Continua Managers. To pair the device with a Manager, the following steps had to be carried out [49]:

1. All four batteries needed to be removed and the device had to be discharged compeltely.
2. All batteries had to be placed back into the device.
3. After battery insertion the device was discoverable for a period of 60 seconds to be found and selected by the AHD.

In order, to measure the weight and transmit the value to the manager it is important that the switch underneath the scale is adjusted to select the Weight B category. Measurement results were automatically sent to the paired AHD. In the case of unsuccessful transmission, the device stored the last 25 measurements in memory. In this case the device sent all of the data when the next successful connection was established and cleared the memory. The devices had class 1 Bluetooth antennas, allowing the nominal range to be approximately about 100 meters.

2.5.0.4 Sports and fitness watch

In order to track the patient's fitness and sports activities, a sport watch (Forerunner 405cx, Garmin, Olathe, Kansas USA) was utilized. This device featured GPS recording capability and a wireless heart rate monitor (chest belt) together with a step counter. Distance, pace and heart rate were logged and stored in the memory of the wristband device. When the user came close to the AHD, the watch synchronized the data automatically via ANT+ without any user interaction. Networks as shown in figure 2.20 and figure 2.21 were established.

Figure 2.20. Network for data acquisition in activity monitoring

Figure 2.20 shows the network between the sports watch and its accessories. This network was active during collection of data whilst the user exercises.

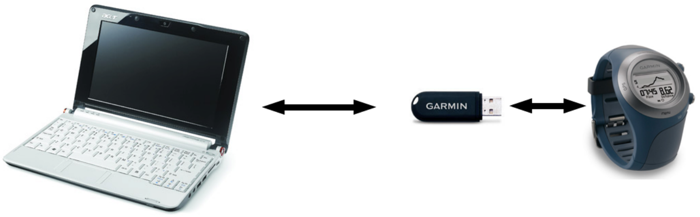


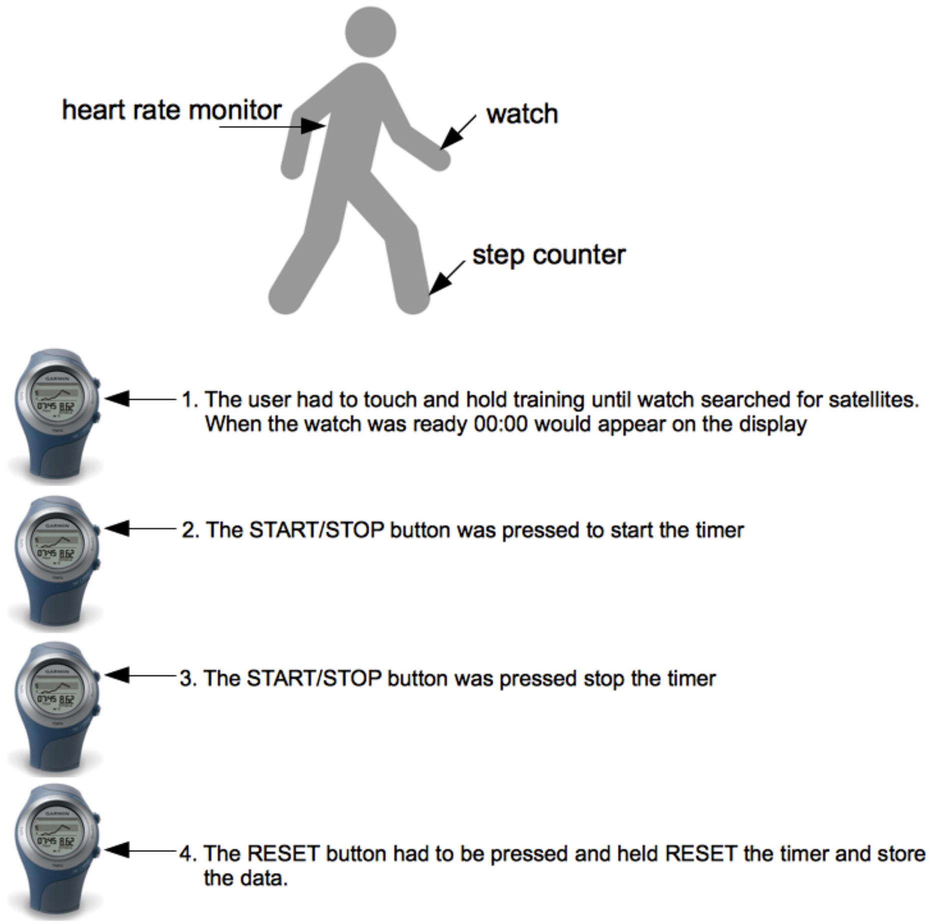
Figure 2.21. Network for data transmission in activity monitoring

Figure 2.21 shows the network that was established between the prototype AHD and the sports watch. This connection was only established when a data transfer to the AHD was necessary.

Pairing the sports watch

Only one pairing of the sports watch was necessary, after which the system recognized the watch automatically and received new records stored in the memory. To pair the devices a script needed to be executed, containing pairing information such as host name and data exchange parameters.

Figure 2.22 shows the data acquisition process from the sports watch. After the user had brought the watch close to the AHD, data transmission started automatically. The user had to perform sports activity data acquisition includes the following steps:



1. The user had to touch and hold training until watch searched for satellites. When the watch was ready 00:00 would appear on the display
2. The START/STOP button was pressed to start the timer
3. The START/STOP button was pressed stop the timer
4. The RESET button had to be pressed and held RESET the timer and store the data.

Figure 2.22. User instructions to record sports and fitness activity

2.5.0.5 Environment monitor

The developed environmental data sensor note was used to monitor temperature, humidity, luminance and ambient air pressure. Therefore, it was linked to the AHD via the ZigBee based wireless interface. Environment was not monitored continuously during the test period, rather measurements were taken on selected days. The sensor node was placed outside the northward window of the flat for these measurements. Temperature, humidity, luminance and ambient air pressure were monitored successfully. These data were sampled every 10 seconds and stored in log files.

CHAPTER 3

RESULTS

In this chapter the implementation of the prototype is presented. The requirements which were described in the previous chapter were implemented. Furthermore the results of the evaluation are analysed.

3.1 Market overview

In the present day existing systems for monitoring use only one or two of the mentioned wireless communication standards mentioned in Chapter 2.

Manufacturers such as Fujitsu Ltd. (Tokio, Japan), Toshiba (Tokio, Japan), Texas Instruments (Austin, Texas, USA), Panasonic (Osaka, Japan), Insung Information Ltd. (Seoul, South Korea) and Bluegiga (Espoo, Finland) offer AHD to collect data from various consumer electronic devices. Most of those devices use USB and Bluetooth as a communication protocol.

Fujitsu Limited offers a HDP Manager for mobile phones which are included NTT DoCoMo 3G mobile phones. Smart or mobile phones providing these software packages can connect to any Continua certified blood pressure monitor and weight scale. Panasonic and Toshiba offer a Continua certified notebook able to collect data from weight scales, blood pressure monitor, pulse oximeter and glucose meter. However, those systems lack multimodality and the costs are high for use in a home monitoring environment.

Table 3.1. Existing Application Hosting Devices

Product	**Manufacturer**	**Device type**	**Components**	**Wired Interfaces**	**PAN**	**LAN**	**WAN**
DoCoMo	Fujitsu Limited	Phone	1.4 MHz, 512 MB RAM, Touchscreen	USB 2.0, micro USB	Bluetooth	WiFi	3G
Hicare Home Doctor (HX461)	Insung Information Ltd.	AHD	Screen, Video call	USB 2.0, RS232	Bluetooth	WiFi, Ethernet	N/A
Toughbook H2	Panasonic	Notebook	Intel i5, 4 GB RAM, fingerprint scanner	USB 2.0, RS232	Bluetooth	WiFi, Ethernet	3G, 4G(optional)
AM/DM 37x	Texas Instruments	AHD	multimodal, embedded board	USB 2.0	ANT, Bluetooth	ZigBee, WiFi, Ethernet	N/A
eHealth Bluetooth Gateway	Bluegiga	Gateway		USB 2.0	Bluetooth	WiFi, Ethernet	N/A
dynabook	Toshiba	Notebook	Intel i5, 4 GB RAM, Windows 7	USB 3.0, HDMI	Bluetooth	WiFi, Ethernet	N/A

Software manufacturers such as MindTree (Bangalore, India), Toshiba (Tokio, Japan), Intel (Santa Clara, California ,USA), Samsung (Seoul, South Korea), Vignet Inc. (McLean, Virginia, USA), Lamprey Networks Inc. (Durham, New Hampshire, USA) and Elbrys Networks (Portsmouth, New Hampshire, USA) also offer Sofware Development Kits to ease development and reduce development time.

Market research done in the context of this thesis showed that Elbrys Networks in cooperation with Texas Instruments are already offering the desired system. The system is based on TI's AM37x EVM and offers multimodality as all the necessary interfaces such as Bluetooth, ANT+ and ZigBee are built in. The system has already been Continua certified and was presented at the Consumer Electronics Show (CES) in February 2011[14].

Table 3.2. Existing Software Development Kits

Product	**Manufacturer**	**Operating System**	**Certified Products**
EtherMind Health Device SDK	MindTree	Windows, Linux	Thermometer, Heart Rate Monitor, Blood Pressure Monitor
Continua Bluetooth Manager	Toshiba	Windows	Thermometer, Glucose Meter, Blood Pressure Monitor, Pulse oximeter, Weighing scale
Evaluation Kit with IEEE 11073 Continua	Intel	Windows	Thermometer, Glucose Meter, Blood Pressure Monitor, Pulse oximeter, Weighing scale, Activity hub
Healthcare Manager	Samsung Electronics	Linux	Thermometer, Glucose Meter, Blood Pressure Monitor, Pulse oximeter, Weighing scale
Vignet Manager	Vignet Inc.	Windows	Pulse oximeter
HealthLink PC Manager	Lamprey Networks Inc.	Windows	Thermometer, Glucose Meter, Blood Pressure Monitor, Weighing scale
Secure Personal Sensor SDK	Elbrys Networks	Windows, Android, Linux	Blood Pressure Monitor, Weighing scale

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[14] www.elbrys.com, last checked Nov. 16, 2011

3.2 Prototype

Based on the requirement analysis, a PC based patient terminal for data acquisition for telemonitoring was designed and implemented. The patient terminal enabled patients to log in via RFID cards and then take measurements on the provided devices without having to worry about sending them to the data center. The designed prototype was able to support four different communication scenarios.

1. ACS[15] NFC Reader (ACR122U, ACS Ltd., Hong Kong) and RFID cards (Mifare 1k, NXP Semiconductors, Eindhoven, Netherlands) were utilized for user identification.
2. A&D[16] Continua Bluetooth enabled weight scale (UC-321PlusBT-C, A&D Medical, Tokyo, Japan) and blood pressure monitor (UA-767PlusBT-C, A&D Medical, Tokyo, Japan) were used for medical data acquisition.
3. A sports watch[17] (Garmin Forerunner 405cx, Garmin, Kansas, USA) was employed for patient activity.
4. Temperature, humidity, ambient air pressure and illuminance were recorded by a separately developed sensor module based on a wireless development board.

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[15] www.acs.com.hk

[16] www.telemedicine.jp

[17] www.garmin.com

Figure 3.1 shows all the elements of the system together, which were used by the user.

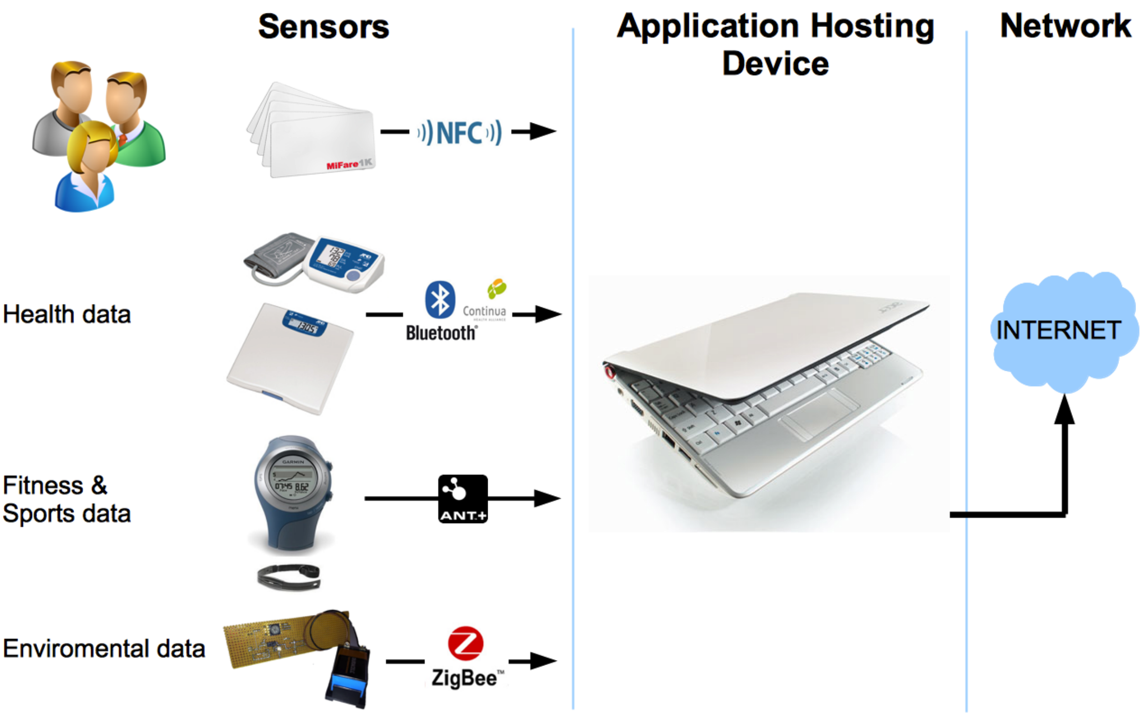


Figure 3.1. System overview of the developed prototype system, with a NFC smart card reader for user identification, Bluetooth for medical data, ANT+ for sports and fitness data and ZigBee for environmental data acquisition.

After the user placed the tag on the NFC reader, the UID was read and stored with the insertion time in a log file. The process was repeated upon removal of the card.

The interaction between the AHD and health devices was based on Bluetooth. The Bluetooth data acquisition daemon was running when boot-up of the AHD began and continued to do so until shutdown. As soon as a health device was brought into the system, 'pairing' of the Bluetooth devices was necessary. Once the health device was used, a Bluetooth connection was established and the medical device sent its data to the AHD. The medical devices were equipped with Bluetooth Ver.2.1 Class 1 antennas. In case the AHD did not receive the data, the data were saved automatically, (up to the last 25 measurements) and transmitted at the next connection together with a timestamp of the time the measurement was taken.

All collected data were stored in different log files. The Continua devices did send data in XML format so they were imported easily into Excel.

3.3 Evaluation

The evaluation scenario consisted of two independent trial periods of three weeks in total. Table 3.3 shows the participants.

Table 3.3. Evaluation scenario

	Gender	**Age**	**Duration**
Student A	male	27 years	two weeks
Student B	male	26 years	
User A	female	46 years	one week
User B	male	56 years	

From the patient's point of view, the data acquisition process for the health parameters and sports and fitness data included the following steps:

1. The patient had to put his or her RFID card on the RFID card reader.
2. The patient had to apply the cuff and press START to measure blood pressure or step on the weight scale.
3. After the data acquisition was finished the patient had to remove his RFID card from the reader to indicate that data acquisition was finished.

In the first test period, two students (both male) were asked to evaluate the system. The students used the system over a period of two weeks on an irregular basis. The aim was to test the system's stability and accuracy.

In a second test to evaluate the usability of the prototype a test environment was prepared to be used by computer inexperienced persons. A computer illiterate couple aged 56 years and 46 years was asked to use the system over a one week period.

In both test periods users had to use the same device set. To assign parameters correctly, the participants were asked to place their RFID card on the NFC reader before taking measurements. Additionally, one test person was asked to wear the sports watch, heart rate monitor and step counter when cycling to work or going for a walk. For the first trial period, the evaluation environment was utilized in an office.

For the second period, the hub was placed at an easily accessible position in their living room and the environmental data sensor was located outside of a north-facing window. The goal of this test was to show if the prototype can be used by computer inexperienced people and to get feedback about usability and robustness in a real home environment. Figure 3.2 shows the utilized test environment.

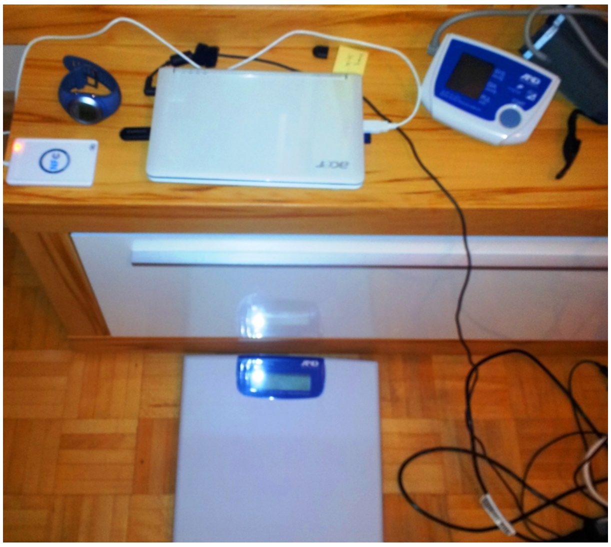


Figure 3.2. Patient environment consisting of a data hub (netbook), smart card reader, blood pressure meter, weight scale and sports watch

3.4 Results of the evaluation

In the course of both evaluation cycles the following data were recorded and stored for post-analysis. A total of 77 logins were registered. During both periods 158 weight and blood pressure values were recorded. 31 sport sessions were tracked in total using the sports watch. Environmental data measurements were monitored inconsistently across four different days to test the developed sensor module.

In the second evaluation process the system was utilized in a flat to monitor two computer illiterate subjects. A third person who lived in the flat was not part of the evaluation process, but was permitted to use the devices to check vital parameters. An RFID card was used in order to assign individual vital parameters from Bluetooth weight scale and blood pressure monitor. Only one subject involved in the evaluation process was assigned a sports watch.

3.4.1 Identification data

During the test period on the computer illiterate group a total of 33 logins were registered. Placement and removal of the RFID card was monitored and stored in a log file. The data shows when the participants of the test system logged in and then measured their data.

Table 3.4 presents the login times of the participants during the first three days of the trial, showing that they logged in twice a day. The login and logout times were stored in a file to be merged with collected vital data.

Table 3.4. Login times of computer illiterate users

User	**UID**	**Card action**	**Timestamp**
User A	2cdfe78c	insertion removal	12/01/2012 16 : 50 : 36 12/01/2012 16 : 58 : 33
User B	dc29ea8c	insertion removal	12/01/2012 17 : 00 : 12 12/01/2012 17 : 10 : 58
User B	dc29ea8c	insertion removal	13/01/2012 06 : 06 : 59 13/01/2012 06 : 17 : 09
User A	2cdfe78c	insertion removal	13/01/2012 07 : 41 : 39 13/01/2012 08 : 11 : 39
User A	2cdfe78c	insertion removal	13/01/2012 17 : 59 : 30 13/01/2012 18 : 56 : 03
User B	dc29ea8c	insertion removal	13/01/2012 18 : 56 : 07 13/01/2012 20 : 27 : 41
User A	2cdfe78c	insertion removal	14/01/2012 08 : 43 : 48 14/01/2012 08 : 52 : 09
User B	dc29ea8c	insertion removal	14/01/2012 08 : 52 : 12 14/01/2012 08 : 57 : 41
User A	2cdfe78c	insertion removal	14/01/2012 17 : 06 : 38 14/01/2012 17 : 16 : 45
User B	dc29ea8c	insertion removal	14/01/2012 17 : 21 : 47 14/01/2012 17 : 24 : 42

3.4.2 Medical data

Participants were asked to measure their weight and blood pressure twice a day if possible during the trial period with the computer illiterate subjects. In this group a total of 69 health values were transmitted to the AHD. 32 values could be matched to the female test person, 26 to the male test person. 11 health data values could not be assigned to any of the test persons. The data were stored locally in 'XML' files and interpreted after the trial via Microsoft Excel.

Table 3.5 shows the medical data recorded by the weight scale and blood pressure monitor during three day of the test period with computer illiterate users. The data were assigned to a specific user after the medical data were combined with the user identification data. The measured data could therefore be assigned to the two persons who participated in this test.

The developed concept also allowed persons who were not monitored by the system to perform some measurements with the blood pressure meter and body weight scale. Since this person did not own a RFID card these measurements were not assigned to any person. Hence, these data were filtered and consequently not considered for further analysis at the telemonitoring service center.

Table 3.5: Medical data collected during test period with computer illiterate users

Time	Weight	SBP	MAP	DBP	Pulse
12/01/2012 16:56:04		119.0	83.0	95.0	
12/01/2012 16:56:04					70.0
12/01/2012 16:57:26	82.4				
12/01/2012 17:05:43		131.0	78.0	101.0	
12/01/2012 17:05:43					72.0
12/01/2012 17:07:41	79.8				
13/01/2012 06:11:59	79.1				
13/01/2012 06:12:41		135.0	77.0	109.0	
13/01/2012 06:12:41					64.0
13/01/2012 07:47:22		103.0	68.0	93.0	
13/01/2012 07:47:22					68.0

Continued on Next Page...

Table 3.5 – Continued

Time	**Weight**	**SBP**	**MAP**	**DBP**	**Pulse**
13/01/2012 07:49:22	81.0				
13/01/2012 15:35:34	69.6				
13/01/2012 18:04:48		106.0	72.0	84.0	
13/01/2012 18:04:48					70.0
13/01/2012 18:06:23	81.6				
13/01/2012 18:55:21	81.2				
14/01/2012 08:49:42		93.0	62.0	80.0	
14/01/2012 08:49:42					62.0
14/01/2012 08:51:34	80.7				
14/01/2012 08:52:50		122.0	78.0	100.0	
14/01/2012 08:52:50					64.0
14/01/2012 08:54:14	79.6				
14/01/2012 12:26:30	70.3				
14/01/2012 17:12:19		114.0	74.0	88.0	
14/01/2012 17:12:19					65.0
14/01/2012 17:14:02	82.5				
14/01/2012 17:22:21	80.3				
14/01/2012 17:23:12		130.0	84.0	106.0	
14/01/2012 17:23:12					65.0
14/01/2012 17:30:49	70.6				

The whole data of User A collected during the test period are illustrated in figure 3.3. The participant measured his/her weight and blood pressure, which was transmitted to the AHD. Again the measurement data were sent along with a timestamp of the measurement time.

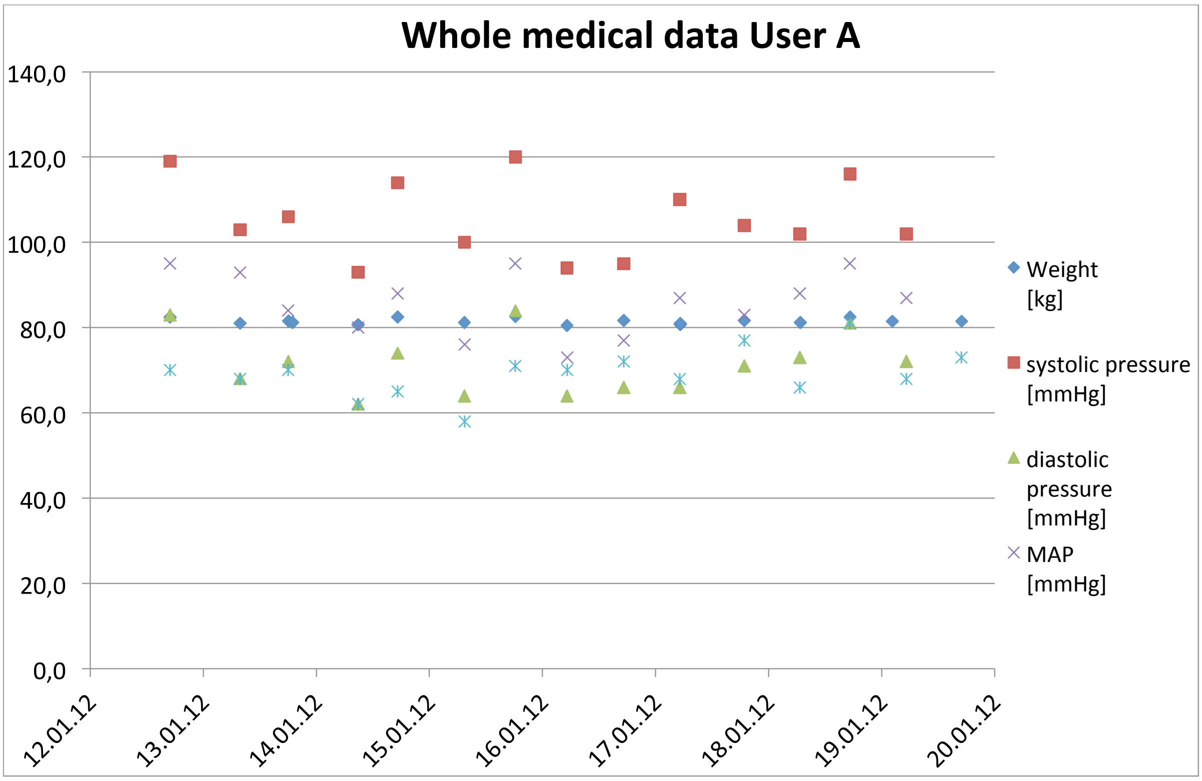


Figure 3.3. All data collected over test period from User A.

A detailed view of the data acquired in one day is shown in figure 3.4. The participants logged in and took measurements in the morning and in the afternoon. The weight was measured in kg, blood pressure in mmHg and pulse in beats per second.

A weight measurement was taken in the morning at approximately 10:00 AM. This measurement could not be assigned to one of the two participants who received an RFID card. The female test participant was logged in from 7:21 to 7:30 AM and from 4:49 to 6:06 PM. The male test participant was logged in from 7:48 to 8:26 AM and from 6:06 to 6:17 PM.

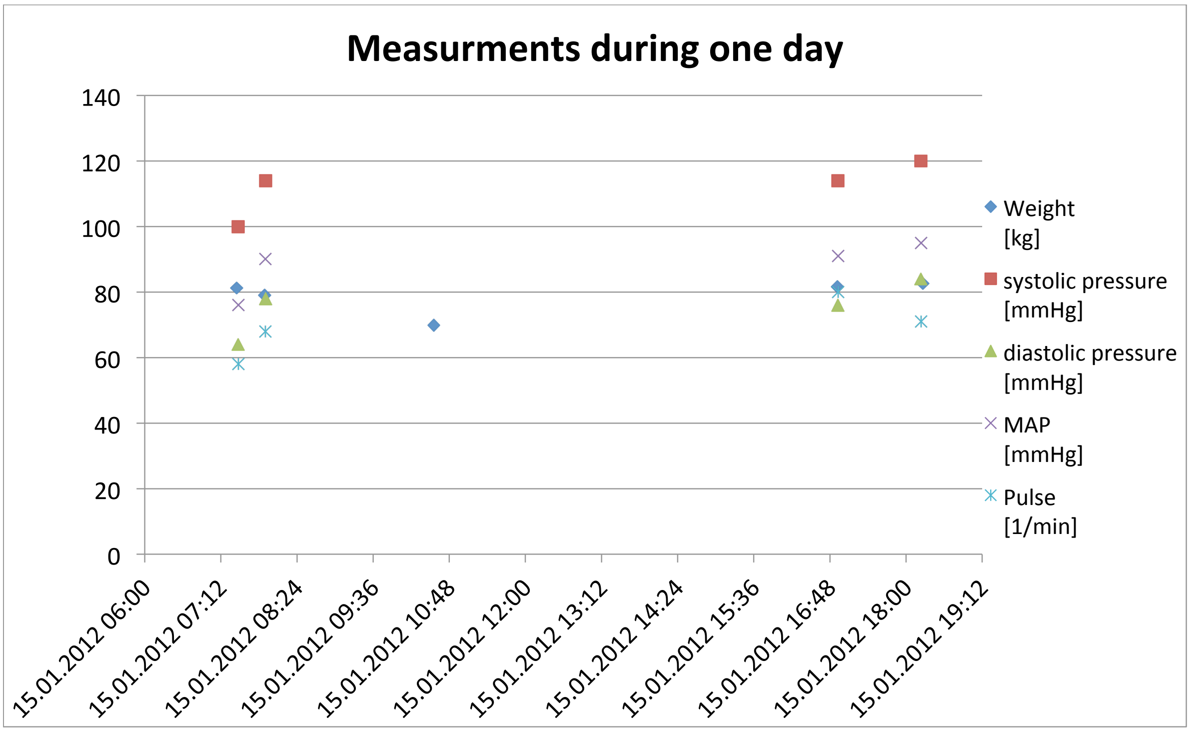


Figure 3.4. Data of one day

The test environment consisted of a three person household. Two of the subjects where equipped with an RFID card. Figure 3.5 shows the measurement values that could not be assigned to any of the test participants.

The third person in the household measured, his/her weight on a regular basis. At the end of the test period some blood pressure measurements and a weight measurement were taken, when no RFID card was placed on the reader. The weight outlier indicates that this measurements did belong to User A.

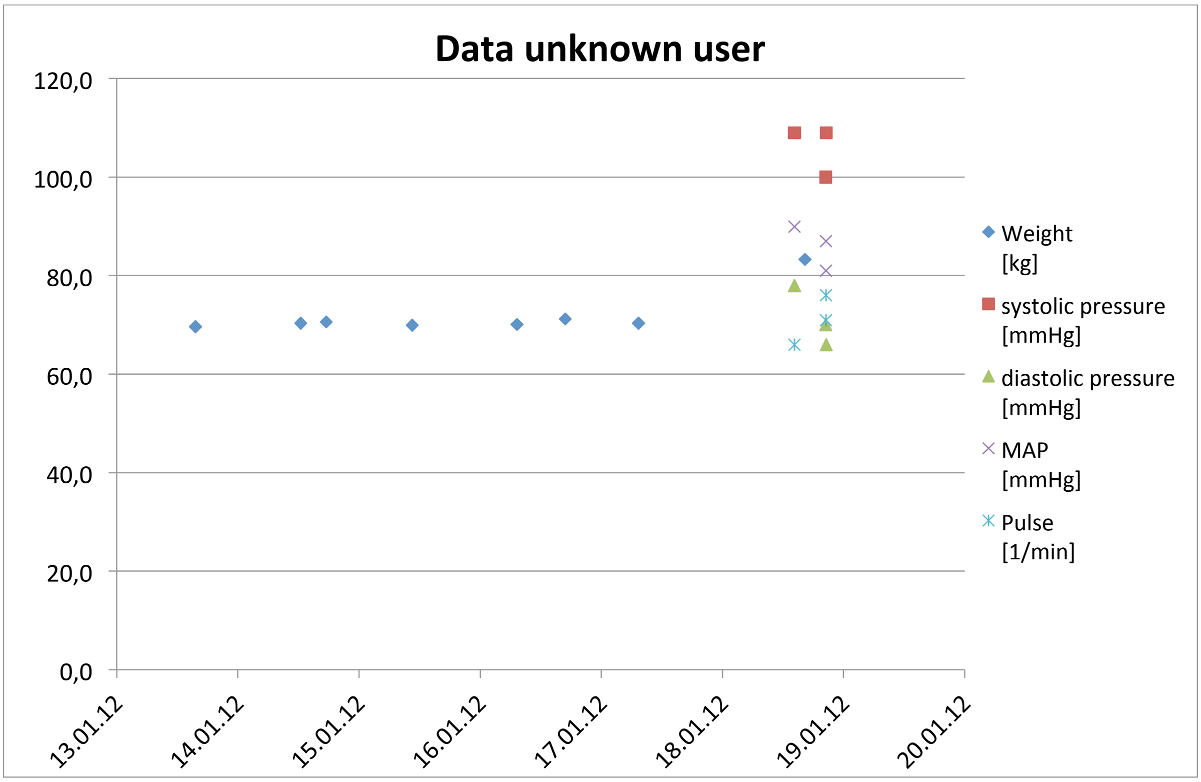
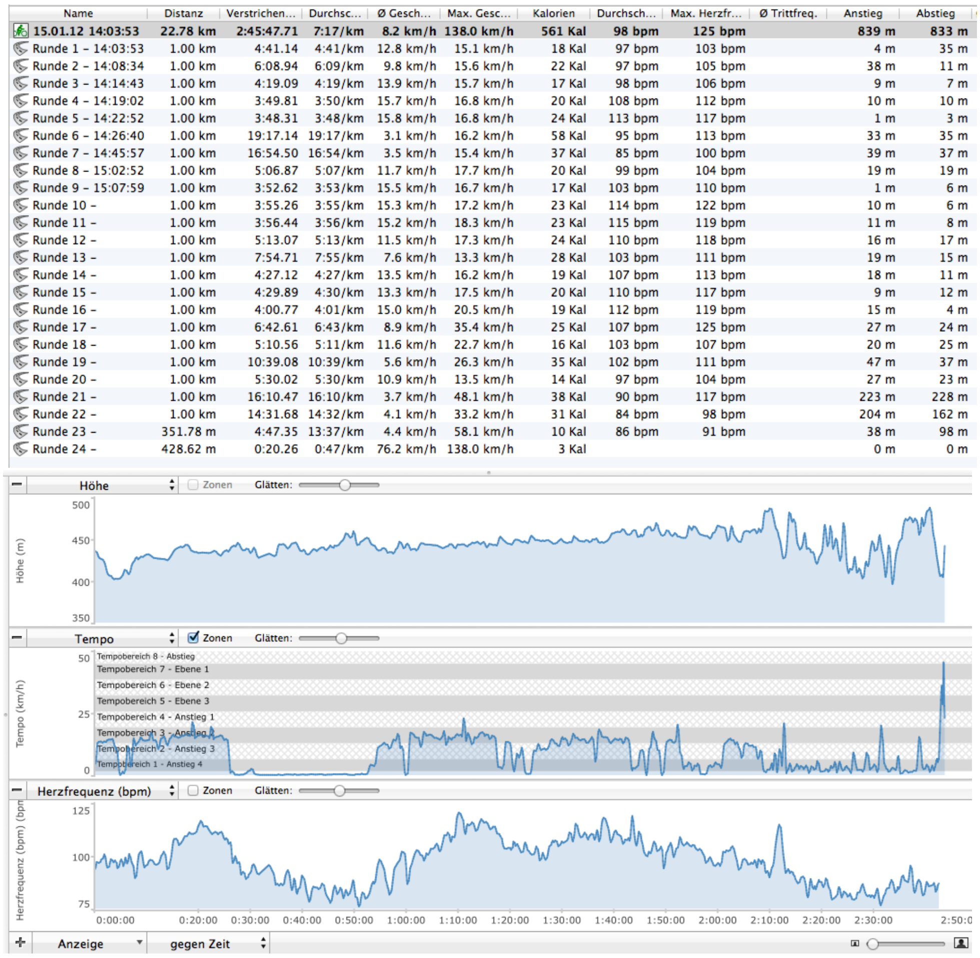


Figure 3.5. Data of unknown users

3.4.3 Activity data

One participant (male, 56 years) was asked to wear a watch during his/her activities and to record these activities. He was also asked to evaluate the usability of the watch as an activity monitoring system. The results shown in figure 3.6 illustrate the activity of the test person during cycling. GPS position, altitude, distance and pace were monitored. Figure 3.6, shows that the participant cycled for 2 hours and 45 minutes a distance of 22.78 km with an average speed of 8.2 km/h. The test person also had a break after he had cycled for half an hour. 17 data sets were recorded during the test period with the computer illiterate participants, 8 out of them could be used for data analysis. The remaining 'TCX' files contained no activity data.



Name	Distanz	Verstrichen...	Durchsc...	Ø Gesch...	Max. Gesc...	Kalorien	Durchsch...	Max. Herzfr...	Ø Trittfreq.	Anstieg	Abstieg
15.01.12 14:03:53	**22.78 km**	**2:45:47.71**	**7:17/km**	**8.2 km/h**	**138.0 km/h**	**561 Kal**	**98 bpm**	**125 bpm**		**839 m**	**833 m**
Runde 1 – 14:03:53	1.00 km	4:41.14	4:41/km	12.8 km/h	15.1 km/h	18 Kal	97 bpm	103 bpm		4 m	35 m
Runde 2 – 14:08:34	1.00 km	6:08.94	6:09/km	9.8 km/h	15.6 km/h	22 Kal	97 bpm	105 bpm		38 m	11 m
Runde 3 – 14:14:43	1.00 km	4:19.09	4:19/km	13.9 km/h	15.7 km/h	17 Kal	98 bpm	106 bpm		9 m	7 m
Runde 4 – 14:19:02	1.00 km	3:49.81	3:50/km	15.7 km/h	16.8 km/h	20 Kal	108 bpm	112 bpm		10 m	10 m
Runde 5 – 14:22:52	1.00 km	3:48.31	3:48/km	15.8 km/h	16.8 km/h	24 Kal	113 bpm	117 bpm		1 m	3 m
Runde 6 – 14:26:40	1.00 km	19:17.14	19:17/km	3.1 km/h	16.2 km/h	58 Kal	95 bpm	113 bpm		33 m	35 m
Runde 7 – 14:45:57	1.00 km	16:54.50	16:54/km	3.5 km/h	15.4 km/h	37 Kal	85 bpm	100 bpm		39 m	37 m
Runde 8 – 15:02:52	1.00 km	5:06.87	5:07/km	11.7 km/h	17.7 km/h	20 Kal	99 bpm	104 bpm		19 m	19 m
Runde 9 – 15:07:59	1.00 km	3:52.62	3:53/km	15.5 km/h	16.7 km/h	17 Kal	103 bpm	110 bpm		1 m	6 m
Runde 10 –	1.00 km	3:55.26	3:55/km	15.3 km/h	17.2 km/h	23 Kal	114 bpm	122 bpm		10 m	6 m
Runde 11 –	1.00 km	3:56.44	3:56/km	15.2 km/h	18.3 km/h	23 Kal	115 bpm	119 bpm		11 m	8 m
Runde 12 –	1.00 km	5:13.07	5:13/km	11.5 km/h	17.3 km/h	24 Kal	110 bpm	118 bpm		16 m	17 m
Runde 13 –	1.00 km	7:54.71	7:55/km	7.6 km/h	13.3 km/h	28 Kal	103 bpm	111 bpm		19 m	15 m
Runde 14 –	1.00 km	4:27.12	4:27/km	13.5 km/h	16.2 km/h	19 Kal	107 bpm	113 bpm		18 m	11 m
Runde 15 –	1.00 km	4:29.89	4:30/km	13.3 km/h	17.5 km/h	20 Kal	110 bpm	117 bpm		9 m	12 m
Runde 16 –	1.00 km	4:00.77	4:01/km	15.0 km/h	20.5 km/h	19 Kal	112 bpm	119 bpm		15 m	4 m
Runde 17 –	1.00 km	6:42.61	6:43/km	8.9 km/h	35.4 km/h	25 Kal	107 bpm	125 bpm		27 m	24 m
Runde 18 –	1.00 km	5:10.56	5:11/km	11.6 km/h	22.7 km/h	16 Kal	103 bpm	107 bpm		20 m	25 m
Runde 19 –	1.00 km	10:39.08	10:39/km	5.6 km/h	26.3 km/h	35 Kal	102 bpm	111 bpm		47 m	37 m
Runde 20 –	1.00 km	5:30.02	5:30/km	10.9 km/h	13.5 km/h	14 Kal	97 bpm	104 bpm		27 m	23 m
Runde 21 –	1.00 km	16:10.47	16:10/km	3.7 km/h	48.1 km/h	38 Kal	90 bpm	117 bpm		223 m	228 m
Runde 22 –	1.00 km	14:31.68	14:32/km	4.1 km/h	33.2 km/h	31 Kal	84 bpm	98 bpm		204 m	162 m
Runde 23 –	351.78 m	4:47.35	13:37/km	4.4 km/h	58.1 km/h	10 Kal	86 bpm	91 bpm		38 m	98 m
Runde 24 –	428.62 m	0:20.26	0:47/km	76.2 km/h	138.0 km/h	3 Kal				0 m	0 m

Figure 3.6. Activity record during cycling

3.4.4 Environmental data

Figure 3.7 shows the temperature trend during one day of measurement. Because of the timely high sampling rate the sensors were highly power consuming.

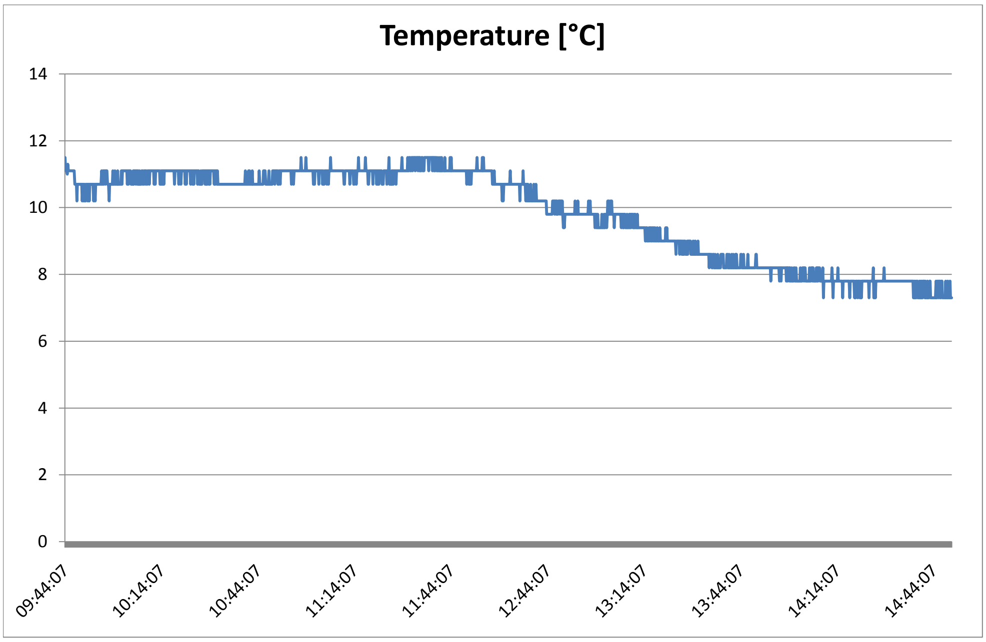


Figure 3.7. Temperature on one measurement day

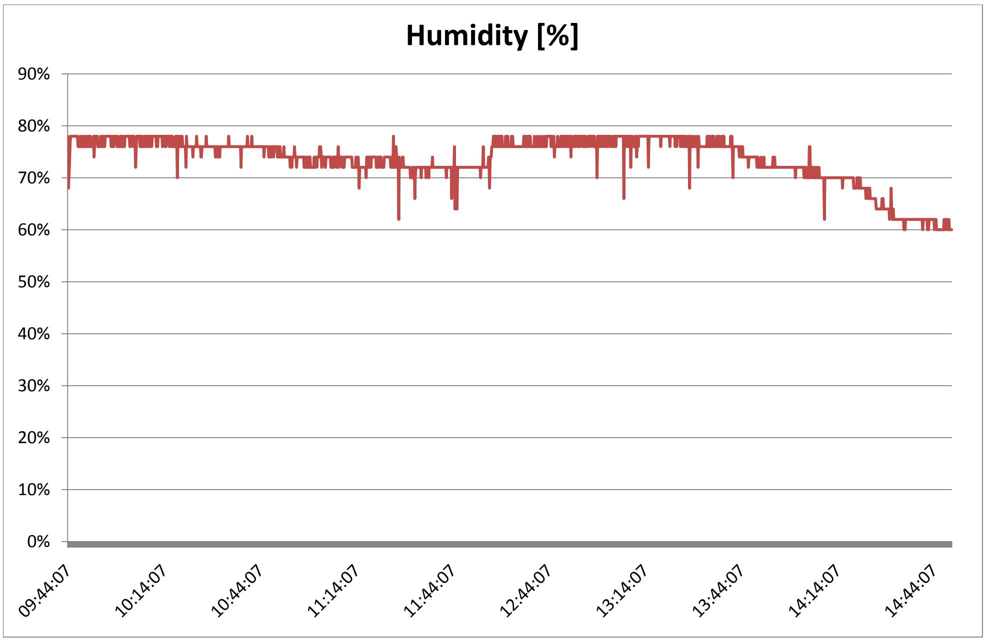


Figure 3.8. Humidity on one measurement day

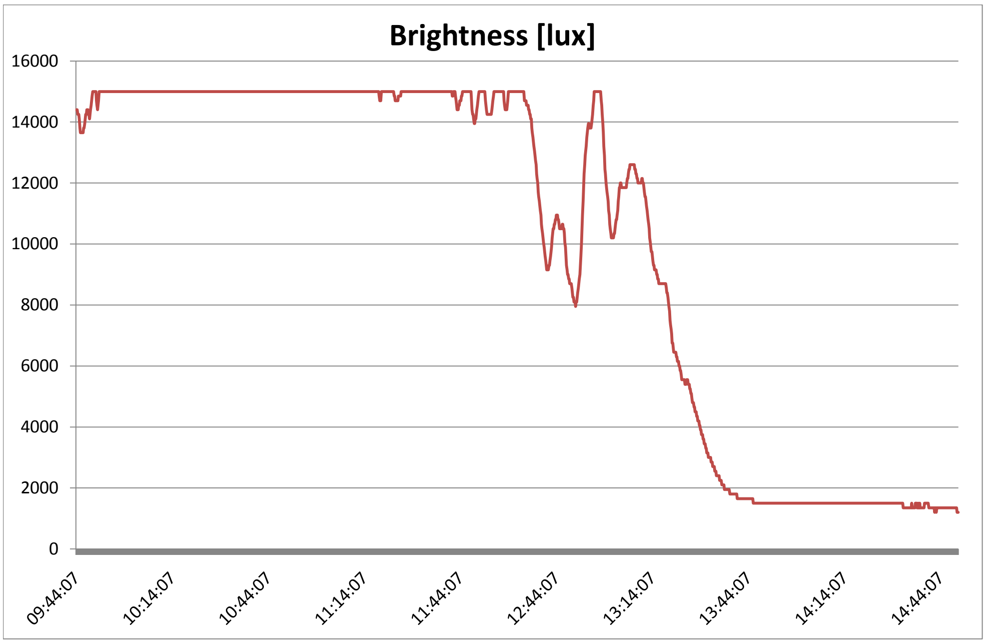


Figure 3.9. Brightness on one measurement day

In figure 3.8 the atmospheric humidity is illustrated.

Figure 3.9 shows the illumination level during one day. The measurement values exceeded the saturation of the brightness sensor.

Ambient air pressure did not change significantly over the course of the day, the values varied between 1015 hPa and 1040 hPa.

CHAPTER 4

DISCUSSION

A prototype of a x86 based multiuser and multimodal AHD was developed and therefore a platform for easy integration of health devices, ambient area sensors and activity sensors was realised. The x86 based AHD was proven to be feasible. Data acquisition from health devices, activity data and ambient environmental data was proven feasible. The usability feedback indicated that the AHD could be used easily and was well accepted by the users.

In the evaluation scenario with computer illiterate subjects the developed system was used in a three persons household. Two of them were equipped with RFID cards. The third person used the weight scale on a regular and the blood pressure meter on an occasionally basis. By using RFID cards, for authentication and identification of a user data of unknown users could be filtered before transmission to a telemedicine service center.

In the following sections a critical eye is cast on the current thesis. The relevance for practical usage of telemonitoring for chronically ill patients is discussed and a comparison between x86 based and other types of patient terminals is made. The results of the evaluation are reviewed and optimization for future devices are presented. Finally, future prospects for a new AHD are given.

4.1 Feasibility

The feasibility tests showed that the prototype was able to monitor health parameters. In some rare cases data sent to the hub after measurements were taken were incomplete. Devices were disassociated and disconnected too early, which shows the instabilities of Bluetooth. However, measurement data were not lost because devices stored the data to be sent at the next switch-on of the device.

NFC based identification worked fine in all cases and timestamps of placment and removal of the RFID cards were logged correctly in all cases. So far establishing a Bluetooth connection and enabling devices to communicate with each other is not intuitive. Establishing such a connection takes a few steps to perform device discovery and pairing. In this prototype device pairing was done manually, for a future development pairing via NFC could be realised to improve usability.

Pairing health devices was done in four steps described in chapter 2.5.0.3. On the AHD part the Simple Secure Pairing process had to be started. In Morak et al. (2012) [50] an intuitive pairing process was proposed to resolve the manual pairing process which was a burden for elderly and computer illiterate persons. A NFC triggered Bluetooth link was established when a mobile phone and a blood pressure monitor was brought together. A Java 2 Micro Edition (J2ME) application was launched and requested a dedicated Bluetooth service on a certain device defined by its MAC address. This makes the search and select part of the pairing process obsolete. Keys can also be exchanged automatically to secure the communication link without the need of entering a pin code.

Monitoring activity was successful, but feedback from computer illiterate users was that the handling of the sports watch was too tricky. The touch based user interface did not always respond to the user and the establishment of a GPS connection took too much time. These problems could probably be managed by using a more user friendly sports watch or even a completely different activity monitoring device (e.g. Bluetooth enabled pedometer).

The environmental sensor worked with a frequency of 0.1 Hz, which lead to a permanent connection effecting the energy performance. Monitoring environmental data with a frequency of 0.1 Hz only makes sense, if the user has a display to visualize the environmental data in real time. Sampling every hour would be sufficient.

NFC, Bluetooth, ANT+ and ZigBee technologies were used for this prototype due to the fact that off-the-shelf consumer electronics exist. The system can be easily extended in the future.

4.2 Relevance for practical usage of the system

Costs, usability and user acceptance are crucial factors, when bringing ICT into healthcare. Assistive systems should support the user in their daily activities without interfering too much with the user's daily routine. AAL technologies can improve a patient's wellbeing and compensate his/her impairments. ICT can help elderly individuals to improve his/her quality of life, stay healthier, live independently for a longer period and counteract the decrease in performance which are more prevalent with age. As described in chapter 1 the effective and efficient management of chronically ill and elderly patients is one of the major challenges for healthcare systems. Initiatives aimed at the promotion of technologies for aging well can help to increase the efficiency and quality of healthcare. AAL can help to reduce high healthcare costs.

An optimized system works in the background without the knowledge of the user. Assistive systems draw a fine line between user acceptance and total rejection caused by too much interference in patients activities of daily living. Elderly patients with lower cognitive abilities see the usability of such a system as a burden. Making ICT tools and services easy to use for the elderly can help to enhance the technology acceptance.

Innovations in assistive technology can only be successful when they fit the needs and possibilities of the end-users. If this is not given, the innovation will not be accepted and a broad deployment will not be possible.

4.3 Relevance of the collected data in prospect to AAL

The possibility to monitor medical data, sports and fitness and environment data gives caregivers the opportunity to create an ambient assisted environment. This enables several benefits for the user such as: [40]

- Patients can be ranked into the NYHA classes continuously.
- Monitoring environment gives more information about the patient's surroundings, boosting the care for the patient.
- Increased safety through the feeling that there is somebody who cares.
- When data acquisition happens in the background there is no feeling of being controlled (in comparison to installed cameras in the home environment).
- No expensive adaptations necessary, sensors can be battery-powered or plugged into existing wall sockets.

In an AAL, scenario ubiquitous monitoring is important. User acceptance is much higher, when the user does not feel they are actually using technology.

4.4 Comparison between PC patient terminals and mobile phones

In a telemonitoring scenario, it is essential to provide patients with an easy-to-use patient terminal to be integrated into daily life to perform data acquisition on a regular basis. Today, a number of devices are already commercially available (e.g. PC, set-top boxes[18], mobile phones) which are utilized as patient terminals. However, most of these devices lack usability, mobility, interoperability and finally, yet the most importantly, such systems are often too expensive for a widespread usage.

PCs or set-top boxes are stationary, whereas mobile phones can be used for in- and outdoor applications. Furthermore, mobile phones are characterized by widespread usage and provide several interfaces to interlink devices and services (e.g. Bluetooth, NFC, ANT+).

Limited resources concerning memory capacity and processing power are the main disadvantages of mobile phones. These limitations have to be considered when designing and implementing mobile phone-based applications. Mobile phones often lack consistency in operating system and design. The mobile phone market is fast moving so every year new handsets appear on the market. That makes it difficult to develop an application software that does not need software maintenance. When a device, such as a mobile phone which has telephoning as a primary function, is used for some other purpose older patients sometimes react with refusal and mistrust.

In most cases elderly people prefer to stay at home and rarely go on vacation or visits of longer than one day. Therefore, health data collection via mobile phone, which is more complicated for cognitively limited elderly patients, becomes redundant [30].

Reliable identity management of personalised data (i.e. the assignment of a data set to a patient) is one of the big challenges in future telemonitoring scenarios.
Today entering username and password is the gold standard for personalising data on the internet and authentication. However, it is well known that this may also be an issue for elderly patients. Not only is it hard for them to keep the username and password in mind, impaired patients are also unable to enter the data using the alphanumeric keypad. Using RFID cards, which have the patient's username and password stored, could be a good solution as demonstrated above.

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

4.5 Workflow and usability

The major goal of this thesis was the design and implementation of a PC based AHD, which can be handled intuitively and easily by elderly people. This user group not only has problems with handling small keypads or reading from small displays but also with using technology in general. To bypass these problems several steps concerning usability were taken which are described in chapter 2.3.

The workflow was designed so that the number of user interactions was reduced to a minimum. The patient had to put the RFID card on the reader and started taking measurements. After that all collected data in the time period were assigned to this patient. No keystroke was required to collect and send data to the AHD.

The results of the usability test conducted within this thesis indicate that the AHD can be used intuitively and easily. However, the results of the usability test were limited because the test group only contained four participants. For more representative results, the developed AHD has to be tested on a much bigger group of elderly people.

4.6 Future prospects

The prototype realised within this thesis offers a telemonitoring solution for chronically ill patients and elderly people. Looking into future designs and usage of the proposed technology leaves room for other potential scenarios. The current use case is that a household has one AHD which is placed in an easily accessible place. Medical devices namely weight scales and blood pressure meters are paired with the AHD. Since the AHD is capable to collect data from multiple users, it can be placed in a nursing home or a hospital. The idea of a smart home could be realised if the building was equipped with environment sensors. Within the nursing home all residents could be equipped with a RFID based identification card and sports watches. Their daily health data could be monitored continuously. Thus, the system would record and process information about the patient's health status and their physical activity.

In all the multi user scenarios described above each user would send a unique identifier in order to indicate that the acquired data belongs to him. The AHD would be responsible for identity management, because it is involved in all communication scenarios of the entire monitoring system. This ensures that every event can be correlated with the appropriate user.

In the following section a future mobile version of the AHD is discussed. New handsets with more processing power end less energy consumption are being developed to appear on the market. It is crucial that data acquisition continues in order to achieve the best possible therapy for the patient. A future AHD for handheld devices could be developed to give patients the freedom to travel.

If a chronically ill patient is on vacation, it is crucial that daily acquiring of health data continues in order to maintain therapy management. A mobile version of the system proposed within this thesis would satisfy this requirement.

Further future application areas of the presented system can be generated when using the AHD for other purposes. The connection with a monitor would allow AHD to give feedback to the user. Medical data from the health devices, fitness and sports data and environmental data could be displayed to inform the patient about his/her current condition. The AHD could be used for personal fitness training. This could help with rehabilitation and weight loss.

In the context of AAL the AHD 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 physically being in the room with them.

Another possible application for the system would be fall detection. Falling down is the biggest fear of elderly people who live on their own. The AHD could be connected to accelerometers, to detect long periods of inactivity. The AHD could manage emergency calls if a fall were to be detected.

In conclusion, there are vast opportunities for the development of a future prototype, as realized in the present thesis.

CHAPTER 5

CONCLUSION

A prototype of a multichannel and multimodal wireless AHD was to collect various vital parameters and sports data in a multiuser environment as well as environmental data was developed. The presented multimodal platform infrastructure is an excellent chance to obtain general information about a user while at home, and a wearable sports watch can gather data wherever the user may go outside.

Costs are a very important part of the system particularly for pensioners. The modules already implemented are using free software and relatively inexpensive hardware elements. One possibility for optimization is to build a GUI to interact with the user.

Although the prototype showed potential for optimization, the basic features could be tested successfully. The results show that a single point of data collection may be feasible to serve several eHealth applications, i.e. telemonitoring, AAL, environmental monitoring as well as sport and fitness tracking. Results show that the AHD can be used to monitor multiple users.

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