Sensor-enhanced health information system architectures for home and telecare: concept and prototype

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Abstract: Demographic trends towards an aging society motivate the search for alternative health care paradigms. Information technology driven home-care and telecare are popular concepts, and a lot of projects resulted in corresponding systems. Thus the question arises what implications for health information system (HIS) architectures emerge and how sensor technology as a core technology for home and telecare can systematically be integrated into HIS architectures. Based on respective literature and previous experience in home and telecare projects basic components and services of a sensor-enhanced HIS are identified and exemplified by a research prototype of a sensor enhanced telematics platform. The research prototype makes intensive use of international standards (e.g. HL7 CDA and the Arden syntax). The results of first evaluations of the prototype system in a laboratory environment and in the context of telemedical surveillance of home exercises in case of cardio-vascular diseases are described. First evaluations demonstrate the feasibility of the approach. Further work is needed towards ensuring ad hoc connectivity of sensor systems and further elaborating cascaded sensor data analysis.

1 Introduction

Demographic trends especially in western societies towards an aging society bear hopes and concerns equally. The UN Department of Social and Economic estimates an increase of the life expectancy across countries from 46-89 years in 2004 to 66-97 years in 2100 and 87-106 years in 2300 [UN04]. Thus people have a growing chance to live to a ripe old age, but with growing age the risk of suffering from diseases, especially chronic ones, increases. Goldman et al. based on Medicare data estimated an increase of the prevalence of the five leading diseases arthritis, hypertension, heart disease, diabetes mellitus and cancer from 1998 to 2030 by 11.1%, 3%, 1.9%, 2.4%, and 1.3% [Go04].

One example of a severe cognitive impairment related to old age, that usually induces a higher need for personal care, is dementia. Brayne et al. reported in a recent study an overall prevalence of dementia at death of 30%, with an increase for those aged 65-69 years (6%) to those aged 95 years and above of 52% up to 58% [Br06].

Simultaneously the rate of people 65 years and younger that can potentially contribute to firstly finance health care and secondly carry out care will decrease from 76% in 2100 to 68% in 2300 [UN04]. Another UN study impressively underlines this problem: the potential support ratio that relates the number of people aged 15-65 to older ones is expected to decrease from 9:1 today to 4:1 in 2050 [UN06]. Thus we can conclude, that the amount of people that will need health care increases dramatically whereas the means to finance health care and the number of people who can carry out health care decreases. One approach to face these developments are home care based concepts for disease prevention, care for chronic diseases and assisted living. Through the intensive use of technology like "telecare and home monitoring", "smart homes and robotics" and "health information systems and knowledge management" [Ko06] these concepts often aim at reducing the costs for health care by reducing the need for face to face contacts with care and medical personnel [Bo05].

In recent years a lot of home care and telemedicine projects (e.g. [La06], [To06]) elaborated these ideas and resulted in solutions that often (not always) have proven usability and have shown effects in terms of clinical outcome or cost efficiency [Her06]. Based on these developments and findings one might assume that this kind of technology-driven support of health care will find its way into routine use. A prerequisite therefore is that technological islands are avoided, i.e. home-care and telemedicine concepts are systematically integrated in health information system (HIS) architectures. Thus the question arises how sensor technology as a base technology for home-care and telemonitoring can systematically be integrated into HIS architectures.

2 Methods

Based on current, respective literature and previous experience in home and telecare projects in the context if diabetes care [Bo05b, Bo06], and telecare for patients with cardiovascular diseases [Ge06, Rh06] this paper aims at identifying basic components and services of a sensor enhanced HIS architecture on a logical level. Additionally first experiences with a research prototype for a sensor-enhanced telematics platform that instantiates this architecture are presented. The paper closes with a discussion and conclusion.

3 Basic components and services of a sensor enhanced HIS

Sensors and sensor systems are basic building blocks of sensor-enhanced HIS and a suitable starting point to identify basic services and components of such systems on a logical level (see Fig. 1). Sensors[1] can be differentiated into the categories of environmental sensors like cameras, pressure sensors, humidity and temperature sensors often used in the context of smart houses [St04] and body related sensors. The latter can be subdivided into invasive sensors e.g. used in internal pacemakers or cardioverter defibrillators [Me06], and on-body or near-body wearable sensors like ECG sensors, pulse monitors, or accelerometers [An04, Lu04].

Sensors usually are *prescribed* (service 1) by a health care professional (HCP) and/or bought by the patient. In both cases the sensor might need to get *configured* (service 2) concerning its mode of operation. This can be done prior to sensor *integration* (service 3) or afterwards remotely or directly using the sensors user interface by persons allowed to change the *sensor configuration* (data entity 1). Preferably integration and configuration should be conducted ad hoc and without external influence [Ha04, NSG04]. After integration and configuration the sensor *acquires data and communicates* (service 4) them wirelessly or based on cable connections to a storage system that stores the *sensor data stream* (data entity 2). Sensor status information is part of its configuration data, i.e. the status of the sensor system of a person can be assessed by the sensor configuration service.

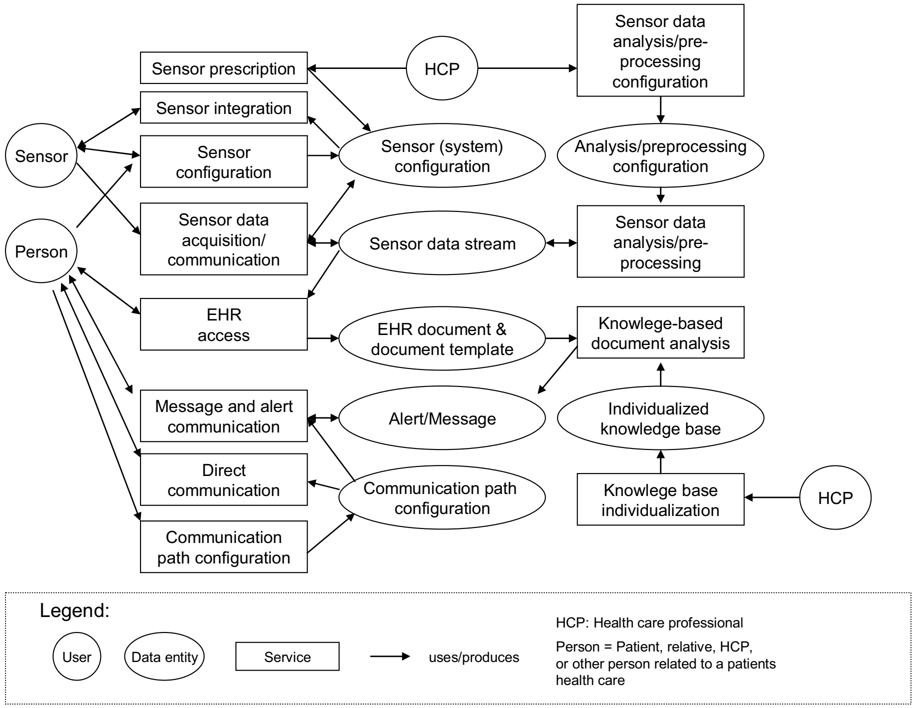

Fig. 1: Basic services of a sensor-enhanced HIS

[1] A comprehensive survey of sensors in medicine and health care is provided by Öberg et al. [ÖTS04].

The sensor data stream can be subject to *data preprocessing and analysis* (service 5) before or after persistently storing the data stream. Data stream preprocessing in the sense of filtering is necessary when the amount of data produced by a sensor system prohibits communication and storage of the complete data. Like in intensive care sophisticated preprocessing algorithms are needed to detect relevant information [SFG06]. Furthermore specific data analysis and data mining methods can be applied effectively to multiple time series produced by sensor systems [Ke06]. Thus a data analysis and preprocessing service needs to get configured for a certain patient by a HCP towards detecting data patterns respectively events of clinical relevance (service 6 and data entity 3: *analysis/preprocessing configuration*).

An EHR is a core component of a sensor-enhanced HIS storing all relevant health related information in form of electronic documents (data entity 4). Being able to also store data coming from sensor, sensor systems or sensor data analysis and preprocessing enhances the traditional EHR concept towards a *sensor-enhanced EHR*. Based on the definition of Shabo [Sh06, Sh06b] such an EHR aggregates "… recordings created by all healthcare enterprises from which the subject of the lifetime record has received medical care throughout his/her life" enhanced by sensor data and derived data. The *EHR access service* (service 7) comprises the usual services for storing and accessing electronic health related documents and document templates. The latter are usually forms to be filled in by a person.

The electronic documents being part of EHR are the basis for their *knowledge-based document analysis* (service 8). The analysis is conducted whenever new documents are added or the *individualized knowledge base* (data entity 5) of the patient changes. The individualized knowledge base is a collection of knowledge declared relevant for the patient by a HCP using a *knowledge base individualization service* (service 9) based on global knowledge bases. Main functionality of the knowledge based document service is to produce and communicate messages (data entity 6) or alerts (alerts are messages with certain urgency) for the person, a responsible HCP or other persons responsible for the care of a person (service 10). That a message or alert reaches the right person in the right time using the right communication channel and device requires a comprehensive definition of responsibilities, representation rules, communication device directories and escalation strategies [Ka04]. A corresponding *communication path configuration service* (service 11, data entity 7) has to be provided for the patient and his health care team. A typical message is the hint that a certain document template has to be filled in by the user. Direct communication (service 12) channels also need to be supported.

4 Research prototype of a sensor-enhanced telematics platform

Based on the logical service-oriented architecture for sensor-enhanced HIS described in section 3 we have developed a research prototype that instantiates some of the components and services presented. The prototype architecture (see Fig. 2) bases on the concept of a *sensor-enhanced telematics platform* and offers services and corresponding user interfaces. The platform connects *institutional HIS* (hospital information systems, general practice information systems, etc.), and the patient at home respectively in his personal environment (the *personalized HIS*). A core component of this platform is an e-consent based shared EHR system developed for supporting integrated healthcare networks [Be06]. It supports the HL7 CDA Release 2 standard for clinical documents [Do05], virtually integrates distributed document sources, and provides secure access based on patient and health professional cards. Electronic signature of documents is also supported. Besides interfaces for storing electronic clinical documents coming from institutional HIS, the system provides user interfaces based on web technology for filling in specific health-related forms or questionnaires (i.e. document templates).

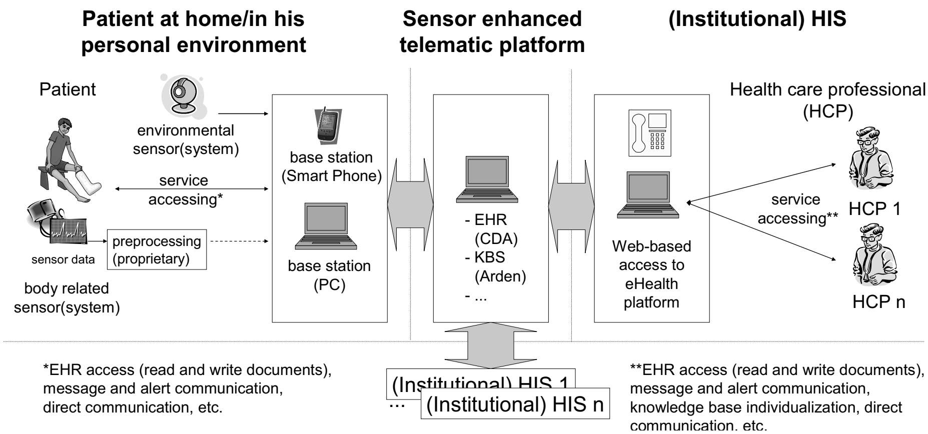

Fig. 2: Research prototype realizing parts of the proposed sensor-enhanced HIS architecture

The knowledge-based document analysis service is realized with an implementation of an Arden-engine [Ge06] based on the HL7 Arden Syntax for Medical Logical Systems [AH02]. The Arden-engine, that is part of the sensor-enhanced telematics platform interprets Medical Logic Modules (MLM) that are written using the Arden syntax. MLMs are rule-based and event-driven descriptions of medical knowledge. Whenever a new clinical document is stored in the EHR the Arden engine checks if an MLM is listening for such documents and then starts its interpretation. The interpretation of an MLM can include access to further EHR documents, the activation of other MLMs, the generation and communication of messages or alarms, or the storage of documents in the EHR. The knowledge base individualization service for HCP is also implemented in form of user interfaces that enable HCP to select and adapt MLMs for a certain patient.

The concept for realizing sensor prescription, integration and configuration is to store corresponding clinical documents in the EHR of the patient. This concept has been partly implemented for the scenario of remote programming of a bicycle ergometer that integrates a sensor system (see 5.2). In this scenario a HCP can integrate the ergometer program in a clinical document that is stored in the EHR of the patient. When the patient starts the next training session she/he transfers the ergometer program from his EHR to the ergometer using a smart phone and a SD-card. Sensor data analysis and pre-processing is currently programmed manually.

5 Evaluation

The sensor-enhanced HIS concept and the corresponding research prototype are currently evaluated technically in a laboratory installation and within the TeleTraining project described in the following. Further projects make use of the sensor-enhanced telematics platform like the LASS-project that is described elsewhere [Ma07].

5.1 Laboratory evaluation

The research prototype described in section 4 is currently installed in our health-enabling technologies lab. The lab consists of an apartment equipped with different sensors, an installation of the sensor-enhanced telematics platform including EHR system and Arden-engine, and a virtual institutional HIS for accessing the services provided by the sensor enhanced telematics platform. Sensors systems currently in use are e.g. triaxial accelerometers for fall detection. The sensor data is analyzed in real-time and aggregated into CDA R2 level 3 documents that afterwards are subject to their analysis based on the Arden-engine and corresponding MLMs. Thus the laboratory allows technical and formative evaluations of the research prototype of a sensor enhanced telematics platform prior to its use in projects.

5.2 Telemedical surveillance of home exercises in case of cardiovascular diseases

Exercise training for patients with coronary artery disease is recommended but has to be supervised to avoid overload [Te04]. Clinical studies have shown that in addition to medical aftercare an individualized, remotely controlled and partly supervised phase III rehabilitation program including exercise training has positive effects concerning the exercise capacity of patients after heart transplantation [Te06]. Based on this knowledge the objective of the project is to evaluate the sensor-enhanced telematics platform prototype concerning its suitability to support remote home-ergometer training for patients with cardiovascular diseases.

Several parts of the sensor-enhanced HIS architecture have therefore been instantiated (see Fig. 3): Document templates and corresponding editors have been developed for the EHR component to support editing and viewing training programs and advice, questionnaires and sensor data. A smart phone application has been implemented using Java 2 ME Personal Profile [Sun07] that allows the patient to contact the EHR component via UMTS and to exchange data with a bicycle ergometer including heart rate monitoring recorded by the ergometer. The HCP gets in contact with the platform by a PC and a web-based Java application.

The HCP (in this scenario a sports medicine specialist) uses the EHR component of the sensor-enhanced telematics platform to store for the patient individual training programs, therapy and training advice, and individual configured questionnaires that have to be filled in before and after the training and weekly. The patient can download these electronic documents via UMTS at home or elsewhere into a smart phone when she/he wants to conduct a training session. The patient reads the training recommendations, fills in the questionnaire and then transfers the training program using a SD-card to the bicycle ergometer. After his training session including heart rate recording using a corresponding sensor, the patient transfers the training results back to the smart phone again using a SD-card. After filling in a second questionnaire on the smart phone she/he transfers the data back into her/his EHR using UMTS.

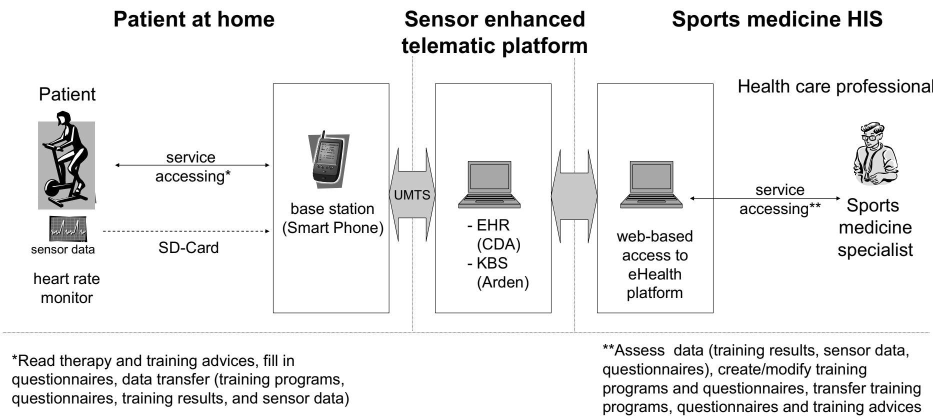

Fig. 3: Instantiation of the architecture of a sensor-enhanced HIS: Telemedical surveillance of home exercises in case of cardiovascular diseases

The knowledge-based component of the sensor-enhanced telematics platform (the Arden-engine) has been equipped with four MLMs for analysing heart rate variability, objective and subjective physical capacity. Based on the training results, heart rate data and questionnaires that are stored as electronic documents in the EHR, the MLMs are executed and produce messages for the HCP when corresponding rules of the MLMs are satisfied [Ge06]. The HCP can analyse these messages as well as the raw data using a special web-based access client for the sensor-enhanced telematics platform including the EHR of the patient.

The system has been evaluated in a four week lasting feasibility study with two healthy volunteers [Rh06]. It worked reliably concerning server availability (100%) and UMTS data transfer (no connection problems). Minor problems have been observed at the beginning of the four weeks phase with the SD-Card data transfer and the wireless data transfer from the heart rate monitor to the ergometer. The users assessed the usability of the system on a scale from 0 (very bad) to 4 (very good) with good or very good. HCP as well as volunteers assessed the system as being a good support for the rehabilitation program. The most valuable effect from the HCPs point of view is the shortened time for feedback on training results from several weeks in the worst case to few hours. In average the test persons got a new training program every 2-3 days.

6 Discussion

Ubiquitous computing environments and sensor-based technologies for health monitoring can be regarded as one line of development for HIS [Ha06]. The architecture proposed focuses on generic concepts for integrating sensor technology in a home-care and telecare context and identifies basic services usable in future models of health care that integrates such technologies. Architectural aspects of such systems for a broader range of diseases and conditions have already been considered in 2000 when the Work on Synergy for Europe (WISE) project defined a basic set of 18 services for regional health care networks (RHCN) classified in “Clinical Services and Telemedicine”, “Health Information Services”, and “Administrative Services and Electronic Commerce” [Oa00]. Home-care monitoring and telemedicine were two services of the first class. Ten of these services were used as a starting point of the PICNIC project (Professionals and Citizens Network for Integrated Care) that focused on the development of architectural descriptions, components and services for RHCN [Ka05]. PICNIC concentrated on three groups of services for RHCN: messaging, access to patient data and collaboration. But generic concepts for integrating sensor technology have not been addressed explicitly.

A service-oriented architecture for HIS is also currently addressed by CEN TC 251 Working Group 1 in the context of the revision of 1998 published ENV 12967 “Medical Informatics - Healthcare Information Systems Architecture - Part 1: Healthcare Middleware Layer” [CEN97]. Based on the ISO Open Distributed Processing Reference model [ISO98] the revision currently specifies the Enterprise Viewpoint, the Information Viewpoint and the Computation Viewpoint of HIS architectures. Especially the Computational Viewpoint in its final version specifies “the scope and characteristics of the services that must be provided by a middleware for allowing the access to the common data as well as the execution of the business logic ...” [CEN05]. Thus current developments and standards in the area of HIS and especially regional HIS focus on service oriented architectures for HIS. These standards are currently in early stages of development and services for the systematic integration of sensor technology are currently not elaborated. The presented architecture and the proposed set of services are an attempt to differentiate these service oriented HIS concepts towards supporting sensor-based home-care and telecare.

Further projects focus more explicitly on the definition of HIS architectures for home-care and telecare like the Citizen Health System (CHS) project [Ma05] or the Saphire project [Hei06]. Both projects define services and components directed towards the systematic integration of sensor technology in a telematics platform that also integrates EHR services and decision support services. The main difference between the research prototype described in section 4 and the CHS is that the first bases on a standard based document oriented EHR system. Whereas the Saphire project focus on a Guidelines based approach of decision support, the approach presented uses an Arden-engine for decision support. This is a marginal difference because further decision support approaches can be integrated in the architecture presented in an incremental way using the message and alert generating decision support functionality. More important the architecture presented explicitly addresses the aspect of sensor prescription, integration, configuration and a cascaded and configurable approach of analyzing sensor data.

This implies that technical connectivity of sensors and sensor systems is a basic prerequisite for efficiently establishing sensor-enhanced HIS corresponding to the proposed service based architecture. Thus standardization of sensor interfaces is of uppermost importance. Even if standards like ISO/IEEE 11073 [IE04] or CLSI POCT-1A [CL06] exists the integration of devices in HIS often needs proprietary interface use or programming. Further work on ad hoc connectivity, i.e. a corresponding plug and play sensor integration service, based on standards is needed.

7 Conclusion

Health information system architectures are facing the challenge of integrating sensor technology and supporting sensor-based home- and telecare concepts. We have proposed a logical architecture for a sensor-enhanced HIS that identifies core components and services. The research prototype presented instantiates this architecture based on international standards for EHR systems and knowledge-based decision support components. First evaluations demonstrate the feasibility of the approach. Further work is needed towards ensuring ad hoc connectivity of sensor systems and further elaborating cascaded sensor data analysis.

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