Communication Architecture for AAL

Supporting Patient Care by Health Care Providers in AAL-enhanced Living Quarters

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Summary
Introduction: This article is part of the Focus Theme of Methods of Information in Medicine on “Using Data from Ambient Assisted Living and Smart Homes in Electronic Health Records”. Background: Concepts of Ambient Assisted Living (AAL) support a long-term health monitoring and further medical and other services for multi-morbid patients with chronic diseases. In Germany many AAL and telemedical applications exist. Synergy effects by common agreements for essential application components and standards are not achieved. Objectives: It is necessary to define a communication architecture which is based on common definitions of communication scenarios, application components and communication standards.

Methods: The development of a communication architecture requires different steps. To gain a reference model for the problem area different AAL and telemedicine projects were compared and relevant data elements were generalized. The derived reference model defines standardized communication links. Results: As a result the authors present an approach towards a reference architecture for AAL-communication. The focus of the architecture lays on the communication layer. The necessary application components are identified and a communication based on standards and their extensions is highlighted. Conclusion: The exchange of patient individual events supported by an event classification model, raw and aggregated data from the personal home area over a telemedicine center to health care providers is possible.

1. Introduction

In Germany, a steadily increasing demand of medical services for elderly and multi-morbid patients, accompanied attempts to reduce costs and an increasing shift of therapy and treatment change from inpatient to outpatient care is taking place. Furthermore chronic diseases are under specific focus of interest because these diseases are increasing [1]. Due to the fact that Germany currently has considerable deficits and gaps in the coordination of treatments of chronically ill patients (compared with ten other countries) [2], the efforts to support ill patients at home are high.

These problems are addressed by concepts of Ambient Assisted Living (AAL) and Telemedicine. The goal of AAL is to support age-appropriate assistance systems for older people to continue to live safe and independently in their personal homes [3]. Telemedicine as a part of AAL focusses on supporting of health care services while health care providers and patients are physically separated. For both, AAL and Telemedicine Assistive Technology, i.e. sensors, actors and smart applications to assist elderly people, is needed.

In the European Union, as well as in the United States, nation-wide norms and implementations for the promotion of Assistive Technologies exist [4, 5]. This is achieved through application components, like national master patient indexes (MPI) and nation-wide electronic health records (EHR). In Germany, the Telematic Infrastructure is a project towards this outcome, but at the moment this nationwide implementation does not exist. Also synergy effects by common agreements for essential application components and standards are not achieved.

For long-term health monitoring and the support of medical and other services, health care providers in Germany need to access telemedical- and AAL-relevant data from different information systems, especially from the home area. If patient data that is acquired in the personal home area should be helpful to health care profes-
sions, a consistent electronic data exchange between health care locations (home area, inpatient and outpatient care sectors) without media disruptions is required. In Germany many AAL and telemedical applications exist.

This paper introduces a proposal for a communication architecture as a reference for the problem area of chronic diseases (esp. coronary heart disease, diabetes mellitus). To make use of synergy effects from the resulting infrastructure on a technical level and to support independence of the elderly people, the healthcare network shall not only involve private residential homes but also leverage communities and living quarters.

2. Objectives

Health care providers from different domains use special application components, standards, processes and data objects in AAL and telemedicine scenarios. Because of different application systems and the heterogeneous processes in patient care between the established health care providers and the new healthcare sector, e.g. residential homes and living quarters, a well-defined communication architecture is required. The aim of the paper is to present a way how a communication architecture for Assistive Technologies can be conceptualized.

The communication architecture has to apply widely used communication standards in AAL scenarios to ensure interoperability and data integration between the various information sources and electronic health records of the patients. Fluent data exchange between the health care providers has also to take the medical services (e.g. nutritional advisory, surveillance of current medication) into account, which are used in the treatment.

To solve the integration problem on a technical level, insights about basic components, their functions, national norms and the convergence of different standards are needed.

3. Methods

To reach the objectives the authors defined a process in steps as a conceptual approach for the development of the communication architecture. It comprises the following steps:

1. Identification of the components in AAL and telemedicine projects and their generalization.
2. Representation of the standard components of AAL and telemedicine environments and standard enterprise functions on the basis of the generalized model.
3. Derivation of a service catalog from the domain layer of the generalized model and provision of services of the service catalog for process support by enhanced clinical guidelines.
4. Identification of the communication standards to support the identified services.
5. Creation of an integration profile based on existing communication standards as a reference concept for a communication architecture.

The first step of identification is necessary to gain a basic understanding of the problem area. To find opportunities for generalization and usage on larger residential homes, step 2 is necessary. In the AAL environments supported services for different chronic diseases overlap. Due to the fact, that these services are not used identically, a universally valid service catalog is developed in step 3. These services will be presented as proposals for acceptance into the clinical guidelines to ensure an evidence-based approach for clinicians for the AAL scenarios. Step 4 identifies the existing standards for the meaningful use in the different services. To technically represent the standards for the individual services, an integration profile is described in step 5.

This paper highlights step 1, 2 and 4. The service catalog from step 3 has been developed [6], but the results will not be discussed further in this paper. The aim of the paper does not lay on the presentation of the domain layer, but rather the logical layer. At the moment, step 5 is in the spotlight of current research.

Because no reference models for the problem field were found in a PubMed search, a generalized model was created from the description of all projects in the "eHealth-Landkarte" (eHealth map) of the "Institut Arbeit und Technik" [7]. This map is an initiative of the Federal Ministry of Education and Research that gives an overview of existing telemedicine services and pilot projects in Germany. Based on different criteria, like project type, project duration, disease focus and overlap with other diseases or telemedical focus, a selection of 154 projects was made. A subset of chosen projects was selected by the help of a randomized lottery with 29 draws. The information from the eHealth map is used only for the purpose of categorization of the chosen projects. Essential information of the projects was uplifted by a subsequent sighting, analysis and processing of a variety of sources in literature (individually for each project). By counting the occurrence of data elements a comprehensive generalization of recurring or similar elements while maintaining similar functionality was made. As a result a generalized model which provides all components found in the projects is created. The authors decided to model the communication architecture with the modeling methodology 3lgm² [7]. A 3lgm² model consists of three layers, the domain layer, logical and physical tool layer, and the inter-layer-relationships. The 3lgm² modeling concept was used due to the fact, that it shows all relevant information (data objects, enterprise functions and processes, technical and physical components) on the available three layers for describing an architecture and to enable interconnections between them. The domain layer consists of relevant information entities and enterprise functions. At the logical tool layer different application components that are necessary to support the enterprise functions are modeled. The physical tool layer consists of physical components, on which the logical application components run.

Not all projects in literature provide a communication architecture. Depending on the project focus and target various methods in different software tools are possibly useful (e.g. methods like UML, ARIS, BPMN, 3lgm², ARCUS). These tools
are describing models that represent facts concerning an information system architecture. To ensure a standardized communication, the identification of the common used communication standards in the healthcare domain is essential. The generalized model was reviewed for standardized communication. All proprietary communication links are evaluated to identify possible standards for data communication. For this, the documentation of medical communication standards like Health Level 7 (HL7), Integrating the Healthcare Enterprise (IHE profiles) and Continua Health Alliance (CHA profiles) [9] were analyzed. Subsequently, a selection and expansion of these standards for the field of AAL was made. This information resulted in a derived reference model [6]. The reference model is more precise as the generalized model in terms of necessary components for the problem area and well-defined standardized communication links. It consists of a wider and consistent integration profile that enables the communication of the telemedical enterprise functions between the health locations. For the reference model and the integration profile specific IHE profiles are analyzed. The proven method for the documentation of technical frameworks of suitable IHE profiles was adopted.

4. Results

The conceived generalized model of the architecture of AAL and telemedicine projects is the result of the database search of German projects in the eHealth map. The resulting 3lgm² model incorporates the information of the projects listed in the eHealth map and represents the generalized model [6].

▶ Figure 1 depicts the logical tool layer of the 3lgm². The domain layer, physical tool layer and inter-layer-relationships are not shown due to non-primary relevance for this paper (like the data types and enterprise functions to derive a service catalog as well as the physical components to describe the physical subsystems). In the logical tool layer, three relevant locations (personal home area, outpatient and inpatient sectors and the telemedical center (TMC)) with the standard components are shown. The standard components consist of different application systems (AS) and application components (AC). AS are computer based subsystems of information systems (like Medical Sensor AS) and AC are computer based subsystems of AS (like Alerting AC). Most projects define systems like AAL-AS, Hospital-AS, Ambulatory-AS, Report-AC, Sensor-AC. A smaller amount of projects define e.g. Alerting-AC or Configuration-Setting-AC. These components were stated as standard components and transmitted into the reference model. Three aspects of the logical tool layer of the generalized model will be highlighted.

**Figure 1** Logical tool layer of the developed architecture model
4.1 Telemedical Center with a TMC-AS

The intermediary TMC as a key player in the doctors’ sector provides every function to integrate the locations like a data wheel, e.g. receiving, transforming and forwarding of medical parameters or generating and escalating of reports or alerts to the clinical systems (Hospital-AS, Ambulatory-AS). It also contains, besides the data storage of a cross-domain electronic patient record AC (ePA-AC), a subject-specific telemedical treatment process organization of a patient and application-specific functionalities of

- Routing of messages to the correct target systems based on the patient-specific supply contracts (Routing-AC),
- transformation of messages to resolve the various communication standards for the respective target systems of the respective health locations (Transformation-AC),
- reporting for health care providers in support of the doctors (Report-AC, Statistics-AC) and
- alerting capabilities for the timely intervention in critical situations (Alerting-AC).

4.2 Several Patient Records in the Domains

The application systems to store patient data from different health locations consist of different data models. Different electronic health records take place in communication scenarios with different health locations and providers. In the homes a patient moderated and institutional (home) personal electronical patient record AC (ePA-AC), in ambulatory care and in the hospitals different doctor-moderated and institutional EHR-AC are installed. In the TMC an electronic cross-institutional doctor-moderated ePA-AC is needed. Synchronization of health records between the home sector with that patient moderated ePA-AC and the cross-institutional and doctor moderated ePA-AC in the TMC for consistent data sources is not considered. Healthcare professionals decide whether data is relevant to transmit into another electronical record source. No synchronization is caused by sharp distinctions between a home area and the outpatient care sector and a different focus concerning users and processes. Relevant data is communicated on the basis of a defined integration profile (step 5). The problem of data polling or high traffic volume does not exist.

4.3 Data-Evaluation-AC in the AAL-AS

The AAL-AS consists among others of a Data-Evaluation-AC. This application component generates alerting messages and emergency events. Therefore a subset of individual events, raw and aggregated data and limit values of a patient stored in the ePA-AC are used. To fire an alert or an event this component interprets the rules for usage of the personal and disease-specific functions derived from services of the defined service catalog. The events triggered by rules can be communicated from the AAL-AS to the TMC-AS. The developed event classification model for the transmission of events from the home area to the TMC provides AAL and telemedicine events. The events are divided in the four defined classes not critical (C1), medium critical (C2), highly critical (C3) and unknown (C9). Events in critical situations can be sent according to defined personal rules and system configuration. For a fast assessment of the current events the use of color schemes in analogy to a traffic light is useful. The TMC does also receive C3-events based on AAL-events from home areas and living quarters which can be monitored and reviewed by professionals to immediately respond to hazards, e.g. “very low blood pressure”.

When looking at standards, different application systems, electronic health record structures, terminologies, nomenclatures and classifications for encoding data (such as Identifier for the identification of diagnosis (Alpha-ID), Logical Observation Identifiers Names and Codes (LOINC), Unified Code for Units of Measure (UCUM) and International Classification of Disease (ICD-10) in clinical applications as well as ICD-10 and International Classification of Functioning, Disability and Health (ICF) in the doctors’ sector) and also certain communication standards (such as HL7 in clinical applications as well as the German specific group of data exchange standards (xDT) [10] in the doctors’ sector) are found in specific health locations because of their historical evolution. Standardizing initiatives like CHA and IHE are doing first steps to harmonize these standards for the problem area and define task solving concepts. But it is noticeable, that in Germany the inconsistently interpreted use of standards and the additional extension with proprietary variants [11] take place. Also most of the AAL and telemedicine projects in Germany use different communication standards or even develop own proprietary formats while focusing on similar functions [7]. It varies in the home area for transferring data (vital data and events) from full standards (defined by a standards organization, like IEEE 11073) to semi-standards (otherwise used existing standards, like HL7 with no common agreement or German specific xDT) to proprietary “standards” (XML derivates with proprietary schemes which are not defined by a standards organization) [12].

The generalized model contains eight standardized communication links based on IEEE 11073–20601, HL7 order and medical document messages (ORU, MDM) and German xDT and 9 communication links that are proprietary based on individual HL7 and CSV structures or binary data. The HL7 based and proprietary communication links were adopted to IHE profiles (like IHE document exchange (XDS)) and CHA interfaces (like WAN Interface).

This information resulted in the derived reference model with a wider integration profile. It eliminates “proprietary standards” by adding semi-standards for new or not defined communication links. By analyzing the CHA the centralized AAL-AS is referred to as the Application Hosting Device (AHD). It attaches the various sensor and actuator systems and provides the compliant WAN-Interface with the TMC-AS for a (bi-)directional communication. It also evaluates gathered sensor data with patient and disease individual data by rules as well as alerts doctors and patients in critical situations. For the extensions of the integration profile of CHA specific trans-
actions IHE and HL7 are required. The transmission of events shall use HL7 V2.6 ORU_R01 as well besides the communication of sensor and home data. In this context, it is recommended to develop a consistent terminology for possible events in the homes (e.g. heat detection in entrance hall). An event catalogue for AAL and telemedical events has been defined. Further enhancements in the reference model include for instance:

• Transfer of the automated configuration from the TMC to the AHD,
• transmission of standard and limit values from the TMC to the AHD, defined by the provider,
• ensuring organizational functions, such as device management,
• delivery of AAL and telemedical events from the AHD to the TMC and from there to the health care providers.

To highlight a scenario, the use case Tele-monitoring (TM) with Alarm will be described. This example specifies the information flow between the various components and their interaction. A fictional patient in a home area collects vital data (enterprise function (EF) TM-Elicitation). These vital data is analyzed and evaluated together with the patient context information (EF TM-Evaluation). The delivery of vital data and patient information (EF TM-Delivery) to the TMC and in case of a limit exceedence sent as an alarm (EF TM-Alarm) to a TMC and from there in defined cases for the output data and boundary value to an Emergency Control Center. On the logical layer a Medical Sensor-AS, like ECG- and BP-AC, sends an ISO/IEEE 11073 message (event report) to the AAL-AS and from there through an IHE PCD-01 (ORU_R01) to the eePA-AC. Further it gets passed internally to the Data Evaluation-AC and the Alerting-AC. The Alerting-AC sends an alert through an IHE PCD-04 (ORU_R40) to the TMC-AS (Alert-AC). Triggered by a rule or a human workflow, the Comm-AC in the ECC-AS gets informed about the alarm also by an IHE PCD-04 (ORU_R40).

5. Discussions

The reference model consists of components on the different layers which can be reused, the communication is based on standards and semi-standards. The reference character makes it easier to build new applications on existing components and to cover new diseases and patient individual data. It is a proposition to make projects comparable to each other especially for the extraction of evidence.

Therefore the reference model is a template which is customizable at any time and flexible through supplements or omission. For the different health care provider and technicians it will be a concept for guidance for creating interoperable systems in the field of AAL and telemedicine scenarios. The reference model supports all instances of home constellations e.g. single residential buildings, living quarters and residential care homes for the elderly.

5.1. Criticism on the Reference Model

The eHealth map was used to gather different projects. For every project all detectable sources in the literature (individually for each project) were analyzed and processed. Based on the information a generalized model was created. The resulting reference model was derived from this generalized model. It can be discussed, whether the eHealth map gives a comprehensive sample for the analysis. But the eHealth map was chosen because every user can contribute in this database and add projects to it. Therefore a wide range of projects can be found at this point. Other sources did not guarantee a “free spectrum” of projects. They are editorially selected and prepared in magazines and other databases which are not based on non-public selection criteria. Especially the pure analysis of projects in the EU framework programs restricts the selection of a reference model [13].

A constraint in the search criteria was made for two chronic diseases. Since each disease has special requirements, appropriate functions in application components are used. The portability of the reference model for other diseases, esp. chronic diseases, where such systems are preferably used, has still to be evaluated. But since it is a reference model that can be adapted to the circumstances, the hope is high.

5.2. Criticism on Logical Components

All components on the logical tool layer were modeled because of their existence in the different analyzed projects from the eHealth map. The TMC-AS serves an additional layer which reflects the complexity of the IT landscape in the German health care. Without such a mediator, the integration efforts to integrate an AAL-AS in multiple homes, e.g. living quarters, and the AS of the healthcare providers are rising to an extent level. The TMC-AS is also described by the AAL-area active CHA referring to a Health Reporting Network (HRN). Facing the implementation of TMC in Germany barriers like financing, certification and operation need to be removed. This type of organization is needed if Assistive Technologies in Germany shall spread.

5.3 Clearance of Used Communication Standards and Legal Issues

A specification for communication of raw and aggregated medical data and events must be made in a standardized form. In addition, no uniform compensation structures for the health care providers exist. Therefore funds for establishment and operation of TMC are not available. Health insurance funds often do not participate in the cost for telemedicine, although the cost savings can be demonstrated in different studies [14],[15]. To support telemedicine and AAL scenarios for health care providers from a medical view, the integration of telemedicine enterprise functions in the medical guidelines is also necessary. Hence the need and acceptance to extend AAL and telemedicine scenarios more widely are not given. Therefore AAL and telemedical data is not integrated into the electronic patient records with the exception of local projects and regional isolated applications.
5.4 Harmonization of Domains and Systems

Currently AS for telemedicine and AAL exist in parallel in one home area. For the future, it is purposeful that comprehensive AAL-AS with disease-specific telemedical components will be established in the home area which reflects the various actuators, sensors, data, functions and processes. Especially the proper use of the gathered data in the home area for a continuous patient care and the understanding of the information which were exchanged between the different health care providers is a future goal. Frequently discussed approaches in research, esp. which come in use within universAAL (Implementation of a software-middleware in context of AAL) [16], should be considered to combine various concepts and to develop a potential standard.

Future research must be done for step 5 of the development approach of the communication architecture (creation of an integration profile). After the realization of this step, the created integration profile defines an extract of necessary communication links of the preceding steps. This profile describes a communication architecture which finally supports use cases in the area of AAL and telemedicine.

6. Conclusions

This paper has shown that a specially designed communication architecture allows the standardized communication of AAL and telemedical data from the home area to the health care providers and back. This architecture makes provision for the interconnection of AAL and telemedical AS and components from the homes with the appropriate AS of the health care providers. These two sectors are linked by a TMC-AS. Both raw and aggregated data as well as selected events are to be transferred from the homes over the TMC-AS to the systems of the health care providers. An important role is the transfer of the events for residential neighborhoods. In that case, the TMC has an overview of the AAL and telemedicine situation in the homes of the patients. In order to do so, an event classification model was developed.

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