Clinical Decision Support Service for Elderly People in Smart Home Environment

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***Abstract*—With the advent of smart technologies potential ideas have been emerged to facilitate human lives. Based on sensor technologies, smart homes concept is prevailing now a days that intends to bring tremendous changes in human lifestyle. The most prominent application is to equip the smart home with monitoring system that facilitate in managing care for elderly people. Elderly people with chronic disease need continuous care for managing their activities specially medications. The cost is increasing on care of elderly people and often needs sparing of family resource to take care during management of their activities and medications. This paper propose idea of Clinical Decision Support Service (CDSS) that provides guidelines and recommendation based on observed activities of patient. Our proposed CDSS service called Smart CDSS is deployed on platform that support various sensors and emotion recognition applications. The Smart CDSS knowledge base is currently supporting diabetes rules extracted from online resources and validated against recommendation from physician for 100 patients during their visits to local hospital. The Smart CDSS service allow interaction through standard base interfaces following HL7 vMR standard that allow seamless integration to underlying platform. Moreover, HL7 Arden Syntax is incorporated to scale up knowledge base for other diseases and allows sharing of clinician knowledge.**

I. Introduction

It has been observed that global population is increasing very rapidly [1]. It is also the fact that elderly population ratio is increasing with constant rate. According to study in [2],it has been predicted that one fourth of US population will be over age of 65 by 2040. Associated with age, the chronic diseases are increasing rapidly, such as heart failure, diabetes, dementia, sleep apnea, cancer and chronic obstructive pulmonary disease [3] [4] [5]. Diabetes is considered as the most prominent disease that is diagnosed at increasing rate across the whole population and particular in aged population [6]. Statistics shows that there is close relationship of age with increasing incident of type 2 diabetes and other associated complications and comorbidities [7]. Diabetes can be cause of developing other complications particularly in older peoples, so some of these related complications need to be address properly [6]. The risk increases with age for diabetes, therefore self-strategies are highly recommended for older adults [8]. In order to achieve this goal, the older people should be motivated towards understanding their health conditions and proper decision making regarding their health. In addition to diabetes, the older people also suffer from other comorbities such as disability, cognitive dysfunction, depression and difficulties in mobility. All these complications cause mismanagement of diabetes care for older peoples. Research work [8] revealed that older people have reasonable understanding of diabetes management, but the problem is severe with patients that suffers from cognitive impairment. To handle aged population, healthcare costs is increasing and productivity are declining by engaging resources such as family members for assisting aged patients [1]. Moreover, effective diabetes care within homecare fails due to lack of defined medical, nursing and social care responsibilities [9]. The research [9] propose key guidelines such as individualized diabetes care plan for each resident, developing proper policy for diabetes care and development of audit tools to asses the quality and extent of diabetes care within care homes.

To enable individuals and home care givers for proper management of chronic diseases such as diabetes, there is need of some innovative approach coming out from emerging technologies and IT solutions. The availability of variety of bio sensors and video cameras are used to detect activities of individuals in specific environment. The efficient integration and usage of these sensors within home setup can provide baseline to monitor patients and manage their care. The solution becomes more efficient and manageable with provision of set of services to underline infrastructure. The most prominent services in context of patient care, can be safety services, recommendation and guideline services that should be invoked as result of activities during patient care at home. An individual patient or care givers can take advantages of these services to manage chronic disease such as diabetes.

To monitor low level activities using sensor and video base environment, we have already developed platform architecture, called Secured Wireless Sensor Network (WSN)integrated Cloud Computing for u-Life Care (SC^3) [10]. SC^3 platform is equipped with different wireless sensors that collect real time data and transmit it through cloud base gateway [11]. In order to develop high level context of low level information, formal ontologies of tracking activities are used that is manipulated by Context-aware manipulation Engine (CAME) to provide more meaningful information [12]. SC^3 also has the capability of activity recognition in complex scenarios such as concurrent situation assessment and domination of major over the minor activities [13].

To make SC^3 platform aware of intelligent services which is based on experiences and guidelines of clinician using domain knowledge, we proposed Smart CDSS (Clinical Decision Support System) [14].Smart CDSS provides guidelines and alerts in monitoring elderly people using authentic knowledged base populated from experiences of clinicians. Patient monitoring service is enabled by many platforms but most of them lacks deriving guidelines from domain expert knowledge. As an example, the system described in [15] has potential service to manage patient medications and monitoring other activities of elderly people.

In this paper, Smart CDSS service is explained to provide guidelines and recommendation for diabetic patients in home care environment. Design and architecture of Smart CDSS has been proposed while keeping following objectives in mind.

1) Developing Knowledge Base (KB) that practice standards like HL7 Arden Syntax for ease of sharing clinical knowledge [16].
2) Smart CDSS incorporates emerging HL7 vMR (virtual Medical Record) [17] to allow access to KB using standard base interfaces for seamless integration with diverse healthcare systems.
3) To use existing system (which is tested for Alzheimer patient at UC Lab) of smart home [10] for diabetic patients and provide alerts and reminders from Smart CDSS service.
4) In order to achieve interoperability for smart home application as mentioned in [18], the output of the smart home application [10] is transformed to standard input based on vMR [17] and get reminders and guidelines from Smart CDSS in standard format.
5) Based on layered architecture [19] for smart home, we propose clinical decision aware service that provide diabetic patient with guidelines and reminders from standard clinical knowledge base.

The Smart CDSS service is deployed on Microsoft Azure cloud infrastructure as Windows Communication Foundation (WCF) service [20].The service is tested for diabetes data on 100 patients clinical information collected from hospital and some example dataset generated by SC^3 platform.

II. Smart Home Application Architecture: Business Process Modeling

Keeping in view complexity of smart home applications and business workflows, smart home application can be designed into four layers. Fig. 1 show, the analysis of each layer in terms of business processes to be modeled according to layered architecture addressed in [19].

A. Hardware Layer: Sensor and Actuators

At this level variety of sensors are deployed to monitor various activities at smart home. For healthcare application, various bio-medical sensors are planted to observe activities of patient regarding medication and daily routines. The patient activities data is collected and stored in raw format for further processing.

B. Home Communication Network Layer: HCN

HCN support services for various networks including ZigBee, Wi-fi and blue-tooth. It discovers various hardware and appliances in smart home and coordinate its data with decision making layer.

C. Autonomous Decision Making Layer: ADM

ADM services take raw sensory data and organized it by applying designed filters. At this level minimal decision services are also incorporated to make decision regarding various activities. It coordinates the structured data to services layer in order to equip smart home with higher level user friendly facilities.

D. Services Layer

Services layer enclosed all facilities that smart home users expect. It provides with set of services comprising safety, remote support and clinical decision support services. to equip the resident with all intended facilities. The structural activity data is consumed and forwarded to various services for providing intended goal. For example, Smart CDSS service expects clinical observation like activity of diabetic patient and provides guidelines and reminders based on the activity information.

III. Overview of SC^3 Architecture

SC^3 platform include modules that provide interface for various wireless based sensors and video camera to detect human activities within home environment. To provide high level contextual information, various services are incorporated. Fig. 2 depicts the architecture and the following section briefly explain each module.

A. Hardware Layer: Sensors and Video Cameras

SC^3 provide interface for various type of sensors including binary sensors, wearable sensors, embedded sensors, sound sensors and various type of 2D and 3D cameras [12]. All these sensors and cameras can be setup in home environment or attach to human body for detecting health related activities. The raw sensory data is disseminated to activity and emotion recognition module for deriving high level context.

B. Activity and Emotion Recognizer (AER)

AER derive high level context from raw sensory and video based information. The information collected through various sensors and cameras are combined with context of situation and location, to detect actual activity of subject under observation. As an example, video camera detect person within kitchen while location based sensors provide the location informaion yields to the conclusion that person is cooking.

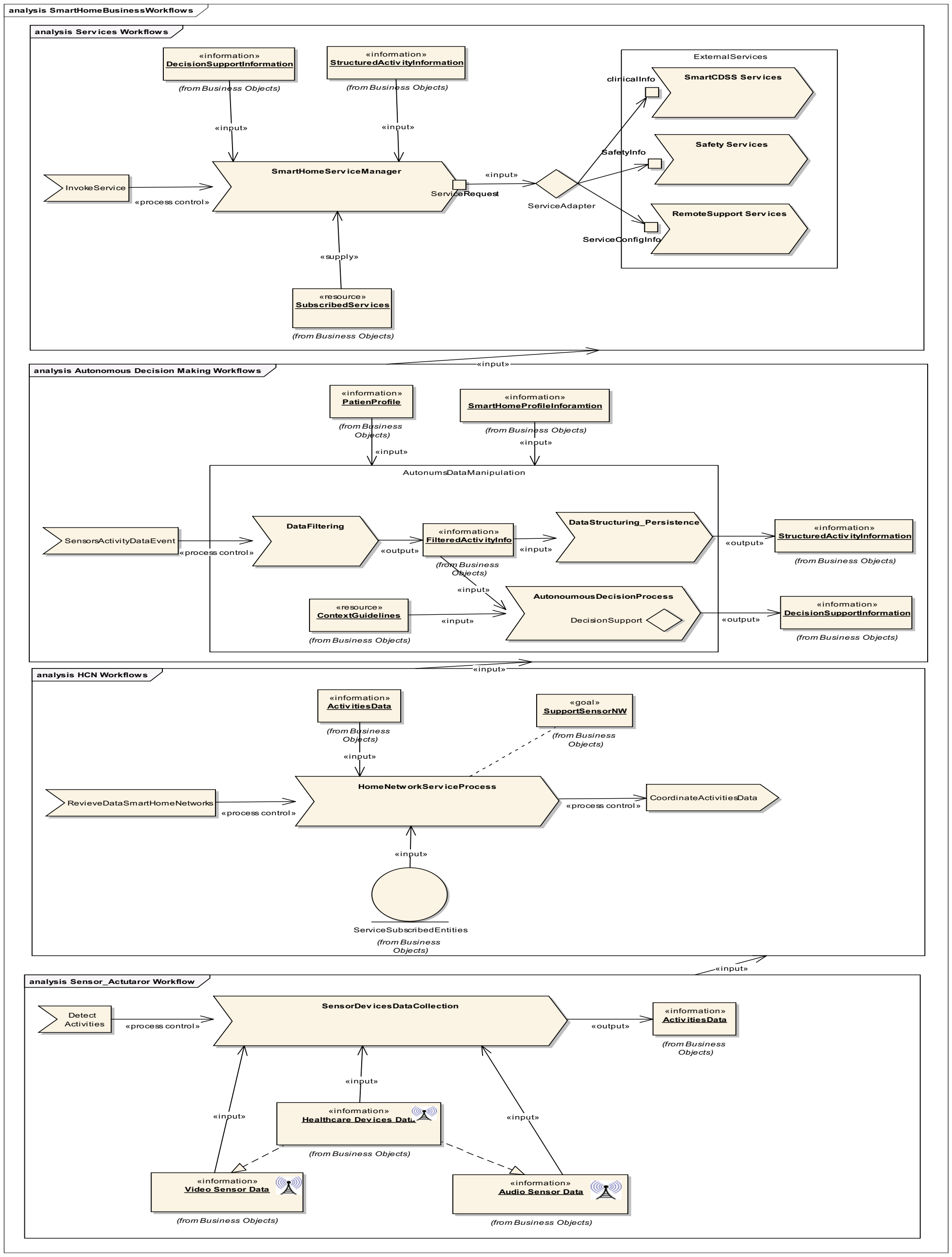

Fig. 1. Business Process Model of Smart Home Applications

C. Context-Aware Activity Manipulation Engine (CAME)

CAME provides additional context to the information recognized by AER module. It represents the situation information in high level ontology that assist in finding the exact identification of occurred activity. For example, the information of fall down collected from sensors will direct emergency alarms. On the other hand, CAME will differentiate fall down information from simple jumping by consulting ontology with concepts of time, location and other related factors [12].

D. HAE Repository

HAE repository provide persistence for activity recognized for subject under observation. It holds information in various format such as XML and OWL to be used and transformed for deriving high level context. Moreover, it also provides support to be extended for clinical information for deriving patient activities.

IV. Smart CDSS Design and Architecture

Smart CDSS is cloud base service that accept input of patient diagnosis and activities in standard HL7 vMR format

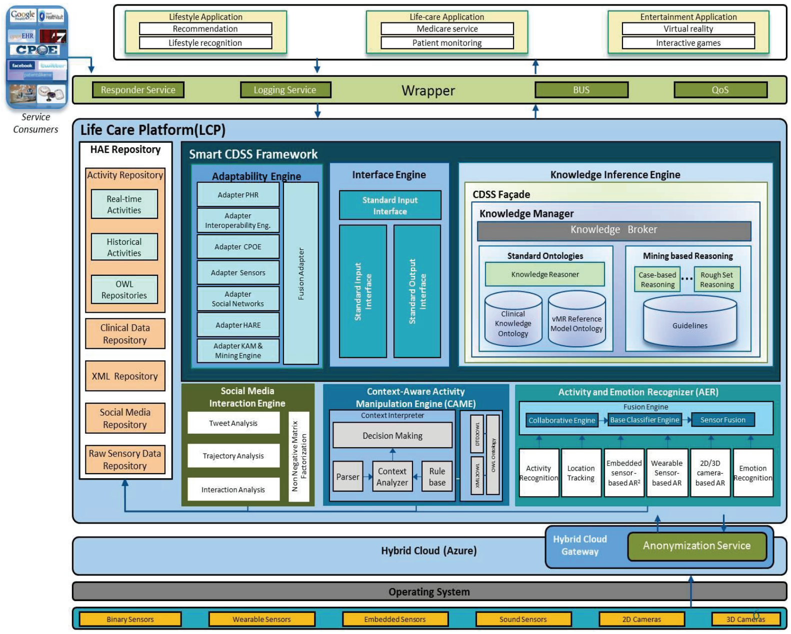

Fig. 2. SC^3 Architecture

and produce reminders and guidelines based on the stored knowledge base generated by clinicians and other domain experts. The ultimate consumer of Smart CDSS service can be patient monitoring system at smart homes, external EMR/EHR, PHR, social media or Computrized Physician Order Entry system (CPOE). Fig. 3 highlights the main components of Smart CDSS service with cloud infrastructure. To keep privacy of patient data, some basic information of patient are anonymized before putting for decision support using annonymization service.

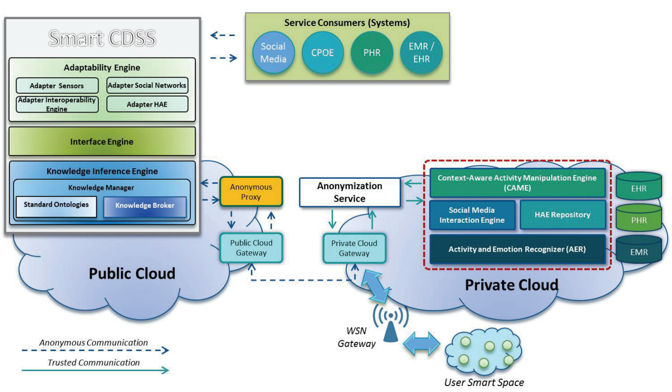

Fig. 3. Smart CDSS Service Architecture

A. Use Case: Request For Generating Guidelines/Reminders/Alerts

Smart CDSS service accept request in standard HL7 vMR format. To adapt Smart CDSS standard interfaces, consumers should transform their proprietary format to HL7 vMR format. Adaptability Engine provides room to all consumer applications to derive corresponding adapter. Example of such adapters include Sensors Adapter, Adapter Social Networks and Adapter Interoperability Engine for standard clinical data. Moreover, to collect data of patient from different resources, the Fusion Adapter is defined to merge input of diverse sources with single patient context into standard vMR format. In homecare, the elderly people data can be collected using activity recognition system (i.e. using sensory data) and clinical information prescribed by physician to monitor patient health condition. Fig. 4 depicts the data capture for a patient from three different sources; Sensory data from activity recognition, clinical data from physicians and also considering the patient records on some social media like twitter and PatientLikeMe.

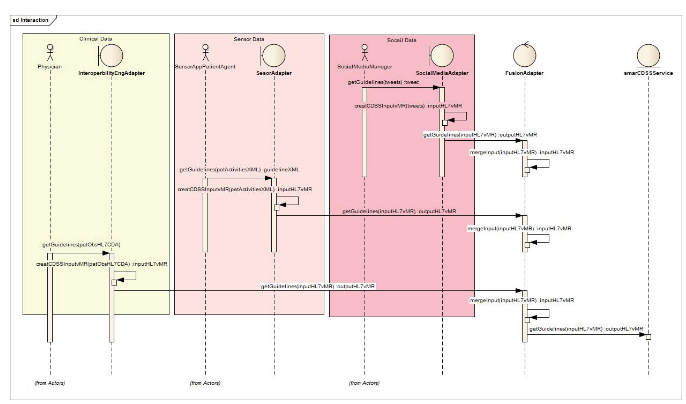

Fig. 4. Smart CDSS Standard based Request Sequence Diagram

```xml
<?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="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. 5. Diabetic Patient Activities under Observation

B. Request Transformation to Standard Input: Sensory Input

To keep example simple and understandable, consider transforming patient sensory information into standard Smart CDSS input. Fig. 5 represent partial information of patient activity in XML format. Corresponding standard input for Smart CDSS is shown in Fig. 6. The normal activity information has been transformed into standard format using standard terminology of SNOMED CT.

C. Use Case: Generating Guidelines

Smart CDSS knowledge base consists of rules published by clinicians in form of HL7 Arden Syntax. Each individual rule construct some recommendations, alerts or guidelines called Medical Logic Module (MLM). MLM has well define structure to represent rule. For example, ”maintenance” section define the title of MLM, author of the MLM and date and time of the creation of the MLM. ”library” section capture information that describe purpose of the MLM. ”knowledge” section captures the data and logic of the MLM that will generate recommendation or alerts. Fig. 7 depict partial MLM which is used to diagnose diabetes mellitus based on glucose observations. MLM execution is critical process of Smart CDSS knowledge base. Based on the triggered events, knowledge base reasoner load all corresponding MLMs and execute it for possible recommendations. The recommendations are send back to consumer of Smart CDSS in standard vMR format. Fig. 8 depicts sequence of interactions to generate guidelines or reminders.

V. Implementation and Results

Smart CDSS service is designed using web services top down approach. The WSDL contracts are defined based on standard vMR input and output. In WSDL contract, we have defined two way method operation to generate guidelines. The standard input and output is validated against schema representing vMR structure. These schemas are formally included in WSDL contract. Based on the defined WSDL, corresponding WCF (Window Communication Foundation) service is generated and deployed. WCF has advantage to be integrated with Windows Workflows and provides SOA environment.

For each MLM, we are creating separate C# class and compile to knowledge base. All MLM classes are bound to implement *MLMBaseInterface*, that expose interface of executing MLM using *MLMMetaData*. Fig. 9 depicts the static model of knowledge base and its execution environment. The MLMs are executed in separate thread and the result is combined after finishing all related MLM execution.

Smart CDSS service is deployed on Microsoft Azure. Microsoft Azure run the Smart CDSS service as worker role and support WCF services. The Smart CDSS service was tested for 100 diabetes patients with 40 type 1, 20 type 2 diabetes and 40 with diagnosing no diabetes mellitus. Seven different MLMs for this trial was obtained from online resources which covers some fundamental rules for diagnosing and managing diabetes chronic disease. For 100 patients, the service triggered diagnosis of diabetes for all patients based on laboratory observations. Base on sensory data, which was very generic, the Smart CDSS service triggered some basic recommendations. As the implementation is at initial stage, the performance of the system is not measured. However, taking advantage of multithreading environment, the MLMs execution seems as parallel as possible.

```xml
<vmrInput>
    <templateId root="2.16.840.1.113883.3.795.11.1.1"/>
    <patient>
        ...........
        <clinicalStatements>
            <!-- current problems -->
            <problems>
                <problem>
                    <id root="d7ebd80c-a28f-438f-9457-d3f92ea124ad"/>
                    <!-- Diabetes -->
                    <problemCode codeSystem="2.16.840.1.113883.6.96"
                        codeSystemName="SNOMED CT" code="73211009"/>
                </problem>
            </problems>
            <!-- current medications -->
            <substanceAdministrationEvents>
                <substanceAdministrationEvent>
                    <id root="54277620-9128-4c13-8fc8-623a38532627"/>
                    <substance>
                        <id root="2c803900-c8d1-457d-9567-4c92d75a0e23"/>
                        <!-- Morning after diabetic pill  -->
                        <substanceCode codeSystem="2.16.840.1.113883.6.96"
                             codeSystemName="SNOMED CT" code="102954005" />
                    </substance>
                    <documentationTime low="20110516" high="20110516"/>
                </substanceAdministrationEvent>
            </substanceAdministrationEvents>
        </clinicalStatements>
    </patient>
 </vmrInput>
```

Fig. 6. Diabetic Patient Activities: Standard Smart CDSS Input

```
maintenance:
title: Diabetes Mellitus

library:
purpose: "Finding VPGC[Venous Plasma Glucose Concentration] to identify
Diabetes Mellitus (DM)

knowledge:

logic:
If [fasting and VPGC =126 (mg/dL)] OR
[2-hour post 75 g glucose load and VPGC = 200 (mg/dL)]

then

Diabetes Mellitus (DM)

Else if [fasting and VPGC = 100 and < 126 (mg/dL)] AND
[2-hour post 75 g glucose load and VPGC < 140 (mg/dL)]

then
Impaired Glucose Tolerance (IGT)


Else if[fasting and VPGC < 126 (mg/dL)] AND
[2-hour post 75 g glucose load and VPGC = 140 and < 200 (mg/dL)]

then
Impaired Fasting Glycaemia (IFG)
```

Fig. 7. Diabetic MLM for Diagnosing diabetes

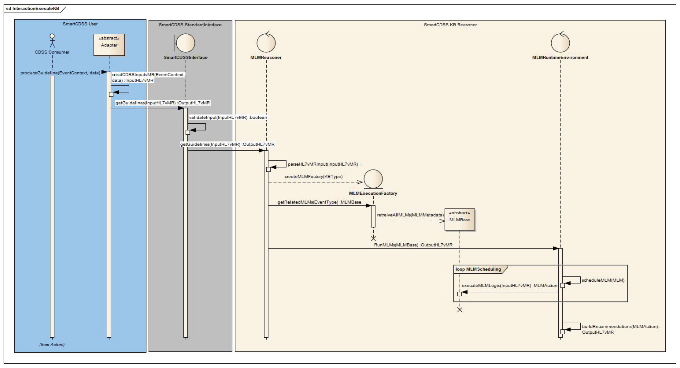

Fig. 8. Smart CDSS Recommendation Sequence Diagram

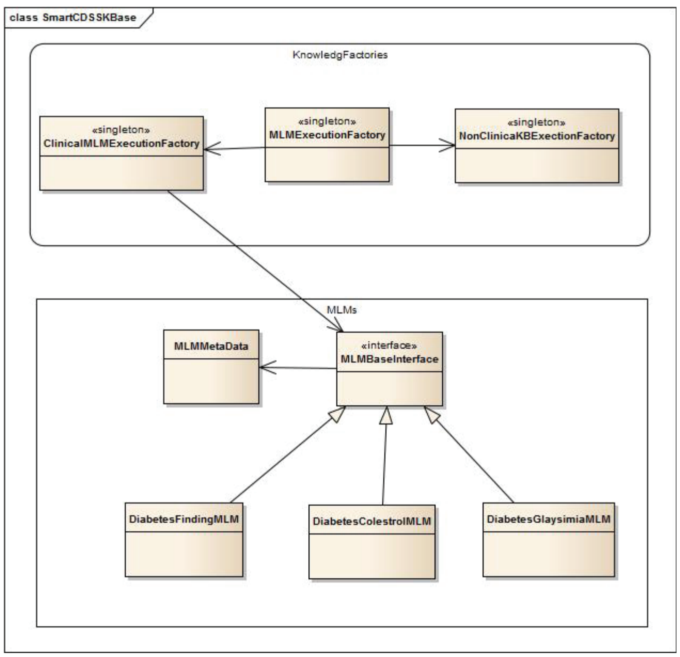

Fig. 9. Smart CDSS Knowledge Base Design

VI. Conclusion

In this paper, we have discussed the clinical decision support service - Smart CDSS to be deployed in smart home environment. The scope of Smart CDSS was discussed for diabetes in aged population. We have briefly explained the SC^3 architecture with corresponding modules. Detail analysis and design of Smart CDSS is presented and standard interfaces and knowledge base was explored with diabetes examples. Finally, we have discussed the implementation detail and possible results from initial trial of the Smart CDSS service for 100 patients data.

Future work includes providing authoring tools to clinicians that can enter rules directly using Arden Syntax. Based on run time rule publishing, the compiler will be build to compile MLMs at run time into C# classes.

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