Structured Documentation of Physiological Models and Behavioural Patterns containing Uncertainty

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***Abstract*—In this article, two main requirements on medical documentation in the field of assisted technologies at home (so called AAL) and a process model are introduced. For an integrated health care, the medical documents make interoperability possible. These document formats should be able to be at least structured for further information processing. In the field of AAL it is important to store functional aspects of human activities and data containing uncertainty because patient's health state is measured in a different way than in hospitals. Unknown states of circumstances and context, bad quality sensors and 24/7 measurements can be made. This leads to data containing uncertainty and trends (e.g fitness trend). This data can be stored in structured medical documents though data types and code systems. CDA documents are a medical standard format with a machine-processable and human-readable part. CDA has to be extended in order to be able to represent functional data through equation and data with uncertainty. A process model supports the creation of structured medical documents with AAL-specific data. It supports the mapping of AAL data into a structured document by an application flow. This process is supported by a model-driven technique which makes data description and transformation possible.**

***Keywords*-AAL; CDA; eHealth; Tele-Rehabilitation; Human Models; Uncertainty, Interoperability; PHMR**

I. 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, gait analysis [1] or activity detection. Many applications incorporate medical and non-medical sensors from different vendors and different domains. Important questions are: What is a health relevant information, that need to be stored and be communicated to the an external service provider such as a doctor or hospital? How to deal with unclear sensor data? Are standardized medical documents suitable to represent data gathered in home applications?

The need for a standardized representation of medical information in a semantically annotated and further machine processable format is crucial for the interoperability of health supporting systems at home. 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 health supporting applications at home refers to a distributed architecture with loosely coupled components, sensors and actuators. The aim is to enable people to live an independent life in their home environment. Therefore, the collected data are of prime importance for medical care. The state of health is reflected by the 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 consideration of the situational meaning [5], that leads to a degree of uncertainty and behavioural aspects of physical functions. 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. New approaches of medical applications with devices from home automation can derive the activity of daily living (ADL) and gait analysis at home to predict falls or upcoming dementia by building behavioural profiles of person. This applications have to deal with many sensor data which are not primary medical. The interpretation of the data from raw data to a clinical decision can contain degree of uncertainty. This uncertainty has to be stored in a structured medical document for further processing. Document standards must represent on one hand the raw sensor data, and on the other hand the semantic information of the context, which must be mapped into a machine processable format. In addition, the process of handling

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AAL data and their mapping into a standardized medical documents is not fully described yet. The aim of this article is to show that medical document standards need an adaption to store functional aspects and uncertainty's in activities to represent medical data in AAL applications "realistic" and to show that a standardize process of mapping the data into a document needs to be invented. In the next chapter the basics of clinical documents (e.g. templates and data types) are described. To understand the differences of data, collected in AAL applications, a new data model is introduced in section III. The requirements of AAL applications leads to an extension of standardized medical document, which are presented in section IV.

II. 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.

A. 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.

B. Templates

Templates are sets of constrains on a CDA document structure and content, intended to specialize CDA to specific use cases [6]. The Continuity of Care Document [7] (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.

1) Personal Healthcare Monitoring Report (PHMR): 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 [8] 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".

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.

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.

Representation of Waveforms in PHMR

```
<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 ... </digits>
</value>
</observation>
```

C. Data Types

The data carried in a CDA document are the HL7 Version 3 data types which are described in an abstract notation

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for a comprehensive discussion and are also represented in an XML-specific way. The data types can be divided in three categories: (1) boolean, binary, text and multimedia, (2) codes and identifiers, and (3) quantitative data types. The generic data types are collections (sets, lists, interval, etc.) and can be extended to deal with uncertainty, time-dependency and other qualifications of data values. Uncertainty is represented in through two data types which belongs to the category of the generic types extension which are generic types with one parameter. (1) Uncertain Value - Probabilistic (UVP) and (2) Parametric Probability Distribution (PPD). UVP is a generic data type extension used to specify a probability expressing the information producer's belief that the given value holds. PPD is generic data type extension specifying uncertainty of quantitative data using a distribution function. Aside from the specific parameters of the distribution, a mean (expected value) and standard deviation is always given to help maintain a minimum layer of interoperability if receiving applications cannot deal with a certain probability distribution. These two data types are not permit to use in CDA. Beside the semantics all observations are structured by the situation in which they are acquired. Context information about the setting and situational meaning are also data, called context or meta data [9], which are currently not represented in CDA data types. Context information are never 100 percent true or false. And in AAL many sensor data or behavioural patterns contains an amount of uncertainty which has to be expressible in an medical document.

D. Codes

The semantics for carrying the concepts of a a circumstance like a diagnosis or a vital sign is bond by the data type Concept Descriptor (CD) or Coded Value (CV). The Codes systems ICD-10, LOINC or SNOMED CT can be stored in this this data types 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). This terminologies refers to aspects of the medical domain. The purpose of medical terminology is to support the interoperability between different IT systems. In the field of AAL medical terminology like SNOMED CT or LOINC doesn't fit. The AAL domain consists of new applications measuring human behaviour in a different way than in hospital through assessment tests. The terminologies imply a defined contextual setting that addresses so far not the area of AAL.

E. Procedure Model and tools for CDA Documents

The creation of CDA documents is not a common shared process like in the area of software engineering. The implementation approaches were based on XML processing techniques or a RIM-based approach by HL7. The disadvantage is a generic API requiring CDA specific knowledge. On a more supported level first tools came out with a domain specific CDA API for supporting developers in creating CDA documents. The main advantage was to hide the complexity of the CDA standard by providing a domain specific API. The MDHT (Model-Driven Health Tools) interoperability framework goes much further. They provide a model-driven framework for generating implementations of CDA templates that support domain-specific Java API, a construction and consumption of Java objects for XML serialisation and de-serialisation and a validation mechanism based on OCL (Object Constraint Language). MDHT also provides a work flow targeting the role of a "model developer" who uses the tool kit IDE based on the eclipse modelling framework and an "implementer" who uses the generated domain-specific Java API for producing, consuming and validating the CDA instances (XML).

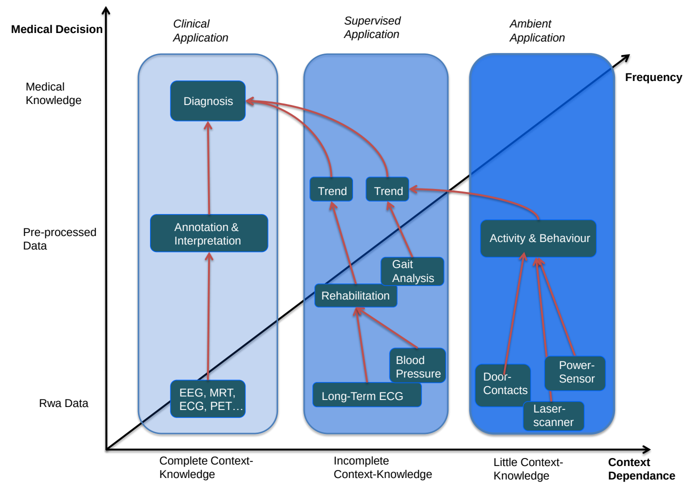

Figure 1. Three Dimensional Layer Context Model (3DLC) [5]

III. Structure of Medical and Non-medical Data in AAL Applications

A. Three Dimensional Layer Model (3DLC)

The 3DLC Models [5] (see figure 1) classifies the medical data from a perspective of context-dependence that is important to differentiate the data gathered in clinical environment or at home. Medical data can produced under laboratory circumstances (hospital), with less context-knowledge in a tele-rehabilitation or with no context-knowledge in Ambient Assisted Living (AAL) application like the gait analysis. Tele-rehabilitation applications such as the OSAmI [10] or SAPHIRE [11] systems developed for patients with cardio-vascular disease take place in the home environment. The data are collected in a semi-controlled environment. The data are interpreted in the context of a training session proceeded on an ergometer with medical sensors like pulse. No context information are available in applications for unsupervised applications.

Beside the context information, sensor quality is lower in home environments than in medical environments. The vital parameters like ECG are of high quality when measured in hospital under laboratory circumstances. Medical applications incorporate vital parameters for usage at home constraint the users themselves to carry out the medical procedure with low-costs sensors. The repeated measurements at home compensate in some degree 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 this kind of applications more or less through the establishment of behavioural profiles combined with trend information. The fact of measuring data over a longer period of time gives a different view on the representation of medical data in a standardized format. A single point documents is not sufficient and should leads to a representation of trends. Nowadays clinical documents do not take this progression of activities in AAL application into account.

IV. Extension of Clinical Documents

A. Functional Model

The description of a functional model reflects an arbitrary human activity that has to be structured represented in a medical document. The mapping of a behavioural pattern, that is reflected through a trend is from a medical point of view a crucial information. This information should be machine processable to derive further information. Mathematical models can represent dynamic processes of a human. A trend is a example for a mathematical view on a human behaviour (see figure 1). Figure 2 depicts the requirements of representing equations in a structured documents by means of a tele-rehabilitation example. Many physiological systems can be seen as a functional model consists of input and output parameters. Also external conditions like weather or other context data can have influence on a patients health. Different scenario and medical problems can lead to diverse mathematical models that needs to be stored in medical documents. At this point a linear model, that is a statistic regression model will explain the process of expanding the document.

In order for a functional model to be represented in a structured document, data types must be defined in an abstract way. With ISO 21090 data types are defined for the purpose of exchange in the health system. These definitions are based on HL7 and ISO/IEC 11404 Information Technology - General Purpose Datatypes (GPD). Linear equations contains place holder with variable-length, for that the equation is expressed as a collection of data types. With this standard ISO 21090 the new data type denoting the equation is derived.

Table I
Semi-formal description of the data type LinearModel

Name	**Type**	**Description**
Variable	$LIST < INT >$	Denotes the variable in an equation
Coefficient	$LIST < INT >$	Gives the quantifier of the variable
Index	INT	Number of variables
Result	INT	result of the equation
Code	CD	Gives the code and semantics

```
type LinearModel class=(
variable : Sequence(Int),
coefficient : Sequence(Int),
index : int,
result : int,
code : CD,
)
```

1) Attribute:

- var.: Sequence(Int). the variable represents the parameters which has influence on the physical model. Dependent on the model the variable denotes the demographic data, the weather or earlier performed training sessions.
- coeff.: Sequence(Int). In the model, the coefficient gives the importance (weight) of the variables.
- index: int. The index i denotes the number coefficient-variable pairs $(b_i * x_i)$
- result: int. The result of the equation gives the represented physiological aspects like heart rate.
- code: CD. The data type CD gives the meaning (semantic) of the data type. This data type is generic, many use cases of physiological aspects can be described through that equation. Therefore a data type CD is needed.

2) Example:

```
<example xsi:type="LinearModel">
<variable value "34, 57, 1" />
<coefficient value "1, 3, 0" />
<index value "3" />
<code="1234..." codeSystem="2.16..."
codeSystemName="name"
displayName="HF Prediction" />
</example>
```

In this example, a linear model shows a prediction of the heart frequency with three variables and no suitable code system. In this scenario, a functional model is established to predict the heart rate from patient with cardiopulmonary diseases in a tele-rehabilitation [12]. It shows that AAL give the opportunity for new kinds of health related applications. To meet the need of these applications new code systems and tags for CDA has to be invented. The representation of an

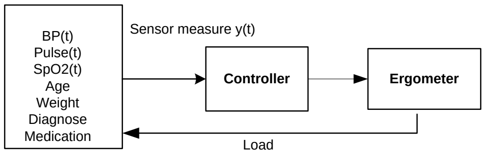

Figure 2. Simplified Block Diagram of an Ergometer Training Session

equation through XML-tags is close to the CDA standard syntax. The abstract notation of the equation gives the possibility to convert it in other medical document standards like DICOM SR [13].

B. Human Model with uncertainty

Sensor data from home applications reflecting the health state of a person. E.g it can reflects problems in mobility or activity (ADL). These data are medical meaningful in a higher abstraction level (see figure 1). Not the raw sensor data shall be stored in a clinical document if there are not from medical or technical importance. In some cases, it is not clear which data have to be stored in a document for further processing. That is where the aspect of uncertainty comes into play.

Damaged sensors, new activity patterns, more than one person in the flat, unclear activities or different kind of problems can occur and leads to misinterpreted data. In worse case, the data are detected as flaws and are deleted. It would be better to categorise the data with a degree of belief and storing them to make a further processing possible. In unsupervised AAL applications the situational-context of a persons behaviour is not fully known, from this it follows that data can be ambiguous. A degree of belief [14] might reflect this lack of knowledge better than deleting it because of uncertainty. The uncertainty could contain information that has to be represented in a medical document. The benefits for representing uncertainty for technicians and doctors are:

- Detection of damaged sensors
- Detection of new activity patterns
- Detection of more than one person at home

Up to now, AAL applications has to deal with uncertain data from an unclear cause. Therefore it is better to document this kind of data as ”unknown data” or with a degree of belief than to delete it. Due to the aspect of interoperability a structured way of storing uncertain data is important.

The reasons for uncertainty in data of home applications are:

- **Erroneous or not interpretable data**: The raw data can not be mapped on events or activities because of measuring errors
- **Vagueness**: Activities are not sharp bounded, they can overlap to each other or be parallel
- **Imperfect data**: In case of a damaged sensor, events or activities can not be detected

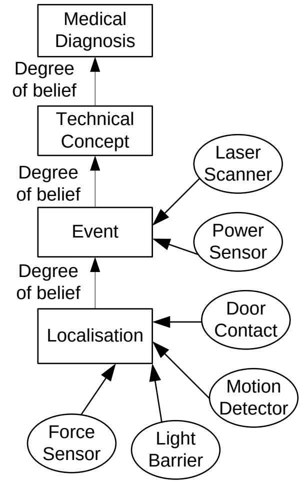

Figure 3. Origins of uncertainty

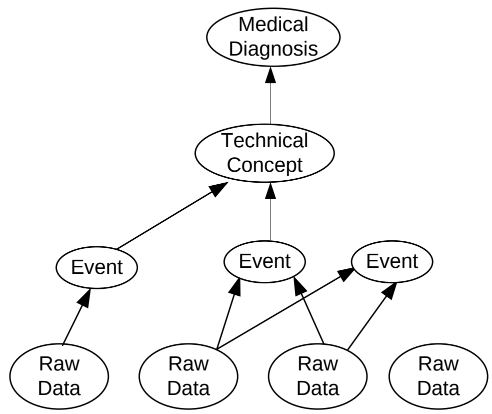

Figure 4. Composite of data

- **Context uncertainty**: Depending on the circumstances (date, place) data can be interpreted as normal or abnormal.

Static sensors like light barriers or door contacts gives pre-existing knowledge about an position unless a spatial model of the flat exists (see figure 3). The trigger of a light barrier is associated with the presence of a person at home. The knowledge of context is limited to one trigger event containing maybe a time stamp and a spatial aspect.

Through the aggregation of more trigger events a higher information like ”primitive events” can be identified. For the chain of raw sensor data to a medical diagnosis a description language is needed. This language describes the origin of the data (the device), the data (data type, unit, etc.), the context (time, space, etc.) and last but not least the uncertainty or degree of belief to transform this information into a structured medical document. Sensors measuring directly an event (like laser scanners or power sensor) should be stored in an medical document if they can not be mapped to a technical concept (automate, pattern matching, profile)(see

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Table II
COMPARED STRUCTURE OF CDA, XML FOR THE CONCEPTS OF INFORMATION, RELATION AND NESTING

	CDA-XML Semantics	XML
Information chunks	section, clinical statement, codes, data types	elements and attributes
Relations	components, entry, entryRelationship	elements and attributes
Nesting	count of elements	count of elements

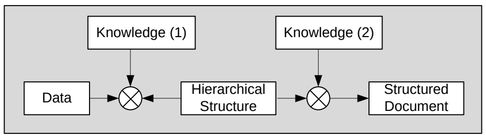

Figure 5. Process Model

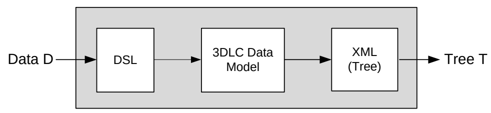

Figure 6. Transformation from AAL data to a tree structure in XML

figure 4 and 3) because not full interpretable data can contain important information, that the AAL application does not observed.

For the structured documentation of uncertain data, the data characteristics, relation, aggregations and the degree of belief shall be described in a formal language. This language can not describe the complete domain of AAL but is applicable in cases where the data are ambiguous or unclear.

C. Process Model

I will develop a process to map AAL specific data with functional aspects and uncertainty into structured medical documents like CDA. To map the data into a structured document a transformation has to be made. By virtue of the standardized approach, mappings into different kind of documents are possible (see figure 5).

The input are the data from the AAL scenario. This can be raw data from a sensor, events or technical concepts which needs to be stored structurally. The knowledge (1) in figure 5 contains three aspects:

1) The input data (data description is taken from the project RAALI [15]) are the data from the AAL scenario. These data are described through a domain-specific language containing the possibility to mark a them with a degree of belief
2) The hierarchical structure (annotated tree graph theory) is the output
3) Function $h = D_{Data} \rightarrow T_{Tree}$. The description how the data are mapped to the tree

The transformation steps from the Data D_{Data} to the T_{Tree} can be seen in figure 6. At first a domain-specific language (DSL) [16] is created with the Xtext (http://www.eclipse.org/Xtext/) framework. It based on the Eclipse Modelling Framework which is extended by Xtext to to build DSL with the extended Backus Naur form (EBNF). The DSL describes the AAL application data with the help of the 3DLC model. An "integrator" can use this DSL to describe his AAL data (containing uncertainty) with this tool. In the next step a domain-specific Java API is generated. This API gives the opportunity for consuming and processing the AAL data. After this, these data are mapped into a tree (graph without cycles) (function $h = D_{Data} \rightarrow T_{Tree}$). This tree is an abstract structure representing a structured document without a commitment to a definite medical document standard (every structured document can be seen as a tree [17]). This step is semi-automated because the "integrator" has the ability to enhance the data through additional knowledge. This knowledge can be

- Codes from a code system
- Re-organisation of data
- Sources of uncertainty (if the "integrator" has knowledge or an idea where the uncertainty could come from)
- Other external sources of information (e.g hospital stay)

This data are represented as a table containing e.g. data and relations to give the "integrator" the possibility to make changes. After the annotated tree is created the notes and arcs are mapped to a specific standard. This procedure is seen in figure 5 in knowledge (2). In this step, a function $f = T_{Tree} \rightarrow D_{Document}$ maps nodes and arcs to the structure of e.g CDA (see table II).

V. CONCLUSION AND FUTURE WORK

In AAL application the patient's health state is measured in a different way than in hospitals. Unknown states of circumstances and context, bad quality sensors on the one hand and 24/7 measurements and trend analysis on the other can be made. The health related states are received through vital sensor data and sensors from power sensors or from home automation. An higher aggregation of these data need to be made to derive medical information for care givers or doctors. 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. For the purpose of AAL the CDA documents need to store more than just the snap shot view of a laboratory result or one monitoring session. To deal with an amount of uncertainty rather than to discard the not perfect data makes further process of the data possible. Damaged sensors, new patterns of activity or different research questions for medical, technicians and scientific staff should be persistent stored. We need to store human models that reflects the physiological aspects through equation enhanced with semantics by a coding scheme and and activity pattern consisting a certain degree of uncertainty. The HL7 Version 3 data types representing uncertainty are not supported in CDA, that makes it impossible to store ambiguous data. Equations and their code systems reflecting functional models does not exist. Therefore CDA needs to be extended. Also a process of creating a structured medical document is described to support the upcoming AAL domain properly. The next step is to provide different users (domain experts, like doctors, developers and other technical staff) with an integrated software tool, that supports the creation of extended medical documents. At least three domain knowledges has to be incorporated in this software tool. First, the domain knowledge of AAL (devices, abstractions, measurements), second, the clinical document knowledge (structure, data types, templates and codes) and third, medical knowledge (e .g diagnosis). This tool is still under construction. It will represents the different knowledges by domain specific languages and a lot of data transformation to help the domain expert in creating AAL specific medical documents.

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References

[1] T. Frenken, E.-E. Steen, M. Brell, W. Nebel, and A. Hein, "Motion Pattern Generation and Recognition for Mobility Assessments in Domestic Environments," in *Proceedings of the 1st International Living Usability Lab Workshop on AAL Latest Solutions, Trends and Applications. In conjunction with BIOSTEC 2011*. SciTePress, 28-29 January 2011, pp. 3–12, ISBN 978-989-8425-39-3.

[2] L. Alschuler, C. Beebe, K. W. Boone, and R. H. Dolin. (2008) Implementation guide for CDA release 2.0 Personal Healthcare Monitoring Report (PHMR).

[3] R. H. Dolin, L. Alschuler, S. Boyer, C. Beebe, F. M. Behlen, P. V. Biron, and A. Shabo (Shvo), "HL7 Clinical Document Architecture, Release 2," *J Am Med Inform Assoc*, vol. 13, no. 1, pp. 30–39, 2006. [Online]. Available: http://www.jamia.org/cgi/content/abstract/13/1/30

[4] IHE, *Technical Framework Volume I Revision 5.0. Technical report Final Text.*, IHE Std.

[5] A. Helmer, M. Lipprandt, T. Frenken, M. Eichelberg, and A. Hein, "3DLC: A Comprehensive Model for Personal Health Records Supporting New Types of Medical Applications," *Journal of Healthcare Engineering*, 2011.

[6] T. Benson, *Principles of Health Interoperability HL7 and SNOMED (Health Informatics)*, 1st ed. Springer, December 2009.

[7] HL7, *Implementation Guide: CDA Release 2 Continuity of Care Document (CCD)*, HL7 Std., 2007.

[8] L. Alschuler, C. Beebe, K. W. Boone, and R. H. Dolin. Implementation Guide for CDA Release 2: History and Physical (H&P) Notes. HL7.

[9] L. Wilkinson, *The Grammar of Graphics (Statistics and Computing)*. Secaucus, NJ, USA: Springer-Verlag New York, Inc., 2005.

[10] M. Lipprandt, M. Eichelberg, W. Thronicke, J. Kruger, I. Druke, D. Willemsen, C. Busch, C. Fiehe, E. Zeeb, and A. Hein, "OSAMI-D: An open service platform for healthcare monitoring applications," in *Proc. 2nd Conference on Human System Interaction HSI '09*, 2009, pp. 139–145.

[11] O. Nee, A. Hein, L. Ludwig, D. Willlemsen, C. Busch, and T. Scheffold, "Cardiac tele-rehabilitation with the SAPHIRE system," in *Med-e-Tel*, Luxembourg, April 2008.

[12] A. Helmer, R. Deparade, F. Kretschmer, O. Lohmann, A. Hein, M. Marschollek, and U. Tegtbur, "A heart rate prediction model for the telerehabilitation training of cardiopulmonary patients," in *5th International Joint Conference on Biomedical Engineering Systems and Technologies*. SciTePress - Science and Technology Publications, 2012, best Paper Award.

[13] *Supplement 23: Structured Reporting Storage SOP Classes*, DICOM Standards Committee Std., April 2000.

[14] S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*, 2nd ed. Prentice-Hall, Englewood Cliffs, NJ, 2003.

[15] R. Welge, B.-H. Busch, K. Kabitzsch, J. Laurila-Duersch, S. Heusinger, M. Lipprandt, M. Eichelberg, E. Eichenberg, H. Engelien, M. Gk, G. Moritz, and A. Hein, "Ontology based approaches for the representation of aal-integration profiles," in *6. Deutscher AAL-Kongress 22.01-23.01.2013 Berlin*, Springer, Ed., 2013 (to appear).

[16] T. Stahl and M. Völter, *Modellgetriebene Softwareentwicklung - Techniken, Engineering, Management*. dpunkt.verlag, 2005.

[17] J. Riesmeier, *Ein generisches Verfahren zur adaptiven Visualisierung von strukturierten medizinischen Befundberichten*. Aschenbeck und Isensee, 2005, vol. ISBN: 3-89995-295-2.