Standardized Representation of Medical Data in AAL Applications

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Abstract. The Personal Healthcare Monitoring Report (PHMR) is a document format for representing measurements based on the HL7 Clinical Document Architecture (CDA), and thus a suitable document type for the storage of data from Ambient Assisted Living (AAL) applications. However, the characteristic of medical data in AAL applications differs fundamentally from the established view on medical data. Whereas clinical data are mostly single point measurements taken under well-controlled conditions in hospital, medical data in AAL applications are continuous, of a low sensor quality and often represent dynamic activities of human behaviour. This leads to a different representation of data in structured format.

1 Introduction

The many funding programs and research projects have over the last couple of years developed a lot of new approaches in the field of Ambient Assisted Living (AAL), which has close links to Ambient Intelligence and and Ubiquitous Computing. These approaches mostly aim at health related use cases such as tele-rehabilitation or gait analysis [1]. All of these applications incorporate medical and non-medical sensors from different vendors and a processing unit like a set-top-box that communicates the relevant health information to an external service provider such as a doctor or hospital. The need for a standardized representation of medical information in a semantically annotated and further machine processable format is crucial for the interoperability of AAL systems. Therefore, the Personal Healthcare Monitoring Report (PHMR) [2] specifies a model to represent both measurements captured by devices, and narrative information. Defining templates for the HL7 Clinical Document Architecture (CDA) [3] and profiles [4] for monitoring applications is a good step forward, but not sufficient to integrate the quintessence of human behaviour in such documents. The technical world of AAL refers to a distributed architecture with loosely coupled components, sensors and actuators. The aim of AAL is to enable elderly or disabled people to live an independent life in their home environment. Therefore, the data acquired by the AAL system are of prime importance for medical care. The state of health is reflected by the AAL application through continuous measuring, plus knowledge that is rather vague and context dependent. This health related information gathered in home environments differs fundamentally from medical information collected in laboratories or hospitals. The main difference is the lack of knowledge to accurately interpret the data under

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consideration of the situational meaning [5]. Vital parameters like blood pressure and pulse react to external factors like weather, sport or stress. A medical decision can only be made when the vital parameters are plausible and when the context is known. For example, a high blood pressure is normal during a training session but requires a treatment when it is long-lasting. Document standards must represent on one hand the raw sesnor data, and on the other hand the semantic information of the AAL context, which must be mapped into a machine processable format. The aim of this work is to show that medical document standards need an adaption and extension to fulfil the needs of medical data in AAL applications.

2 Medical Data in AAL Applications

2.1 Use Case: Tele-rehabilitation

Tele-rehabilitation applications such as the OSAmI [6] or SAPHIRE [7] systems developed for patients with cardiovascular disease take place in the home environment. To improve the heart condition of a patient, a full stress test is carried out to identify the individual performance limits while the patient is still in stationary rehabilitation. Without this stress test it would not be possible to create an individualized training plan. Furthermore, the patient is introduced to the tele-rehabilitation system. He or she receives introductions on how to work with the system and how to apply the vital sensors. Upon discharge from stationary rehabilitation the patient is equipped with an ergometer bicycle and a set of medical sensors like 3-lead ECG, blood pressure and pulse to monitor the heart rate, blood oxygen saturation and blood pressure. Through a computer system the sensor data can be analyzed during a training session to control the ergometer load and to avoid any overload on the patient. Furthermore, an alarm system provides feedback about the current health state while exercising. The needs of an individualized training plan adapted over time makes a connection to the attending rehabiliation clinic necessary. Training reports including all vital parameters and medical events like alarms must be transmitted to the clinic after every training session. The training reports represent the patient's health status and fitness level, based on which a medical supervisor reviews every training report and, if needed, adapts the training plan that can be transmitted to the system at the patient's home. Due to interoperability considerations the gathered vital parameters should be transmitted through a standardized medical document format to make not only reading but also further processing (such as a generation of trend curves or the combination of AAL data with data from other care processes) possible.

2.2 Structure of Medical Data

Beside the context information, sensor quality is lower in home environments than in medical environments. Medical staff is trained to perform medical procedures. The vital parameters like ECG are of high quality when measured in hospital. AAL applications incorporate vital parameters for usage at home. The users themselves have to carry out the medical procedure with low-costs sensors. The repeated nature of measurements at

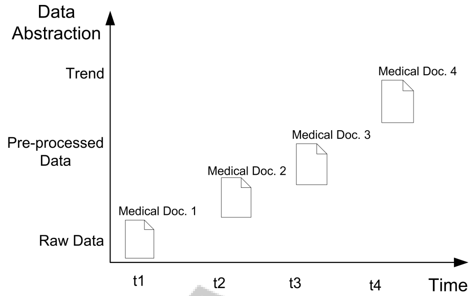

Fig. 1. Evolution of documents in AAL applications.

home to some degree compensate the lack of quality since trends can be derived. This leads to a different interpretation of home-based information. Not a single measurement should be interpreted medically, rather than that a trend analysis is needed. Medical information is provided by AAL applications more or less through the establishment of behavioural profiles combined with trend information. The fact of measuring discrete or continuous data over a longer period of time gives a different view on the representation of medical device observations in a standardized format. Figure 1 depicts the concept of how the evolution of single point documents leads to a representation of trends. Nowadays clinical documents do not take this progression of activities in AAL application into account.

3 Clinical Documents

Structured clinical documents must fulfil the demands of the healthcare system. That is, to exchange documents with clinical content easily and to provide a structured mark-up for representing various kinds of information from patient demographics to sensor data to make further processing possible. Also, the human readability is a core requirement. The legal aspect of storing the health relevant information over 10 or more years requires maximum backward compatibility.

3.1 Clinical Document Architecture

The Clinical Document Architecture (CDA) is a document standard that defines a syntax and semantics for clinical documents like a discharge summary or laboratory results. The structure of CDA is not bound to any exact use case, which makes it applicable for many use cases. Every CDA is a complete information object containing narrative text, images and other content. CDA has a header and a body encoded in Extensible Mark-up Language (XML). The header specifies meta-information about the intended use case, the patient, the author of the document and the custodian. The body is composed of structured mark-up with one or more sections. These sections contains attributes like ID, title, text and a coded value. The body can represent information in three levels of granularity, ranging from simple narrative text (not machine processable) to a completely structured coding in level 3, where even the narrative text is completely machine processable.

3.2 Templates

Templates are sets of constrains on a CDA document structure and content, intended to specialize CDA to specific use cases [8]. The Continuity of Care Document [9] (CCD) is a CDA template that reflects the most relevant administrative, demographic, and clinical information about a patient's healthcare. It provides, for doctors and medical applications, an aggregation of all data about a patient that needs to be stored pertinent to an episode of care or a disease. The primary use case is to provide a snapshot in time to communicate a clinical summary of a patient. The header defines the document meta-data. The body defines sections with semantic coding from "Systematized Nomenclature of Medicine - Clinical Terms" (SNOMED CT) such as past medications, problems, and procedures.

The PHMR is a CDA template that carries personal healthcare monitoring information. That encompasses the representation of measurements captured by devices, graphs that show trends of the users' health status, notes, summaries, and other kinds of narrative information that can be added by caregivers. The header is based on the specification of History and Physical Note (H&P) [10] and the body contains constrained CCD templates. CCD is constrained by adding some section requirements, and a specification of which sections are recommended for use with Personal Healthcare Monitoring Reports, such as "Results" and "Vital Signs".

3.3 Data Types and Codes

The data carried in a CDA document are structured by data types defined in the HL7 version 3 standard. All data types have a structured format. Every field in CDA has a defined data type that controls the meaning of the element. Simple data contains a single value whereas complex data types contain sub-elements, which again can contains simple or complex data types. Complex data types represent an object of associated data, such as a person's name or a period of time with beginning and end. The semantics for carrying the concepts such as LOINC or SNOMED CT can be stored in the Concept Descriptor (CD) data type that contains the field code, codeSystem, codeSystemName, displayName. This data type stores the semantics of the section via a code system (like LOINC or SNOMED CT).

```
<code code="8716-3" codeSystem="2.16.840.1.113883.6.1"
codeSystemName="LOINC" displayName="Vital signs"/>
```

The intended meaning of HL7 data types gives information about their appropriate usage. Beside the semantics all observations are structured by the situation in which they are aquired. Context information about the setting and situational meaning are also data, called context or meta data [11], which are currently not represented in CDA data types.

3.4 Information Model of PHMR

PHMR is a good step forward for a standardized representation of data gathered from monitoring devices at home. The characteristics of observed device data can be separated into continuous (SpO2) and discrete (Blood pressure, Temperature) vital signs and data. Single measurements should be represented with the data type ”Physical Quantity” (*PQ*), shown in the code example below. The ”value” attribute following *PQ* contains a value of the type *REAL* that represents the magnitude of the quantity measured in terms of the unit. The unit is specified in the Unified Code for Units of Measure (UCUM).

Representation of Discrete Measurements in PHMR

```
<observation classCode="OBS" moodCode="EVN">
  <id root="fde90f67-529b-49e4-871b-bab296e8d499"/>
  <code code="271649006" codeSystem="2.16.840.1.113883.6.96"
  codeSystemName="SNOMED CT"
  displayName="Systolic blood pressure"/>
  <statusCode code="completed"/>
  <effectiveTime value="20080501104033-0500"/>
  <value xsi:type="PQ" value="155" unit="mm[Hg]"/>
</observation>
```


For continuous measurements, a sub-template named ”Waveform Observation” handles the series of measurements connected with a sample period (see code example). The sample period is represented through a generic collection that allows for multiple repetitions of other data types. *LIST* contains discrete values in a defined sequence. A *GLIST* is a periodic sequence of values generated from parameters and used to specify regular sampling points for biosignals. A *GLIST_TS* is a generated sequence of ”Point in Time” (*TS*) and has a beginning (*head*) and an increment tag for indicating the step size, that is, the sample period in milliseconds. The *SLIST_PQ* represents the waveform measurements of physical quantities (*PQ*). It is a sequence of sampled values scaled and translated from a list of integer values. The *SLIST* items can be calculated by a formula shown as formula 1 below: Am item at an index i is calculated by multiplying the scale s with the digits d_i and adding the origin x_0.

$$x_i = x_0 + s * d_i \quad (1)$$

Representation of Waveforms in PHMR

```
<entryRelationship typeCode="COMP">
  <observation classCode="OBS" moodCode="EVN">
  <code code="TIME_ABSOLUTE" codeSystem="2.16.840.1.113883.5.4"
  codeSystemName="ActCode" displayName="Absolute Time"/>
  <value xsi:type="GLIST_TS">
    <head value="20071206121000.00"/>
    <!-- The sample period is 13.375 ms -->
    <increment value="0.013375" unit="s"/>
  </value>
  </observation>
</entryRelationship>
<entryRelationship typeCode="COMP">
  <observation classCode="OBS" moodCode="EVN">
  <code code="250864000" codeSystem="2.16.840.1.113883.6.96"
  codeSystemName="SNOMED CT"
  displayName="Pulse oximetry waveform"/>
```

```
  <statusCode code="completed"/>
  <value xsi:type="SLIST_PQ">
    <origin value="0" unit="1"/>
    <scale value="1" unit="1"/>
    <digits>94 92 92 91 90 90 89 88 86 85 84 82 81</digits>
  </value>
  </observation>
</entryRelationship>
```

Figure 2 shows a part of the PHMR data model. The parts are the human behaviour relevant classes. The vital signs, results, medication, exercise and activity represent the human model of behaviour in home care circumstances and AAL applications. The document represents the human model through data types *PQ* and generic collections. To meet the needs of a time-oriented trend analysis, which focuses more on the human behaviour than on raw sensor data, a different view and an extension of CDA and PHMR are needed.

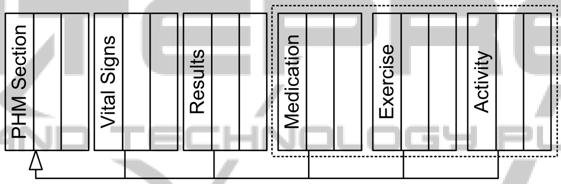

Fig. 2. The partial PHMR data model.

4 Extension of Clinical Documents

4.1 Training Report

All vital parameters and medical events like alarms must be transmitted to the clinic after every training session in a training report. A training report should be represented in a standardized format like PHMR to make a transmission and further processing possible. The training report represents the patient's health status and fitness level. The development of this level is a long-term process: not every training session is of prime importance, but an upward or downward trend is important to notice. For this reason the PHMR can integrate a trend of the user's health status through a graphical representation for human reading. The disadvantage of storing continuous data in an XML structure is the high semantic overhead, which makes the size of a PHMR document very large. Therefore, a change in data representation should be made.

Training reports represent dynamic aspects of human activities, which can be represented as a block diagram of control systems. This leads from raw sensor data to a model-based view of the dynamic vital processes of humans during a training session. Figure 3 shows a simplified view of dynamic behaviour in tele-rehabilitation.

4.2 Human Models in AAL Applications

A model is a limited ”copy” reflecting aspects of the real world. Three properties denote a model: mapping, reducing and pragmatism [12]. Models are a mapping of ”some-

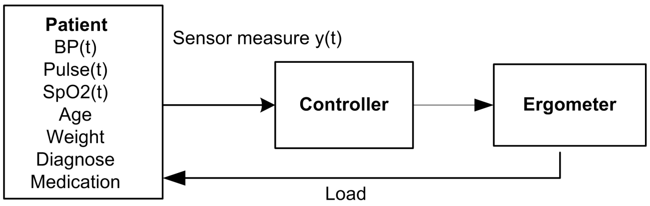

Fig. 3. Simplified block diagram of an ergometer training session.

thing" representing just a a few and not all aspects of a real world, targeting a special purpose (pragmatisms) for e.g. whom, when and why. The adapted SOMA diagram [13] (**S**ubject–**O**riginal–**M**odel–**A**ddressee) consists of a domain (Original) and a model with a relation that reflects the analogy between a model and the domain.

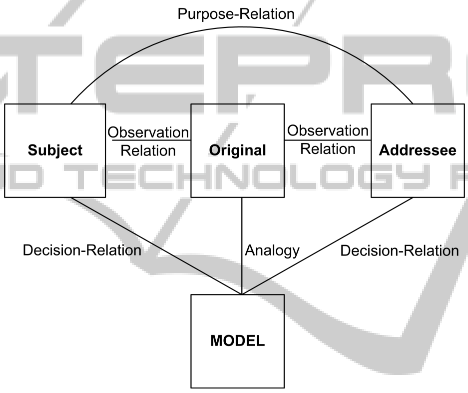

Fig. 4. The SOMA diagram.

Furthermore, a subject and addressee are included, which reflects the observational aspects and directive decisions through relations. Figure 4 shows the SOMA diagram. Figure 5 depicts an adapted diagram showing the relations between the AAL applications and the medical document. The adaptation shows the two components of intrinsic and external representation that represent the model of the computer-processable aspects (intrinsic) and the human readable content (external).

4.3 Systems in Medical Documents

Modeling aspects of physical correlations in rehabilitation training like heart rate and ergometer load lead to a system theoretical view. This implies a distinction between a functional, structural and hierarchical concept of systems [14]. A structural system contains unstructured elements with relations combining these elements to a meaningful entity. The functional concept represents a system as a black box. These concepts hide the internal workflow and focuse on the behaviour of input and output. The hierarchical concept implies multiple steps of granularity. The important aspect of describing rehabilitation training is modeling the changes over time, which makes it a "dynamic

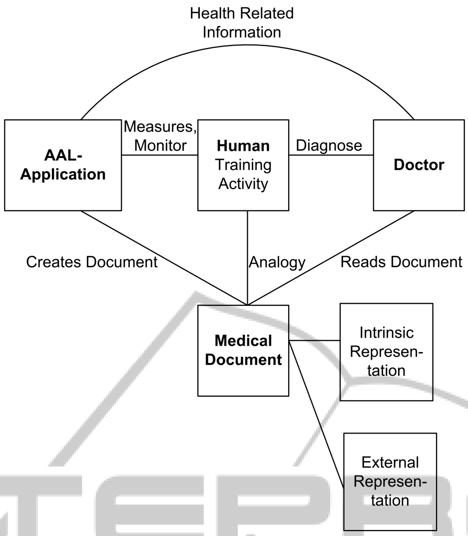

Fig. 5. Adapted SOMA diagram for the PHMR data model.

system". Therefore, the mathematical description of the dynamic rehabilitation system is the intrinsic representation of the model in the PHMR document, usable for further computational processing. The rehabilitation system is a functional dynamic system with input (ergomater load, weather. . .), states (e. g. anaerobic threshold) and an output (vital signs) (see Figure 6).

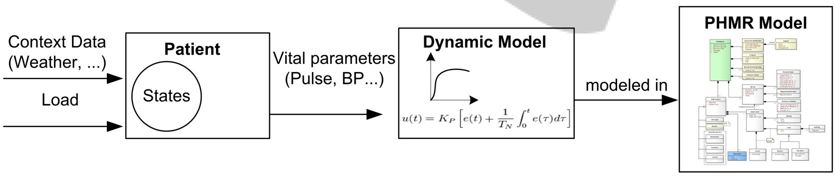

Fig. 6. Functional dynamic system of a rehabilitation training represented in clinical documents.

The formal model (mathematical equation) of the dynamic rehabilitation system has to be integrated in a standardized clinical document format such as PHMR. Therefore, the data types and coded values must be extended to a more dynamic representation of human behaviour in AAL applications. The data types must be extended to store an equation that reflects a dynamic system based on human parameters. This leads to a more integrated view on human behaviour because more parameters can be integrated without storing the whole raw data. Context information, weather, stress level and vital parameters can be expressed through a single but complex equation.

5 Conclusions

Medical requirements in AAL application are based on valid information about the patient's health state. Theses states are received through vital sensor data and higher aggregated information combining context knowledge with sensor data. For an integrated health care, the use of medical document formats makes interoperability possible. CDA documents are a medical standard format with a machine-processable and human-readable part. The data gathered in cardiac tele-rehabilitation are pulse, ECG and SpO2 and have low sensor quality. The meaning of a medical document derived from CDA is provided by the HL7 Version 3 data types, which are defined with regards to their semantics independent from their operational context. An integrated view on the human behaviour in AAL applications is not possible yet. The many use cases of AAL are difficult to represent in CDA PHMR. An integrated process of medical requirements and medical content in health related documents should be developed to cope with challenges in AAL applications.

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