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Representing Sensor Data Using the HL7 CDA Personal Healthcare Monitoring Report Draft

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Abstract. The recently published implementation guide for personal healthcare monitoring report (PHMR) defines a new format to represent measurements. The aim of the presented prototypical implementation is to check the ability of the defined format to represent health-related sensor data using a commercially available multi-sensor-device's measurements. An extensible stylesheet language (XSL) stylesheet has been developed to transform measured data from the multi-sensor device to a valid PHMR document. The resulting documents are validated and evaluated using standard tools for processing extensible markup language (XML) documents. While there are multiple ways to represent data gathered by multi-sensor devices in standard compliant CDA documents, the PHMR defines constraints based on the implementation guide for continuity of care documents (CCD) to support the development of new templates for sensor data and to minimize the variation between different implementations to enhance semantic interoperability. The PHMR implementation guide helps to define interoperable CDA conforming documents encoding data of health related sensors. In some parts the guide should be more restrictive to improve real-life interoperability.

Keywords. telehealth, patient monitoring, data representation standards, document architecture, HL7 CDA

1. Introduction

Telehealth and especially home telehealth have been a key interest in the last decades [1]. Many research projects and funding programs have been conducted and some solutions have been rolled out. While some of the developed solutions have been successfully introduced and are commercially available for medical care, there is no widespread use of these technologies. It is important to understand the reasons for this lack of sustainability, because home telehealth is expected to play an important role for effective and efficient health care of the future.

In particular, the lack of utilization of standards such as the HL7 clinical document architecture (CDA) [2] or ISO13606 [3] and the inadequate integration into regional health information system infrastructures, if existent, are regarded as key factors [4, 5].

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Only few examples of the use of standards in home care can be found in literature. Van der Linden et al. present PropeR, a re-usable, modular EHR system based on open source components such as the openEHR standard, and report on its use for multidisciplinary care of stroke patients [6, 7], but make no statement on the representation of sensor data. In [8] the processes in home care are described in detail and a framework for home care cooperation is proposed. The described framework uses XML to interconnect different health information systems.

To seamlessly integrate data measured by health-related sensors into trans-institutional health information systems these data have to be represented in formats that are able to preserve the semantic concepts of the measurements. Concentrating on the use of standards from the health information system domain, we developed an architectural model and prototypes, heavily utilizing HL7 CDA documents [9]. A similar implementation has been reported by Garsden et al. in [10]. While it is possible to encode sensor measurements in standard CDA there were neither template nor guidelines available. Recently an implementation guide for personal healthcare monitoring report (PHMR) using HL7-CDA release 2.0 has been published as a draft standard for trial use [11].

The aim of this work is to evaluate whether data from continuously measuring multi-sensor devices can be efficiently represented following the implementation guide for personal healthcare monitoring report.

2. Methods and Material

To practically validate the PHMR implementation guide, first of all a device is needed producing data in a form that is accessible and easy to convert. Using the PHMR implementation guide the data model of the device is transformed into a template for a valid CDA document. The next step is to develop a transformation capable to transform data in device-specific form to CDA documents. Using this transformation on a large set of data and analyzing the resulting documents gives further hints at the usefulness of the PHMR.

2.1. Device and Data Format

For this evaluation we used data from the BodyMedia SenseWear Pro² Armband [12]. It is used to monitor subjects in their daily life. Though it may not be an obvious choice, there are good reasons to choose it. First of all it is a multi-sensor device designed to be worn for long periods of time, monitoring health-related parameters like physical activity and energy expenditure. Therefore it represents a class of devices that might be widely used in future healthcare to monitor patients in their everyday lives. Secondly, not all of the included sensors are typical for medical devices. E.g., the installed accelerometer is – to our knowledge – not regularly used in medical settings. Another reason is that the data are saved in compressed XML files. This allows to express the transformation to CDA in an XSL-T stylesheet. Last, but not least, we have used the device in some studies with different kinds of subjects and have a lot of data at our disposal to test the transformation process.

The used source data files contain nearly all pieces of information necessary to build a valid CDA document. The XML-document's root element is called `SaveSet` and contains various elements structuring different pieces of information. The first

child element `SDK` contains calibration data, name-value pairs coding stored subject details and device information such as the serial number and firmware version. The software version used to retrieve the data from the device is stored in the succeeding `History` element. The prevailing part of the XML-document consists of `Series` elements each containing a series of `Event` elements each holding a start and end time and the measured value. The `Series` elements possess attributes to store the kind of measurements enclosed, such as the channel's name, the start and end times of the series and its sample rate. All time values are encoded as date and time pairs with a resolution of 1/10000 second. Most of the measured data are given as integer values representing raw values from analog-digital-conversion or calculated data. It has to be noted that the sample rates of two series can be different.

2.2. The Transformation Process

The test data for our transformation are available in compressed XML files. Therefore the process has to start with the decompression of the source file. Since CDA is an XML format as well, the decompressed XML can be transformed with an XSL processor using an XSL-T stylesheet to the final PHMR. The resulting PHMR documents can be validated by a CDA validator or forwarded to personal health record systems able to handle CDA documents.

3. Implementation

As already mentioned the conversion is performed by applying an XSL-T stylesheet to the source data files. The process is that simple, because all relevant information is contained in the source document. More complex environments might need to aggregate information on the patient, the sensor-systems, the aggregating system and the measurements from different sources, even in different formats than XML.

Representing the transformation using XSL is quite straight-forward if one uses the PHMR implementation guide. In the presented case all information can either be computed from the source document or is a fixed value determined by the PHMR guidelines or the represented device. For the evaluation the information on the author (`assignedAuthoringDevice`) and the represented custodian organization is encoded directly in the stylesheet.

The main differences between the two XML representations of measured data are that in the source document each measurement is accompanied by the period of validity. In CDA this approach is possible, but generates a lot more text, because of the requirements to encode all information about the measurement with its value. Therefore a more simple representation for repeated measurements has been chosen. CDA allows and PHMR recommends and further defines the use of waveform elements. Using the waveform representation a series of measurements of one measured variable can be encoded as a series of integers (`SLIST_PQ`) in a value element. These lists are grouped in an observation element together with preceding elements encoding data related to the measurements. For example the start-time of the measurement and its sample rate must be encoded in an observation element. The start and end time of the whole measurement must be encoded in an `effectiveTime` element.

4. Results

Using the above transformation process all measured or derived data from the multi-sensor device can be represented in a valid PHMR-CDD-CDA document. Some difficulties arose from the special kinds of measurements performed by the device. E.g., no nomenclature known to the authors is capable to encode a measurement of acceleration on the upper arm. Thus using – our institutional OID – we had to define a new terminology for the missing concepts. Another problem arose from the undisclosed proprietary algorithms to calculate real world measured quantities from the stored values. This and the limited ability of the waveform representation to encode values other than integers and mappings other than linear resulted in some measurements to be encoded in a form one cannot easily convert to a physical measurement. It is necessary to convert back to the vendors' format and use the proprietary software to perform the mapping process.

The used way to represent continuous measurements in a waveform resulted in smaller file sizes, because in the source file each measurement is accompanied by two time values, each encoded in 24 Bytes. Comparing the file size, CDA uses extensive coding to describe the measurements. More importantly, CDA requires each value to be present in two places of the file: once in the human readable text section and once in the machine readable section. The test files often included more than 200,000 values, therefore the resulting documents are unnecessarily large due to this redundancy. Reducing the number of elements used in a document has the benefit that it can be more effectively read to memory and be operated on. During our tests XML-capable browsers such as the Internet Explorer or Mozilla Firefox often crashed due to memory exhaustion, even on systems with 4 GB main memory. Their internal representation is optimized for small XML files because they both support memory intensive interactive exploration of the documents loaded.

The one step XSL-only implementation is not capable to generate a graphical representation of the waveforms that is compatible to the CDA requirements.

5. Discussion

The results show that it is possible to represent data from a multi-sensor device in a valid CDA document using the PHMR implementation guide. It turns out that the guide and the accompanying example are very helpful. The defined constraints help to make the right decisions to encode sensor data to a CDA document. In some places the constraints might be more restrictive to reduce the possibilities to encode a measurement in various ways, because thus later automatic interpretation of the documents would become easier. It is very helpful that different measurements and observations can be stored in a single document. Though CDA was designed mainly to enrich digital clinical reports with coded entries and single measurement values, the tests proved that it is possible to use it for long-term observations as well.

The measurements of a channel can be encoded as a waveform quite efficiently. Each of these value-lists includes mapping information for graphical display and must be complemented with timing information and a reference to information in the medical device section. It would be quite easy to enhance the automated transformation process with some additional logic to generate graphical representation and summary results to be included in the final CDA documents. A drawback of the waveform

encoding is that the list of integers is not as easy to process by an XSL stylesheet as the tagged single values in the source document. E.g., it would be more easy to generate a scalable vector graphic (SVG) – being an XML file as well – from the source document. Encoding waveforms in CDA documents it should be considered, whether a human reader really benefits from the repetition of the values in text form. CDA requires all encoded information to be present in text as well. Alternatively, a standard graphical conversion of the encoded values might be defined and required to be displayed. This would significantly decrease the size of the CDA documents and even improve easy interpretation of the contained data by humans.

6. Conclusions

The evaluated draft standard for trial use's first release of the implementation guide for CDA release 2.0 personal healthcare monitoring report (PHMR) proved to be a good way to represent data in the realm of home telehealth. While further evaluation is needed and some improvements can be made, a conforming representation should be used if data from health-related sensors are to be encoded in CDA.

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