OSAMI-D: An Open Service Platform for Healthcare Monitoring Applications

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In this paper conceptions and architectural considerations of the OSAMI project and their specializations towards the requirements of the e-health domain by the German subproject (OSAMI-D) are described. Along with the expected shift of healthcare service from stationary towards ambulatory care, a standardized way of integrating medical data acquired at home into the IT infrastructure of hospitals and the synchronization with medical workflows have to be implemented. Therefore, the OSAMI-D project will provide open source components that implement the required interfaces. Preliminary results of the requirements analysis and the implementation of first domain-specific services are presented. These services are used to realize two home care scenarios, which support ambulant cardiologic rehabilitation (indoor and outdoor). Special emphasis is placed on standards and formats for the communication and storage of patient data.

***Keywords* — Ambient Assisted Living, Service Oriented Architectures, Home Care Monitoring**

I. INTRODUCTION

A. Motivation

Ambient computing systems are more and more pervading different domains of our life. With a ubiquitous Internet the networking of devices and services enables new application areas, for instance sensor-supported medical homecare and Ambient Assisted Living. In order to facilitate efficient design and realization of such applications the European ITEA 2 project *Open Source Ambient Intelligence Commons* (OSAMI Commons) has been launched to provide an open service-oriented platform with common (horizontal) and domain-specific (vertical) services available under an open-source licence.

The OSAMI project consists of a number of semi-independent national sub-projects with a synchronized research agenda, but focus on application in different industrial sectors. The German subproject (OSAMI-D) is focussing on applications in the e-health domain. The main objectives are to enable interoperability, maintainability, and reliability of complex, distributed systems as they are typically used in medical monitoring applications including homecare. The management of medical devices and an automated configuration is also in scope. The goal of the OSAMI platform will be to significantly simplify the development of distributed monitoring and assisting systems, thus enabling new forms of delivery of care. The capabilities of the platform will be demonstrated by an e-health application which supports ambulant cardiologic rehabilitation.

Home Care Monitoring systems have been the subject of research for several years, and a few commercial solutions are already available on the market. In the majority of cases, these solutions rely on medical call-centres and transmit data through proprietary protocols and formats and address only basic monitoring services.

With increasing miniaturization of sensors for monitoring vital parameters and the advent of standardised wireless short-range transmission techniques such as Bluetooth [1] and Zigbee [2], mobile and wireless systems for continuous monitoring also outside of hospitals, e. g. at home, have become realizable. Such medical devices are now increasingly owned by the individuals (personalized medical devices) rather than by healthcare institutions.

The main part of this paper is organized as follows: The following subsection *B* describes the state of the art in home care and monitoring systems and the subsections *C*, *D* and *E* focus on the OSAMI-D application scenarios and describe the training preparation, indoor and outdoor training. Section II introduces the system architecture of the OSAMI-D project and discusses the common requirements of the e-health scenario and the domain-specific requirements. Vertical services of the e-health scenario and the domain-specific aspects of medical standards and their interoperability are discussed in Section II *C* and *D*. Section III presents the conclusion.

B. State of the Art

Fundamentally, three approaches for collecting and forwarding vital parameters can be distinguished. The first approach uses a "body area network" (BAN) [3] where vital parameter sensors perform a short-range transmission

to a "hub" (often a smart phone or personal digital assistant – PDA) that forwards the data using mobile phone protocols. The second approach uses an Internet-connected stationary system in the home environment to which the sensors forward their data using wireless transmission. A third approach is to enable the sensors to perform a direct long-range transmission of vital parameters. In the following a short survey of projects with focus on wireless systems in the home care domain is given.

The project *Wireless Patient Monitoring* (WiPaM) [4] developed a system for transmitting vital parameters from medical devices (blood pressure monitor, spirometer, pulse oxymeter, scale) via Bluetooth technology to a Home Care Unit (HCU). The HCU sends the data to the central WiPaM Server. TOPCARE [5] and Philips' Motiva [6] also use Bluetooth for connecting and forwarding sensor data to the HCU. This unit transmits data via international standards like Integrated Services Digital Network (ISDN), Global System for Mobile Communications (GSM) or Digital Subscriber Line (DSL).

In the project *Integrated Distributed Environment for Application Services* (IDeAS) [7] a Wireless Local Area Network (WLAN) for the connection between HCU and sensors has been used. The HCU consists of a Vital Signal Monitor (VSM) and a Set Top Box (STB). The VSM gathers and monitors vital parameters like blood pressure, pulse, glucose level, electrocardiogram (ECG), pulse oximetry, spirometry, cardiac sound, and communicates with the system through wireless TCP/IP.

Universal Remote Signal Acquisition For hEalth (U-R-SAFE) [8] combines the two technologies BAN and HCU for monitoring a patient around-the-clock. While a patient is at home the HCU transmits the data and outside the home the BAN sends the data. This solution offers a 24 hour monitoring and gives a patient the maximum independence.

At present there is no solution for a telemedical support system in cardiac rehabilitation under medical supervision in operation [9].

The EU 6th Framework Programme project *Intelligent Healthcare Monitoring based on a Semantic Interoperability Platform* (SAPHIRE) [10] can be considered a predecessor of OSAMI-D. It developed a telerehabilitation system enabling remote supervised rehabilitation sports for cardiac patients. This application is extended in OSAMI-D with outdoor training and an indoor training in offline mode. Also the system architecture is quite different; the service-oriented architectures (SOA) paradigm is consequently used in the OSAMI-D architecture. Furthermore, the communication between sensors and HCU (hence gateway) uses Device Profile for Web Services (DPWS) [11] as standardized up-to-date service protocol. It enables new attached sensors to be discovered dynamically and is easily supported by common SOA-based web-service toolkits.

Despite the indisputable results of the projects mentioned above it can be stated that flexibly combinable and co-operating embedded devices and software components are difficult to implement, especially in the healthcare sector, due to the multitude of specialised, partly proprietary communication protocols and interfaces [12][13]. The use of service-oriented architectures together with broadly accepted, open standards could help to cope with these challenges.

C. Preparation

The application scenario for the OSAMI-D project is a remote monitoring system enabling cardiac patients to carry out home-based rehabilitation exercise under medical surveillance [14]. Before patients are permitted to perform their rehabilitation training at home, they will carry out an inpatient training phase at the rehabilitation clinic. During this phase the patient receives an introduction to the home care equipment under medical supervision. At this time, the initial training load is determined and all parameters and thresholds for the home-based training are gathered [15]. Furthermore, the patient is familiarized with the sensors and the overall system.

D. Indoor Training

The indoor training set-up permits patients to perform an ergometer bicycle training at home under medical supervision. After every training session, a report is automatically generated and transmitted to the clinic, where it is reviewed and the settings for the next training are adapted if necessary. Patients are equipped with telemedical equipment, consisting of a modified bicycle ergometer to which a "panel PC" is mounted and a set of sensors (3-lead ECG, blood pressure meter, and pulse oximetry) to monitor heart rate, blood pressure, and oxygen saturation. The home-gateway software controlling the training is hosted on the panel PC, which essentially is a compact embedded PC with a touch screen that acts on one hand as the "resident to clinic gateway" between the patient's home and the clinic and as a local storage for the patient's personal electronic health record (pEHR). On the other hand, it controls the ergometer during the training and analyses the data gathered from the sensors and the ergometer, which permits a reliable operation even if the connection to the rehabilitation clinic breaks during the training or is temporarily unavailable.

In detail, the system works as follows: Before a training session starts, the home gateway connects with the clinic to receive a new training schedule and, if necessary, system updates. Furthermore, the patient is asked about his health status and changes in medication. The system provides help with attaching sensors correctly on the body. The system detects whether the sensors are attached correctly and starts with a first measure in rest. Vital parameters are gathered from the sensors and are transmitted wirelessly to the home gateway.

The system provides three levels of monitoring during the training. In all three levels vital parameters (ECG, blood pressure and pulse oximetry) are acquired during the training, summarized in a training report automatically generated after the training and transmitted to the clinic, where a medical supervisor reviews the report and pro-

vides feedback if necessary. Furthermore, if the vital parameters exceed certain thresholds, the training is eased or stopped immediately and a description of the problem is included in the training report. At the end of the training load phase, the system asks the patient about the perceived physical exertion. The system then proceeds to a final measurement of "post-stress" vital parameters and creates the training report, which includes the sensor data, alerts and feedback from the patient.

This most basic "level 3" monitoring does not require a supervisor to be present in the rehabilitation clinic during the training. Monitoring "level 2" provides all functionality of "level 3", and additionally adds a real-time "live" streaming of the measured vital parameters and ergometer data to the hospital and thus allows the medical supervisor to "watch" the training and, if needed, take corrective actions during the training such as changing the ergometer load or adjusting thresholds for the vital parameters. Finally, "level 1" features an additional video conferencing service between patient and medical supervisor, enabling an immediate communication during the training, and a visual assessment of the patient's status by the cardiologist.

E. Outdoor Training

For outdoor training, patients are equipped with a simplified tele-medical set-up consisting of a mobile gateway and sensors for measuring 1-lead ECG, blood pressure, and pulse oximetry. The mobile gateway provides a functionality similar to that of the "panel PC" in the indoor scenario, but on a mobile device (e. g. a smart-phone). Vital parameters are acquired through sensors connected by Bluetooth radio. The sensor data are stored on the gateway and alarms are raised when necessary.

The thresholds for the vital parameters differ depending on the training program, e. g. Nordic Walking, Walking, and Running. As soon as the patient returns to his home, the mobile gateway forwards the data acquired during the training to the home gateway, where a training report is generated and transmitted to the rehabilitation clinic.

II. OSAMI-D System Architecture

A. Architecture Overview

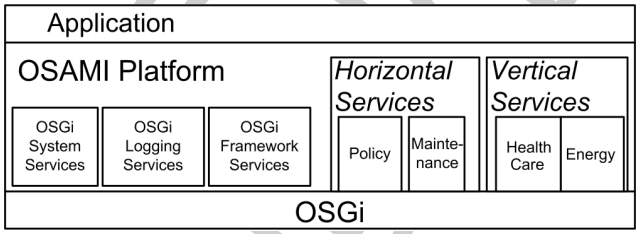

Figure 1. Platform architecture overview

The OSAMI-D software platform is the implementation basis for the system described in the previous section. Figure 1 shows a conceptual design of the platform's architecture. Based on the Open Services Gateway initiative (OSGi) [16], the OSAMI services are implemented utilizing the existing OSGi features. Thus the OSAMI services follow closely the architecture laid out by OSGi. All OSAMI services are implemented as OSGi bundles. As Figure 1 illustrates, the architecture consists of several vertical and horizontal services. The OSGi framework implements "life cycle management" for the services, that is, they can be installed, started and stopped without a reboot of the overall system. In order to bridge the gap between a distributed and a self-contained OSGi environment, OSGi is extended in OSAMI-D by means of the DPWS, a web service stack enabling secure Web Service capabilities on resource-limited devices. DPWS features secure message exchange, dynamic discovery, description and eventing on devices. It is used in OSAMI-D e. g. to enable the discovery of devices such as sensors or mobile phones.

While the vertical services shown in Figure 1 are the domain-specific components (i. e. specific to the health care sector), the horizontal services are domain-independent components of OSAMI-D that are essential for developing vertical domain-specific applications.

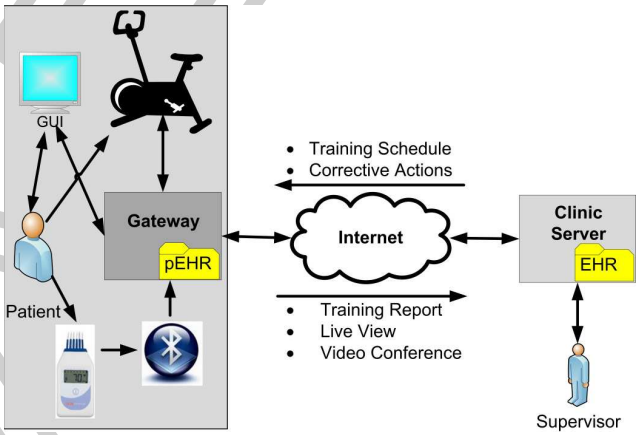

Figure 2. Indoor scenario and data flow

Figure 2 illustrates the technical set-up of the indoor scenario and shows the transport of data. The vital signs of the patient are measured by wireless sensors and transmitted to the home gateway. The home gateway analyses the data and stores them in the pEHR. Depending on the monitoring level, the sensor data, ergometer data, and video/audio signals are sent directly to the clinic via a streaming protocol. At the end of a training session the training report is transferred as a structured medical document to the clinic.

B. Common requirements of the e-health scenario

In the following we discuss the system requirements in terms of communication, Quality of Service, safety / security and system management.

Communication: The application level communication between sensors and gateway should be independent from wireless communication technologies. Bluetooth standardizes all layers beginning from the physical layer up to the application layer. One goal of OSAMI-D is an abstraction from the devices and their physical interfaces. The replacement of physical layer technologies (e. g. sensors with Bluetooth or Zigbee) should not lead to modifications on interfaces or services on the application layer. The communication between sensor and gateway should not be

constrained by radio technology. Newly attached sensors must be detected and activated dynamically. DPWS is independent from physical communication layers and offers interoperability across technologies.

Quality of Service: The integrated video conference system and the transmission of sensor data between patient and supervisor require a certain kind of Quality of Service (QoS). The transmission of sensor data requires a reliable transport protocol such as TCP/IP, whereas video conferencing requires a real-time protocol such as RTP/RTCP (Real Time Protocol / Real Time Control Protocol). Moreover, some kind of adaption is necessary. Video and audio data must be adapted dynamically to changing bandwidth resources. In the worst case, that is, in case of insufficient bandwidth resources, streaming data (audio, video) have to be reduced in favour of the more important sensor data transmission. Furthermore, the QoS service should detect the actual bandwidth, jitter or delay rate and communicate its bandwidth requirements followed by the adaption of streaming data to guarantee the QoS of the system.

Safety, Security: The medical domain OSAMI-D is located in causes several safety and security aspects to be considered. Besides obvious aspects like e. g. not exposing patients to hazards during training due to system failures, there are also issues like to ensure the privacy of a patient respectively the data collected on a patient.

A first measure is to require a login procedure to be used for the application on the gateway. This ensures e. g. that only actual patients are trained, and avoids that unauthorized persons like e. g. family members use the patient training plan and equipment. Also, this procedure guarantees that the correct training profile and schedule for the patient logged on is selected (which is important if the training equipment is used by more than one patient). Using a login furthermore protects the data stored on the gateway by preventing unauthorized persons to access it using the gateway application. This is necessary because this data is personalized and therefore highly sensitive. Apart from the fact that a patient usually wants his privacy to be guaranteed, not protecting those data might also violate law. Especially under that aspect, protecting the data involves some more measures, like e. g. that the communication between home gateway and clinic must be secured. This is required in order to assure that sensitive data cannot get lost, intercepted or manipulated during transmission. Furthermore, the security concept in the clinic must provide that only authorized and authenticated medical supervisors have access to patients health data. A tracking of changes in documents should be recorded in the clinic. Finally, if sensitive data is stored at a location where unauthorized persons might (intentional or even unintentional) access it, the stored data needs to be encrypted.

Management: Management characterizes the adaptation of functional aspects of a system to a new or changing situation. With different modes of operation the configuration and selection of suitable services is handled by management services. Such services support the health check and self-diagnostics of the system itself as well as a policy-based management [17][18] that can control the execution of certain services based on pre-defined “recipes”. Using such techniques, a largely autonomous management of the system can be achieved requiring little human interaction or calls to a service technician or help-desk. As an example the management system may select certain service configurations depending on the quality of connection. The OSAMI-D service landscape will, therefore, be equipped with policy-services and autonomous diagnostic and management capabilities for local and remote administration and management, suitable for different scenarios.

For the medical scenario described here, certain requirements in system operation will be satisfied by the management services pertaining to training control and options, safety and shutdown behaviour, as well as alarm configurations.

C. Domain-specific requirements and vertical services of the e-health scenario

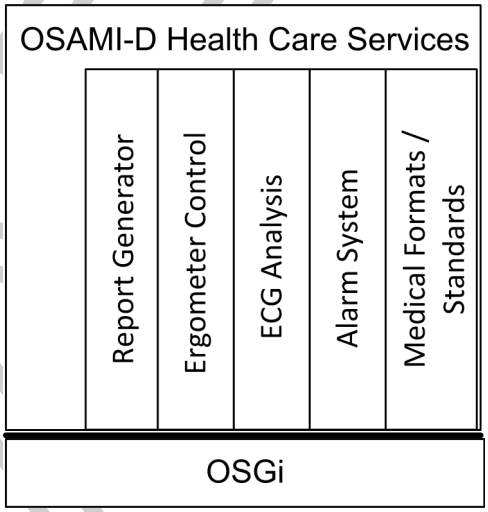

Figure 3. Health Care Services

Figure 3 shows the health care domain-specific services that are required for the scenario chosen in the OSAMI-D project.

Following the description of the scenario and the components of the OSAMI-D architecture, in this section the vertical services are described in detail. To meet the requirements of **vital parameter sensors**, various aspects must be considered during the design of these services. It has been distinguished between the medical point of view, the usability, technical aspects/constrains, and data transmission. A medical requirement refers to the type of information about the patient needed. This implies the use of a certain sensor (e. g. ECG) and the associated analyses. An ECG should not only measure electrical potentials over a number of channels, but an analysis of the raw signal should derive e. g. the heart rate by identifying the r-wave[1] distances. With regard to usability, sensors must display the actual charge of battery, the state of readiness and the state of connection. Furthermore the placement of single

[1] The r-wave is a part of the so-called QRS complex in the ECG recording of a heart cycle corresponding to the depolarization of the ventricles.

electrodes has to be simplified by using belts. From a technical point of view all data ought to be tagged with a timestamp to make processing, sensor data fusion and transmission easier. The data transmission refers to required bandwidth (depending on number of channels and sampling rate) and privacy/identification issues.

The **report generator** collects data and information. It must collect and classified data and information correctly in order to store them in a training report. A semantic enrichment would provide system interoperability with regard to the system in the clinic. A format is needed that enables an exchange of data along with certain "knowledge" about the content. This training report should be structured according to a hierarchy of information. On the highest level, it should contain basic information like name, age and gender. On a second level, training schedule, vital parameters and thresholds should be listed. The outcome of the sensor analysis and the plain sensor data should be collected at a lower hierarchical level.

The **ergometer control** depends on the interaction of the training schedule, the vital parameters and the alarm settings. At the beginning of a training session, the ergometer load increases in x-watt/y-time steps until the required load is reached. During the training, the load is dependent on the training schedule. The required maximum load is adjustable by the supervisor. In case of a medical alarm, the load is dynamically adapted, that is, the load is decreased step-by-step. These dependencies between the ergometer load and vital signs are an "intelligent" conjunction. A rule-based system that handles the ergometer load is needed. This system must trigger the rules in relation to priorities of medical importance. Under no circumstances must the patient be overstressed.

As mentioned above, **ECG analysis** is necessary to derive relevant parameters form the ECG signal. Due to complexity reasons this task is usually not performed by the ECG system itself but rather by a third-party component. This implementation detail can be seen as an example of service encapsulation, where the functionality of a non-SOA component is made available through services. This particular service runs locally since the scenario requires a near-realtime analysis of the ECG signals, and also because of liability and safety issues stemming from the European Medical Device Directive (MDD).

The **alarm system** generates medical alarms and technical alarms. Medical alarms prevent patients from overexerting themselves during a training session. Technical alarms inform patients about hardware or software failure. The home gateway compares the threshold settings for the vital parameters with the actual sensor data. If a vital parameter is out of range, the gateway transmits an alarm. To reduce the number of false positive alarms raised, the vital parameter is revalidated before the alarm is actually generated, thus preventing false alarms due to short-time artefacts in the signal.

Medical formats/standards are an essential prerequisite for the integration of home care in general into clinical workflows and the clinical information and communication infrastructure. One example is the format of the training report. As mentioned above this report should be structured and should not only contain plain text but also machine-readable information. Therefore, the Clinical Document Architecture (CDA) [19] can be used to encode the necessary information into the training report. Due to the complexity of this topic the next subsection describes the state of the art in medical standards and interoperability.

D. Standards and Interoperability

In a system as outlined above, the interoperability of the various components is of prime importance. First of all, various types of vital parameters need to be acquired and interpreted. Standardized interfaces between the sensors and the processing software are highly desirable because they prevent vendor lock-in and the risk of obsolescence of the overall system, should a certain type of sensor go out of production. Furthermore, for an algorithm interpreting, for example, an ECG, it is fairly irrelevant whether the ECG was received over a cable or a wireless connection and which brand and type of ECG device was used exactly, as long as the number of channels, sampling frequency and the "semantics" of the ECG samples are known. This implies not only an abstraction of the transport protocol and physical network connection used, but also the use of a standard representation (data structure) for the vital parameters. A number of standards have been developed in the medical domain for such standard representations, with various degrees of market acceptance, and for different purposes – for example, in addition to the proprietary formats and protocols implemented by most ECG vendors there are at least five competing standards for the representation, storage and exchange of ECG recordings: Health Level Seven annotated ECG (HL7 aECG) [20], Standard Communication Protocol for ECG (SCP-ECG) [21], Digital Imaging and Communications in Medicine (DICOM) Waveforms [22], Medical waveform Format Encoding Rules (MFER) [23] and the ISO/IEEE 11073 family of standards [24]. Most of these standard formats provide a document format in which an ECG recording can be stored, possibly annotated with diagnostic information, and exchanged, but do not support a "streaming" of ECG samples over a network connection in real-time from the acquisition device to a "live display", the exception being ISO/IEEE 11073, which is primarily intended for this purpose. A project like OSAMI actually needs both functions: a "live display" of vital parameters is needed at the rehabilitation clinic during certain phases of the training (level 1 and 2), but vital parameters also need to be recorded as part of the documentation of a training session, for later play-back, post-processing and analysis.

Furthermore, a format for the training reports that are created as part of each training session needs to be defined. While general purpose formats such as Portable Document Format (PDF) are easy to implement and provide for a well-defined visualization of a document no matter where it is displayed, the content of a PDF document is available only to a human reader and not for purposes of further data processing (such as the derivation of trends over longer

periods of time, the re-evaluation of vital parameters of historical training sessions with improved processing algorithms, etc.). Structured medical document formats such as DICOM Structured Reporting, Electronic Health Record Communication (EHRcom) [25] or the HL7 CDA provide this capability. Currently CDA seems the most appropriate choice for the purposes of the OSAMI-D project.

Finally, documents such as training reports, ECG recordings and training plans need to be exchanged between the personal health record maintained in the residential gateway and the IT infrastructure of the rehabilitation clinic for review and updating by the health professionals. Since the documents exchanged contain very personal information, appropriate safeguards need to be taken to ensure authenticity, confidentiality and integrity of documents and communication. In the big picture, one could think of the OSAMI-D system as one out of multiple data sources and data consumers interacting with the life-long, cross-institutional electronic health record that many countries are currently trying to establish on national level. One standard communication protocol for this purpose is the Cross-enterprise Document Sharing (XDS) Integration Profile [26] defined by the "Integrating the Healthcare Enterprise" (IHE) initiative. This specification, which is primarily based on electronic business XML (ebXML) for the functions of a document registry and Web Services for document communication is used by a number of countries (including Canada, France and Austria) as part of their national Electronic Health Record (EHR) activities. In particular, a specific variant of the XDS specification called Cross-Enterprise Document Reliable Interchange (XDR), providing for a direct point-to-point transmission of document instead of the use of a central repository, seems to be most appropriate for OSAMI-D. Being a research project with limited resources, however, OSAMI-D will focus on one of the above mentioned standards to be implemented.

III. Conclusion

In this paper, we described the OSAMI-D Commons project with regard to the domain-specific aspects of the German subproject. The project contributes to the e-health domain. Two scenarios supporting ambulant cardiologic rehabilitation were described. By means of these scenarios, the hardware-components, requirements and domain-specific services were characterized.

A complex and still open task is the implementation of interfaces of such personalized medical devices that allow for the integration of the acquired data into existing information systems of hospitals and general practitioners or into a lifelong (personal) electronic health record. Proprietary formats that are used in most of the existing sensor systems are not suitable for this integration.

Integrating the data of personal medical devices into these health record could give a medical doctor valuable information about the patient's medical history and would be the basis of the observation of long-time trends or sudden events that may indicate the beginning of a disease or may show the progression of chronic diseases.

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