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Real-Time & Autonomous Data Transmission for Vital-Sign Telemonitoring: Requirements & Conceptualization

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Abstract. The alpine space is challenging for mobile care organizations as rural homes of patients are often characterized through long way distances or might be sometimes even isolated due to weather conditions. Real-time monitoring features for supporting mobile care require the easy conduction of self-measurements on vital signs for patients. Therefore, a vital sign telemonitoring system got conceptualized, utilizing the potential of Information and Communication Technology (ICT). The aim of this work was to gather technical and user-related requirements for a patient-centered telemonitoring system. Therefore, a mixed approach was followed comprising a comprehensive technical review, a literature review and interviews with stakeholders. Suitable use cases were derived from the gathered technical and user-related requirements. The results yielded to a concept for a seamless integrated, unobtrusive home monitoring system for elderly people with real-time data synchronization and communication features to support the mobile nurse organization, which got implemented and evaluated in the field. The concept overcomes known barriers of usability on telemonitoring systems like complex interaction which might lead to more efficiency and effectiveness in mobile nursing. The developed concept got further implemented as a prototype and validated within a 3-month test period.

Keywords. Telemedicine, Mobile Applications, Vital Signs

1. Introduction

The demographic transition is changing the age distribution worldwide. Thus, the future will lead to more and more elderly people accompanying the increasing emerge of chronic diseases, which is challenging for sustaining high-quality mobile care. The number of people who received home care services in Austria rose from 123.000 (2011) to 147.000 (2016) [1].

Mobile nursing organizations provide services for the elderlies to visit them at home and support them on everyday activities and monitor the patient's health status.

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Especially in Western Austria, this service is challenging, as the alpine space often hinders accessibility to the people's homes. It is cumbersome for a patient to receive the necessary healthcare as the next hospital or physician is far apart and sometimes the homes are even isolated because of weather conditions.

The proliferation of modern Information and Communication Technology (ICT) has led to new technology paradigms like the Internet of Things (IoT) [2], which opens completely new possibilities for the meaningful use of data and for the support of mobile nurses in rural regions. Mobile care related telemonitoring investigations in the past involved a lot of user interaction and were mainly telephone based [3] and thus hindered its proliferation [4]. ICT-based telemonitoring systems are on the rise, contemplating its benefits (e.g. proactive security, patient safety, reducing readmissions) [5,6] as well as its drawbacks (e.g. poor usability, high implementation costs, privacy concerns, loss of contact) [5]. The measurement of vital parameters is considered to be of great importance in the field of telemonitoring as the measurements are easy to conduct and provide valuable information about the patient's health status [10]. As part of the EU-funded Interreg project INTESI [7], the subproject VITAMO was conducted in 2018 to facilitate everyday work of a nursing organization in the alpine space. The focus of the project was set to prove technical feasibility and the efficiency of the intervention.

The work of this paper is part of VITAMO and the objective is to investigate and gather technical and user-related requirements for an unobtrusive and easy to use ICT system, with the focus on supporting home care nursing in the alpine space. This system got further implemented as a prototype and evaluated in the field.

2. Methods

The present work followed a mixed approach as depicted in Figure 1. Starting with a brainstorming session of the participating researchers, a technology review, a literature review and a group interview involving nursing professionals, regional coordinators and governmental executives were conducted. The brainstorming task ranged over all parts and was considered to reconcile the results and formalize technology requirements and user-related requirements. Based on the requirements, suitable use cases for the support of mobile home care were derived.

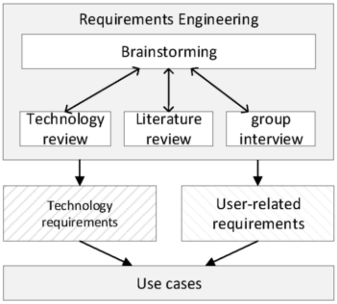

Figure 1. Overview of the requirements engineering process.

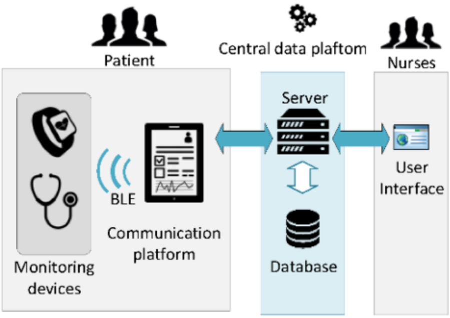

Figure 2. First technical concept comprising the stakeholder's patient and nurses.

The technology review started with a regional environment analysis. Internet accessibility was analyzed according to its availability based on data from the national broadcast and telecommunication regulation organization (RTR Austria). Further, current low energy transmission standards for suitable smart devices [8] were analyzed like NFC, RFID, BLE or ANT+. The technology review for suitable devices on vital sign monitoring was initiated with reviewing existing scientific literature.

A narrative literature review based on publications on PubMed and Google Scholar with the search term "vital sign telemonitoring requirements" was conducted to find suitable papers. The idea was to get an overview of both, general factors and requirements for telemonitoring systems and related devices available for consumers.

A group interview with the local mobile nursing organization of the selected test region was conducted as an early task to identify potentials for utilizing suitable ICT aiming to support mobile nurses within the alpine space. The interview was also used to further specify the necessary requirements for the intended solution. In the interview, a broad mix of perspectives was aimed to be fused into a coherent result. The semi-structured interview guide contained questions about 1) organizational aspects on processes and documentation for managing their patients' health, 2) their existing IT for patient documentation 3) typical patient collective they take care of, 4) internal communication patterns. The interview was held as a discussion with participant nurses, incorporating also findings from the technology review. The results of the interview were utilized for the formalization of user-requirements for the support of mobile home care.

In order to identify potentials of the existing ICT environment together with suitable devices for supporting mobile nursing work, user-related requirements where refined with information gathered from literature based on the selected domain (vital sign self-measurement) and the given context (support of mobile nurses). Results from technical and user-related requirements were aligned and formalized as a functional concept that describes the system requirements as precise use cases.

The stakeholder related (user-)requirements and the overall concept evaluation were aligned with the selected test region. The test region for the project was set to Reutte, a rural district in the province of Tyrol. Tyrol is a 750k population province of Austria, with 45 healthcare organizations active in home nursing / mobile care [9].

The use cases were oriented on the basic need to monitor a patient's vital signs. This fact was used to search the scientific literature for ICT products/devices intended for the distinct use of medically relevant vital sign self-measurement. Suitable vendors and products for vital sign monitoring were collected based on a Google search. The selection of suitable measurement devices was limited to known medical vital sign parameters [8] ("blood pressure", "body weight", "blood glucose", "heart rate", "activity tracking", "sleep tracking") and smart devices. Smart devices are known as electronic devices like sensors for a defined purpose, which are able to interact with other devices [2]. This is usually established through modern wireless interfaces like NFC, Wi-Fi or 3G, which are often designated as IoT-devices.

3. Results

3.1. Requirements Engineering

The initial brainstorming phase resulted in a general overview of the technical conditions and possible starting points for assistive systems in mobile care. The present work is focused on home vital sign monitoring: Nurses of mobile home care are already regularly driving to the patients' homes to check, among other activities, the patients' vital signs like e.g. blood pressure or blood glucose level if necessary. Together with ICT, telemonitoring supports the prevention and early detection of health problems. The solution should let the patients conduct self-measurements and allow for the responsible nurses to get access to the measurement results, monitor possibly critical factors of their patients and react accordingly as well as to foster communication.

The idea was based on the given mobile internet infrastructure utilizing common electronic devices like smartphones and tablets. A first concept was elaborated, which provides medical devices for vital sign self-measurement at the patient's home and integrates them with a server via a mobile connection. An early high-level concept of a solution was defined within the brainstorming sessions as depicted in Figure 2 for further requirement analysis.

The literature review revealed an overview on related requirements for telemonitoring systems [11] which comprise the following parts: 1) Data acquisition using suitable devices, 2) Data transmission between patients and healthcare experts, 3) Integration of data with other data describing the state of the patient, 4) Synthesis of an appropriate action (e.g. decision support) and 5) Data storage.

Those five topics were considered to build the basic principle for further design on the concept of vital sign monitoring, the precise requirements specification was adapted to the use cases. All topics (except 4.) were further implemented as a prototype for vital sign monitoring as published in [12].

Suitable vendors for devices on self-measurement vital sign devices were collected based in the inclusion criteria, whether they provide functionality for measuring at least one of the state vital signs, smart connectivity and description in German or English language. The emerging device types for blood pressure, blood sugar, pulse oximetry, ECG, weight scale, body temperature, activity tracker and spirometer were categorized for all devices of the 51 selected vendors. The selection based on the Google search got filtered from devices that didn't offer any smart functionality or where product information was not available in English or German language. Additionally, to the different device types, it was determined whether the vendor does provide any app e.g. for smartphones to connect to the device (accessing the device' measurement data). The number of available devices per device category can be found in Figure 3. The complete list can be obtained from the authors.

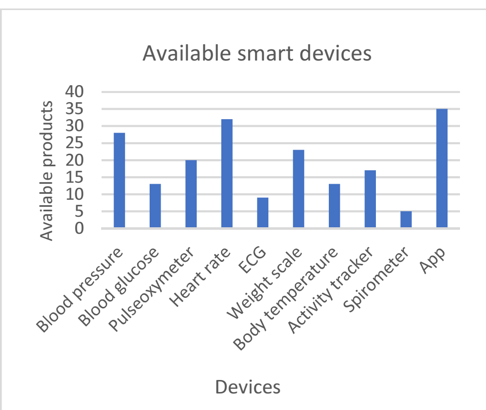

Figure 3. Overview of found available smart devices for vital sign self-measurement grouped by device type.

Patient Interaction: The system must be usable by persons with slight cognitive impairments. Related large font size, big buttons and little interaction between patient and tablet or devices are required.

User Interface: Nurses and patients must have the same UI designs, i.e. web access for the nurses has the same structure and design as the app on the patient's tablet.

Mobility: Nurses must be able to access the patient's vital signs everywhere through mobile internet. The patient's devices must be mobile and must not depend on the patient's environment.

"Out-of-the-Box"-capability: The system must be usable out of the box without any configuration at the patient's home.

Listing 1. Selected usability requirements

A deeper analysis of vendors' apps revealed that data provision is exclusively cloud-based, i.e. the devices store the measured values directly to a cloud-server (via the smartphone) and the user is then able to access this data through the internet. As those apps are provided as closed-source solutions, data privacy is challenging on the cloud-server and during data transmission. There were solutions from 3rd providers (adhering to the GDPR), but its use would create a dependency of the SMART providers, either losing the desired flexibility (limited to the provider's devices) or increasing the complexity of the system dramatically (using different cloud-provider integrated into one system). Due to this case, it was decided to avoid the use of such integrated providers.

The high availability of mobile internet connection was recognized as a key factor for new telemonitoring approaches, as 2G, 3G and even 4G mobile standards were highly available in the test region, even in solitary regions. Further, today's ICT-devices like smartphones or tablets are inexpensive and offer flexible communication interfaces e.g. through Bluetooth or GSM. Based on those results, the 4G mobile connection was also chosen as the long-range data transmission standard for the prototype. The communication between vital sign devices and communication platform implies to avoid any complex data transmission task for the user. Thus, the analysis of existing low energy standards revealed Bluetooth low energy (BLE) to be the most spread and supported standard. Transmission standards for very short distances (< 10 m) like RFID were excluded due to the complex usability of bringing the device near the receiver. A tablet at the patient's home was used as a communication platform between Bluetooth measurement devices and the remote server. Besides the hardware requirements, medical interoperability was deemed necessary for a vital sign monitoring solution. Thus, the adaption with syntactical and semantically medical standards like FHIR or SNOMED-CT was crucial and got integrated into the concept.

Based on the results, related functional and non-functional requirements were elaborated, where a full list can be obtained from the authors. The main categories for functional properties contain access rights, user management, web app nurses, a mobile app for clients, device management, communication and logging. The main non-functional requirement categories comprise usability, security, performance and scalability. For each category, precise requirements were defined.

The remaining part is focusing on the relevant part of usability requirements, where a selection is depicted in Listing 1. The vital sign measurement devices used by patients must adhere to the following requirements: It is necessary that a device is easy to use and ready for use out-of-the-box. Mobile devices are particularly suitable for these requirements as they can be used anywhere and do not have to be installed on site. This means the mobility of devices is crucial. Further patients need to be easily able to use the devices. The system needs to be unobtrusively integrated into the patient's everyday life. Intuitive user interfaces are mandatory and known processes should be sustained. Process analysis revealed, that all patients in care were familiar with vital sign monitoring and had been actively conducting regularly measurements, e.g. for blood pressure. As the available devices of the patients didn't provide any interfaces for accessing the data, they couldn't be used within the project. Nursing staff must be able to access an overview of all patients and display possible graphical trends. Further, direct nurse-patient voice communication was also required. Overall the ICT support needs to seamlessly integrate with the existing nursing process of organizing and conducting home care.

3.2. Prototype Concept

A prototype concept was developed based on the gathered requirements, which offers vital sign self-measurement devices for body weight (including additional body composition values), blood pressure, heart rate, activity (including sleep activity) and blood glucose (whenever needed).

The use case diagram in Figure 4 presents the related functions of the concept and the related prototype implementation. An external administrator actor was responsible for configuring the patients' tablets and devices (e.g. pairing new smart devices with the tablet) as well as maintaining the server infrastructure with user and permission management (nurses and patients). The patient was able to conduct related vital sign measurements with the BLE devices, and related data gets automatically synchronized with the tablet. The tablet exchanges the data with the remote server and nurses were able to access this via a web interface. The patient was able to view past measurement results on the tablet.

Following the functional requirement to remind the patient e.g. to take medication or drink enough, a function for receiving a reminder was added. Thus, a nurse could e.g. set a reminder at 6 p.m. to take medication and the tablet will prompt a message with an audio signal. The patient might confirm or decline the reminder message, which was also stored in the diary. Further, the system could establish a telephone call between patients and nurses.

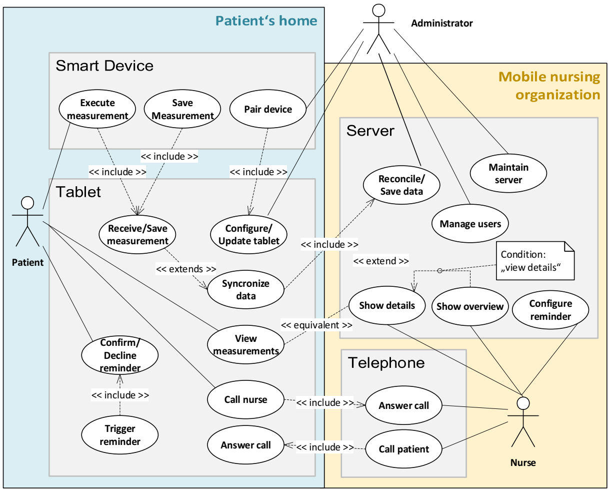

Figure 4. UML use case diagram of the VITAMO telemonitoring system.

The nurse had the possibility to access a list of all patients through a web app with an overview of past results and related metadata (e.g. time of measurement). The detail-view displays all information about the conducted measurements of a patient. Based on the requirement to avoid complex interaction with the smart devices for data transmission, the use of the devices got planned to stick to known processes for the patient: The devices automatically transmitted new data and stored the results in case of a failed transmission. As depicted in the use case diagram, nurses get the same detail view as the patients on the tablet to meet the requirements.

The idea was to create a system that works out of the box, everywhere and with automatic data transmission in real-time. The hardware for patients should be unobtrusive, mobile and not affect everyday life. This also requires avoiding complex interaction with the devices. Details of the prototype implementation can be found in [12]. The selected smart devices for the prototype were all verified medical products (except the fitness tracker), however, the focus of the VITAMO project was to prove technical feasibility without any added medical value first and thus the selection of certified medical devices was not prioritized.

The prototype got tested with the local nursing organization and evaluated in the selected test region in Austria. Patients from the local nursing organization were recruited as participants, who had the physical condition do conduct vital sign self-measurement. As determined by general requirements, the installation effort was low as the mobile system worked out-of-the-box and utilized devices were easy to use. Thus, nurses thought the patients directly at the patients' homes how to use the system. The field test was conducted for three months in 2017. The first test results showed the very good suitability of the selected technical setting (mobile Internet and BLE). The user satisfaction got evaluated and results revealed that the system was easy to use for both, nurses and patients. However, the expected benefit for mobile care could not be achieved, but the detailed evaluation of the test phase is beyond the scope of this paper and will be published separately.

4. Discussion

A concept for a mobile, unobtrusive home monitoring system for elderly persons with real-time data synchronization and communication features to support the mobile nurse organization was developed.

A similar domain of supportive assistance is known as Ambient Assisted Living (AAL). Following the requirements of establishing an unobtrusive system, it was deliberately determined to refuse any integrated AAL solution, e.g. like the complex smart home setting from [13], as the modification on the patients' homes including the potential installation of static sensors were not appropriate.

The followed approach was based on a rough determined plan, conducted with agile adaptions. The idea was to follow a mixed approach, where tasks of technology review, literature review and interview mutually affected. The methodology focused on the intention to develop a suitable solution for the given problem of supporting mobile nursing in rural regions with ICT. The idea was set to position the intended solution in the given context of vital sign monitoring and regulate all internal (user requirements) and external factors (available infrastructure) in order to get a suitable prototype.

The requirements engineering task revealed technology and user-related requirements. Technology requirements were mostly influenced by the available environment of mobile long-distance data transmission standards like LTE and available low energy IoT-devices and connectivity standards like BLE. The solution further integrates with existing medical interoperability standards, thus each measurement was designed as a FHIR-Observation resource with the related SNOMED-CT code.

Devices for vital sign self-measurement need to adapt to the requirements of the elderlies, i.e. to adhere to their known processes and act unobtrusively. In contrast to other available vital sign self-measurement solutions [14], the developed VITAMO system was intended to focus on mobile nursing and provide real-time data synchronization, so nurses were immediately informed about the results. Further, the devices were seamlessly integrated, i.e. patients didn't need to take care of any connectivity. All devices (including the tablet) acted autonomously for synchronizing the data. This means, if the connection between the server and the tablet is lost due to any reason, data will be managed locally and synced immediately after reconnecting. This is also the case for the smart devices: measurement results were stored on the devices if they were not synched with the tablet. The server was self-hosted and data access did not depend on any cloud.

The concept showed a validated solution for supporting nurses from mobile home care. Although requirements were validated within the interviews, the content is related to the selected region and thus results might differ from a broader setting for the alpine space. Further, due to the frequent moving market, it cannot be guaranteed that a complete list of available vital sign devices was found. A 3-month field test in the selected alpine region was conducted subsequently with an evaluation of the prototype and its impact on how such a system performs in supporting mobile care within the alpine space, which is not further described in this paper.

Although the present work was focused on the selected test region in Austria, the novel idea of real-time data synchronization and autonomous data transmission could contribute to the further development of telemonitoring systems. The intention was to overcome the distance barrier of mobile nursing as well as usability barriers by encouraging patients for easy self-monitoring with real-time synchronization, so nurses can meaningfully react to possibly risky measurement results. The system works out of the box and autonomously transmits the data for remote monitoring. The final evaluation revealed valuable first results of the test period.

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