Healthcare Standards based Sensory Data Exchange for Home Healthcare Monitoring System

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***Abstract*— Interoperability is the among the key functionalities of an intelligent systems. Home Healthcare Monitoring Systems (HHMS) investigates patients activities at home, but lacks critical information exchange with Health Management Information System (HMIS). This information is vital for physicians to take necessary steps for timely and effective healthcare provisioning for patients. Physicians can only monitor and prescribe patients in time, if the data is shared with their HMIS. HMIS can be compliant to different healthcare standards. Therefore, mediation system is required to enable interoperability between HHMS and HMIS such that physicians and patients information can easily be exchanged. We propose Interoperability Mediation System (IMS) that provides interoperability services for exchange of information among HHMS and HMIS. We consider that HMIS are compliant to two heterogeneous EHR standards (HL7 CDA and openEHR). Alzheimer's patient case study is described as a proof of concept. Sensory information gathered at HHMS, is communicated with HMIS compliant to EHR based healthcare standards. Sensors information in XML form is converted by interoperability service to HL7 CDA and openEHR instances and communicated to HMIS afterwards. This allows the physicians registered with HHMS to monitor the patient using their HMIS and provide timely healthcare information.**

I. Introduction

The population of the world is growing older and ageing people are increasing more in the developed countries. According to a survey [1], *"the world population is projected to increase 3.7 times from 1950 to 2050, but the number of those aged 60 and over will increase by a factor of nearly 10"*. Diseases are also on a rise with the increase in population, necessitates treatment and management of patients at their doorstep. Home Healthcare Monitoring System (HHMS) supports patients daily healthcare and their quality of life by collecting useful medical and daily routine data. The collected information is valuable enough to be communicated with physicians on time. Physicians spend most of their time in hospitals and are dependent on Hospital Management Information System (HMIS). HMISs are compliant to different healthcare standards therefore requires data in standardized format. Exchange of information among HHMS and different HMISs fails due to lack of data level interoperability.

We propose Interoperability Mediation System (IMS) that behaves as a bridge between HHMS and HMIS. HHMS collects information in raw sensory format and stores it in XML format while HMIS follows standard structure of information based on its compliancy with the healthcare standard. We consider two HMIS compliant to Health Level Seven Clinical Document Architecture (HL7 CDA)[1] and openEHR[2]. Both standards are EHR based standards following the two level modeling approach and conforms to their own reference models.

For proof of concept we considered Alzheimer patient's daily routine data collected using sensors, deployed in home environment. This data is then communicated with the subscribed HMIS in its standardized format. The system results in timely exchange of patient's data collected at home with physicians to evaluate and take necessary action. Enabling the exchange of data among HHMS and HMIS achieves data level interoperability.

II. Sensors based Clinical Information and Standardization

A. Human Activity Recognition Engine (HARE)

HARE engine is designed and developed by our lab for monitoring the activities of Alzheimer disease patients. HARE [2] focuses on monitoring human activities (Alzheimer's patient as case study) using heterogeneous sensor technology. The activities of the Alzheimer's patients are recognized using motion sensors, video based sensors, wearable sensor based, and location based sensors. These activities are intelligently processed by Context-Aware Activity Manipulation Engine (CAME). The intelligent processing is carried out using Human ontology and inference engine that maps the activities to particular disease and identifies context. Other than the mentioned sensors, binary sensors and 2D/3D cameras (depth sensors) can also be used for activities recognition. These activities are then stored in raw sensory data repository and XML repository as shown in Figure 1. *HARE* helps the HHMS to identify and store information about patient activities. Its utility is restricted by its inability to communicate collected information with HMISs compliant to different healthcare standards. Therefore this sensory information needs to be transformed into standardized formats for communicating with HMIS. We consider HL7 CDA and openEHR based record formats for communication of HHMS and HMIS.

B. HL7 Clinical Document Architecture (CDA) & openEHR

The HL7 CDA is a document markup standard that specifies the structure and semantics of "clinical documents"

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[1] http://www.hl7.org/
[2] http://www.openehr.org/

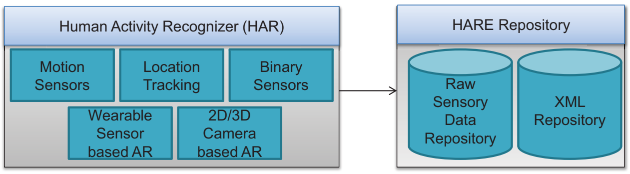

Fig. 1. Activities Recognition using HARE

for the purpose of exchange [3]. All the CDA documents are based on Refined Message Information Model (RMIM) [3], a partial class diagram of CDA RMIM. openEHR is an open standard that describes the management and storage, retrieval and exchange of health data in electronic health records (EHRs) [4]. Reference Model, Service Model and Archetype Model are three categories of openEHR models. These models helps in creation of openEHR instances called EHR Extracts for exchanging information.

The sensors data gathered, processed, and then filtered is made part of CDA document and openEHR-extract as observations. These observations are then communicated with HMISs in compliance with HL7 CDA and openEHR. This makes data level interoperability among healthcare systems possible, as communicating systems interpret the data as desired and responds accordingly.

III. Related Work

Healthcare standards play important role in interoperable HHMS systems. These allow HHMS and HMIS to communicate patient's information easily. J.W.Lebak et al. [5] developed a hierarchy about home to remote database communication using HL7. It is more related to messaging of information among databases and not focus much on standardized document creation from sensory information gathered before exchange of information. M.Galarraga et al. [6] presented review about role of ISO/IEEE 11073 family of standards for interoperability in telemonitoring. The focus of the study is on resolving barriers like heterogeneity of devices and systems and difficulty of its integration with HMIS. They mostly focussed on device level interoperability using ISO/IEEE 11073 standards, leaving aside data level interoperability. T.Perumal et al. [7] focused on interoperability of sub-systems in smart homes using web services. The focus is on cross platform interoperability, enabling subsystems communication among themselves in smart home environment. The proposed approach limits only to the discussion about levels of interoperability in smart home environment. [8] describes a technique based on home healthcare monitoring system data exchange scheme between the HL7 standard and the IEEE 1451 standard. IEEE 1451 standard defines a suite of interfaces that communicate among heterogeneous networks while HL7 standard is used for medical information exchange among medical organizations. Clinical Information Modeling Initiative (CIMI) [9] is an initiative started by healthcare standards stakeholders. This group is dedicated to providing a common format for detailed specifications to represent health information content so that semantically interoperable information can be exchanged. The basic purpose is to define Detail Clinical Models (DCM) in a generic format that can easily be converted to any standardized format. Home monitoring systems aligned with healthcare standardization can play a significant role in CIMI initiative. [2] focuses on low level sensory data and context analysis of the identified activities. This work is our baseline, and our proposed system standardizes sensory data contents in HL7 CDA and openEHR standard before communicating with HMIS.

Although the systems described are contributing effectively to HHMS and interoperability aspects. These systems lacks communicating information of smart home healthcare systems with HMIS. Healthcare standards such as HL7 CDA and openEHR fulfills the mentioned criteria and the proposed system is based on implementing this concept for interoperability among HHMS and HMIS.

IV. Proposed Architecture

The proposed system is based on interoperability service that behaves as mediator among HHMS and HMIS. Mediation is necessary for HHMS easily communication with HMIS compliant with HL7 and openEHR standards. The working of the system would be demonstrated in the next section. The proposed system is shown in Figure 2 and the details of the components of the system is as follows:

A. Home Healthcare Monitoring System (HHMS)

1) HARE Repository and XML Filter: Patient activities are monitored by different sensors in HHMS and this information is made part of *HARE repository*. The data stored in HARE repository is in raw form and it requires preprocessing in order to store it in XML format. This preprocessing is carried out using different algorithms that are proposed and implemented in our lab for sensory based [10], video based [11] and location tracking [12] activity recognition. We assume that the algorithms are applied on the sensory data has stored the preprocessed information in XML format. XML Filter preprocess the information for storing the content in XML format. This XML format consists of the activities, the time duration of the activities taking place, and location of the patient. After a certain interval of time, the HHMS needs to communicate this gathered information with the physicians of a particular hospital. Other than patient information, sensor information is also stored in XML file.

2) Communication Engine: Communication Engine performs two activities of communicating with IMS. Firstly, it subscribes the HHMS information with IMS by invoking its subscription service. Secondly, after subscription it communicates patient activities information in XML format with Interoperability Service of IMS. IMS is further responsible for communicating this information with HMIS.

B. Interoperability Mediation System (IMS)

1) Subscription Service: Subscription service of IMS is responsible for storing the information of the registered

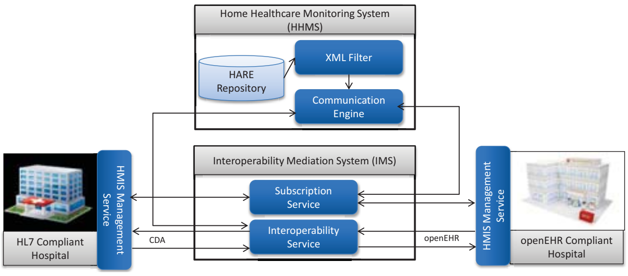

Fig. 2. Working Model

```
<?xml version="1.0" encoding="UTF-8"?>
    <activities>
        <activity type="Motion">
            <detectedBy>Motion Sensor</detectedBy>
            <hasName>Mr J</hasName>
            <activityName>Leaving Bedroom</activityName>
            <id>1</id>
            <time>2011:05:16:01:00:00</time>
        </activity>
        <activity type="Motion">
            <detectedBy>2D Camera</detectedBy>
            <hasName>Mr J</hasName>
            <activityName>Leaving Bedroom</activityName>
            <id>2</id>
            <time>2011:05:16:01:00:00</time>
        </activity>
        <activity type="Medicine">
            <detectedBy>Wearable Sensor</detectedBy>
            <hasName>Mr J</hasName>
            <activityName>Taking Medication</activityName>
            <id>5</id>
            <time>2011:05:16:01:10:40</time>
        </activity>
        .........................
    </activities>
```

Fig. 3. Alzheimer's Patient Activities

HHMS and HMIS. Subscription table stores information of the registered HHMS and HMIS. When Communication Engine invokes *Interoperability Service* for communicating patient activities information, its status being registered HHMS is confirmed using subscription service initially.

2) Interoperability Service: This service is responsible for transformation of sensor based activities recognized in HHMS to standardized format (CDA and openEHR formats). Contents transformed to CDA document is communicated with HMIS compliant to HL7 CDA and openEHR-extract is communicated with HMIS compliant to openEHR. The communication takes place by invoking *HMIS Management Service*.

C. HMIS Management Service

This service is responsible for receiving information from IMS and then communicating back the information with IMS. Information once received by the service is evaluated by the Physician, who provides recommendations that are again communicated with HHMS through IMS services.

V. SCENARIO

We discuss Alzheimer's patient scenario for proof of concept of our proposed system. The information collected about the patient using sensor application is shown in Figure 3. Each activity consist of its type that shows whether patient is moving, sleeping, eating or walking. These activities are identified by particular sensor or camera (example shows Motion sensors, Wearable sensors and 2D Camera). The sensors and cameras are provided unique ID's. Date and time of the activity performed is also maintained in the repository. A threshhold of 1 hour is set for the data to be accumulated and stored in HARE repository. This information is then transformed into CDA document and openEHR-extract for communication with corresponding HMIS.

A. Mapping Alzheimer's Patient Activities to HL7 CDA and openEHR

The activities of Alzheimer's patients are stored in HARE repository and XML file showing these activities is shown in Figure 3. These activities monitored in home environment with the help of sensors and cameras, are part of the HHMS. We generated HL7 CDA document and openEHR-extract from the activities information.

HL7 CDA is generated from standard CDA RMIM and the coded values are derived from standard vocabularies like SNOMED CT and HL7. Sample CDA document generated from XML file is shown in Figure 4. *Organizer* class represents CDA entries in the form of observations for recording Alzheimer's patient activities. *Leaving Room* activity of the patient is recorded as value of *Observation* class, represented by attribute *displayName* having value *Patient works away* and *code* attribute value *184090004* of SNOMED CT. In the same way *Motion Sensor* and *Bedroom* information are represented by *Device* and *PlayingEntity* CDA RMIM classes.

Figure 5 shows sample openEHR-extract generated from patient's activities. It shows *Observation* class of openEHR's EHR Information model to document different activities of the patient. Its *data* attribute uses *Item_Tree* class of Data Structure information model to represent activities as items.

```
<entry>
  <organizer classCode="OBS" moodCode="EVN">
    <code code="161108005" codeSystem="2.16.840.1.113883.6.96"
     codeSystemName="SNOMED CT" displayName="Alzheimer's disease
     society member (finding)">
      <statusCode code="completed"/>
        <component typeCode="COMP">
          <observation classCode="OBS" moodCode="EVN">
             <code code="184090004"
             codeSystem="2.16.840.1.113883.6.96"
             codeSystemName="SNOMED CT" displayName="Patient works away"/>
             <statusCode code="completed"/>
             <effectiveTime value="20110516010000"/>
             <value xsi:type="ST" value="Leaving Room"/>
               <performer typeCode = "PRF">
                 <assignedEntity classCode="ASSIGNED">
                   <id extension="1" root="2.16.840.1.113883.2.99.6.1"/>
                   <code code="408746007" codeSystem="2.16.840.1.113883.6.96"
                   codeSystemName="SNOMED CT" displayName="Sensor Device"/>
                     <Device classCode="DEV" determinerCode="INSTANCE">
                        <manufacturerModelName> Motion Sensor
                        </manufacturerModelName>
                     </Device>
                 </assignedEntity>
               </performer>
               <participant typeCode="LOC" contextControlCode="OP">
                 <participationRole classCode="ROL">
                   <code code="homeHealth" codeSystem="2.16.840.1.113883.5.111"
                   codeSystemName="HL7" displayName="Home Health"/>
                     <playingEntity classCode="ENT" determinerCode="INSTANCE">
                       <code code="224700005" codeSystem="2.16.840.1.113883.6.96"
                         codeSystemName="SNOMED CT" displayName="Bedroom"/>
                     </playingEntity>
                 </participationRole>
               </participant>
          </observation>
        </component>
        ...................................................................
    </organizer>
</entry>
```

Fig. 4. Sample CDA of Patient Activity

```
<content xsi:type="OBSERVATION" archetype_node_id="at0002">
          <name xsi:type="DV_CODED_TEXT">
                <value> Patient Works Away </value>
                <defining_code>
                               <terminology_id>
                               <value> SNOMED-CT06 </value>
                               </terminology_id>
                               <code_string> 184090004 </code_string>
                </defining_code>
          </name>
          <data archetype_node_id="at0001">
                <name>
                      <value> Leaving Bedroom </value>
                </name>
                <data xsi:type="ITEM_TREE" archetype_node_id="at0003">
                      <name>
                            <value> Activity </value>
                      </name>
                      <items xsi:type="ELEMENT" archetype_node_id="at0005">
                             <name>
                                   <value> Motion Sensor </value>
                             </name>
                             <time>
                                    <value>20110516010000</value>
                             </time>
                             <value xsi:type="DV_CODED_TEXT">
                                    <value> Sensor Device </value>
                                    <defining_code>
                                        <terminology_id>
                                           <value> SNOMED-CT06 </value>
                                        </terminology_id>
                                        <code_string> 408746007 </code_string>
                                    </defining_code>
                             </value>
                      </items>
                      ......................................................
          </data>
</content>
```

Fig. 5. Sample openEHR Extract of Patient Activity

Sensor Device information whose *value* is represented using controlled terminology (SNOMED CT), the key (i.e. the code) of which is the *defining_code* attribute. The same way other activities information is also represented as shown in Table I.

Table I summarizes the mappings of patient activities information with HL7 CDA and openEHR. It shows the tags and values of activities mapping to HL7 CDA and openEHR classes and attributes. Patient leaving his bedroom is categorized as *Motion* activity in XML file, mapped with *Observation* class of both the standards. The same way *Motion Sensor* is mapped to *Device* class in HL7 CDA while *Element* class in openEHR.

VI. CONCLUSION

Integration of HHMS and HMIS is critical for providing timely patient care. Healthcare standards plays vital role in ensuring smooth integration of both systems. The proposed system validates this concept by integrating HHMS with HMISs in compliance with heterogeneous standards. Patients activities information gathered and stored in HHMS is communicated with HMISs in their corresponding healthcare standard format. Patients health is monitored at their homes, saving their time and cost of clinic visits. Physicians can easily monitor patients information by staying at hospitals and providing recommendations remotely. We will address issue of data interoperability among HMISs compliant with heterogeneous standards in future. A generic Detailed Clinical Model (DCM) of sensory information for collecting patients activities would be developed for easy transformation of health related data to any healthcare standard format.

TABLE I

CONTENT MAPPING OF ACTIVITIES TO HL7 CDA AND OPENEHR

Tag	**Value**	**openEHR Class[Attribute]**	**HL7 RIM Core Class**	**HL7 Class[Attribute]**	**Terminology [Vocabulary Name]/Value**
activities	(all activities)	Composition	Act	Organizer	Alzheimer's disease society member [SNOMED CT]
activity	(single activity)	Item_Tree	Act	Component	
Type	Motion	Observation	Act	Observation	Patient Works Away [SNOMED CT]
detectedBy	Motion Sensor	Element	Participation	Performer	
			Role	AssignedEntity	Sensor Device [SNOMED CT]
			Entity	Device	Motion Sensor
activityName	Leaving Bedroom	Contact	Participation	Participant	
			Role	ParticipationRole	Home Health [HL7]
			Entity	PlayingEntity	Bedroom [SNOMED CT]
id	1		Entity	AssignedEntity[id]	1
time	2011:05:16: 01:00:00	Item[time]	Act	Observation [effectiveTime]	20110516010000

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