An ontology-based healthcare monitoring system in the Internet of Things

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***Abstract*—Continuous health monitoring is a hopeful solution that can efficiently provide health-related services to elderly people suffering from chronic diseases. The emergence of the Internet of Things (IoT) technologies have led to their adoption in the development of new healthcare systems for efficient healthcare monitoring, diagnosis and treatment. This paper presents a healthcare-IoT based system where an ontology is proposed to provide semantic interoperability among heterogeneous devices and users in healthcare domain. Our work consists on integrating existing ontologies related to health, IoT domain and time, instantiating classes, and establishing reasoning rules. The model created has been validated by semantic querying. The results show the feasibility and efficiency of the proposed ontology and its capability to grow into a more understanding and specialized ontology for health monitoring and treatment.**

***Index Terms*—Healthcare, AmI, Ontology, reasoning, knowledge, IoT**

I. Introduction

Healthcare is one of the fastest growing business field and an important market for many countries. It is the most needed and the most consumed service in the word, especially for elderly people. Besides taking care of this population, healthcare systems should be improved in order to allow long-term management of health conditions, detection of emergency situations and diseases prevention for every citizen everywhere [1]. To reach the goals of offering better healthcare services and improving the living quality of elderly people, new healthcare systems should be designed using the Internet of Things (IoT) based technologies. These technologies enable heterogeneous devices and applications to interwork together to provide seamless and independent services [2]. IoT devices have limited computation and communication abilities. These devices can be connected to any daily life object to collect the required data. In the IoT-based healthcare system, devices should be portable and operate easily. They include various sensors attached to patients for collecting ambient and medical data in order to ensure health status monitoring. Sensing devices communicate with the server using the internet. The server is the most important element of a healthcare-based system. It includes the services, health-related data, and management and analysis functionalities allowing interaction with professionals (doctors, nurses) and patients.

In healthcare systems, IoT technologies enable the exchange of heterogeneous data between entities through communication protocols. The data include health and ambient sensing data, medical history, device information, and other user or health domain-specific data. Interactions between objects in IoT-based healthcare system need a specific data structure to generate high-level corresponding data. Therefore, these interactions require standardized structures to support interoperability between users and devices and devices and the server [3]. Semantic models are based on ontologies that are useful for concept modeling. They include concepts and relationships among the concepts. Ontologies provide a formal specification to present domain knowledge in such a way so that it facilitates its sharing between caregivers. A complete semantic model in IoT-based healthcare systems should include different terminologies related to health domain, sensors, and devices, user profile and time in order to generate high-level information defining the context of all objects constituting IoT-based environment.

In this paper, we present an IoT-based Healthcare system based on an ontology-based model. Our work adopts the integration of existing ontologies related to health, IoT domain and time and then their extension to create a model that ensure meaningful integration, data representation and sharing as well as the analysis of the detected parameters and the proposition of healthcare guidelines and treatment. Therefore, our paper will focus mainly on these two contributions: First, the generic architecture of an IoT-based healthcare system is proposed. Second, we make particular attention to describe the ontology-based model that allow the representation of heterogeneous sensor data captured and the reasoning model that analyze the modeled information to identify health conditions and generate appropriate treatment and recommendations.

The remainder of this paper is organized as follows: Section 2 presents background information in relation to the state of the art and discusses IoT-based architectures and applications in the healthcare domain. Section

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3, gives an overview of the proposed system in terms of components and functionalities. Section 4 details the ontology-based model which is followed by an introduction of our reasoning module in Section 5. Section 6 shows the proposed implementation of the system. Finally, the paper is finished with some concluding remarks and perspectives.

II. Background and Related Works:

This section illustrates background knowledge relevant to the research area. It presents the important ontologies and terminologies that have been introduced to describe health and Internet of Things related domains and details some architectures/platforms and applications in the healthcare field.

A. Ontologies in health domain

In past years, various encoding terminologies and ontologies related to medical concepts have been proposed. These ontologies provide complete and inclusive descriptions of the different medical domain. The most important ones are Systematized Nomenclature of Medicine—Clinical Terms (SNOMED CT) [4] and International Classification of Diseases (ICD)-10 [5]. SNOMED CT standard offers the most exhaustive terminology in the world and provides the most coverage of medical terms. This ontology provides a semantic classification of health-related terms that improve clinical recording of patient data and support effective care. The use of SNOMED-CT in healthcare system can facilitate data interchange and interoperability between users and systems. Different decision support systems DSS are adopted SNOMED CT in their architecture such as [6], [7]. International Classification of Diseases (ICD) is one of the terminologies that are mostly specialized for specific purposes. It presents the standard diagnostic for all general health problems issues. It mainly describes diseases and symptoms.

B. Ontologies in IoT domain

In recent years, semantic web technology has been used to represent Internet of Things domain. Different ontologies representing sensors and devices, their properties and the measured parameters have been proposed. Among we cite SSN ontology, SOSA ontology, and IoT-A. The W3C Semantic Sensor Network (SSN) ontology [8] is one of the most significant models used IoT related terms. It was developed to describe sensors, actuators, and observations, and related concepts. Sensor, Observation, Sample, and Actuator (SOSA) ontology [9] provides a lightweight core for SSN and aims at expanding the target audience and application areas that can take advantage of Semantic Web ontologies. The IoT-A ontology [10] is the extension of SSN ontology. It adds other concepts related to IoT such as services and objects to sensors devices concepts.

C. Ontologies for IoT-based Healthcare applications

An increasing number of research works have been conducted the use of semantic computing and IoT technology in healthcare and AAL domain. We have summarized the related works and inspected their limitations in this section. Chen et al. present in [11] a context-aware system that allows real-time sensing of user's context using wearable and medical devices in order to provide reliable antihypertensive drug recommendations that fulfill user's need for drug information. Another work in the same scope is presented in [12]. It introduced an intelligent system that monitors the activities performed by the patient. The system is based on an ontology that represents the available knowledge related to personal information (biometric data, fitness status, medical information)and the way he performs his activities (level of intensity, heart rate recommended for that activity). Hristoskova et al. proposed in [13] an ambient intelligent framework ensuring real-time monitoring of patient suffering from congestive heart failure (CHF). The framework allows the monitoring of patient's health status, alerting of physicians and detecting risk stage through using ontology-based context model and SWRL reasoning. In [14], a monitoring system based on the IoT sensors is proposed. This system defines a set of medical rules for setting up alarms when patient's health data such as blood pressure, lipid, and heartbeat is beyond the normal range.

As described above, there are so many researches about using ontology in IoT-based healthcare systems. However, almost the proposed systems using ontology-based modeling focus on data measurement analysis and decision making with little attention to describe devices, systems, and how measurements are taken and therefore interoperability between objects and measurement is still deficiently considered. Also In IoT-based healthcare, two classes of data are collected: medical data and ambient data, however, we remark that the majority of systems are interested in analysis and interpretation of medical data and neglected the environmental ones. Moreover, the developed system do not verify the proper functioning of IoT devices and the validity of the captured data which can lead to incorrect interpretation and diagnosis.

III. Overview of the proposed healthcare IoT-based system

The proposed system is designed to support the supervision and follow up of the patient with chronic diseases. It supports the continuous daily monitoring of their health conditions and their environment. It collects data from different devices (ambient and physiological sensors distributed in his environment and worn or implanted in his body) and then uses them to reflect his health status and provide appropriate recommendations. The system can also be used to prevent elderly people from the appearance of new related diseases and further complications by detecting risky situations.

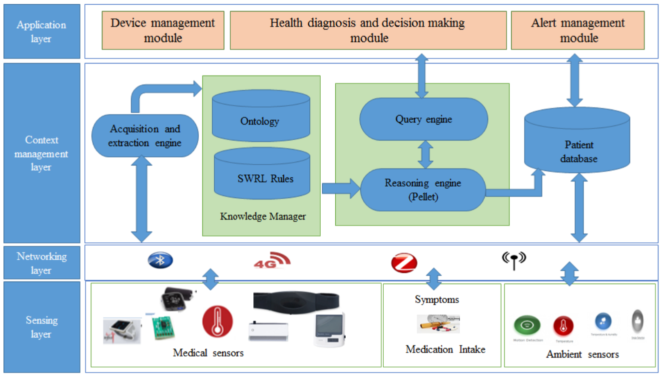

Fig. 1. Ontology-based healthcare system in IoT

Thus the basis of the designed system is to provide the appropriate health services for patient based on the collected data and a rich ontology that formalizes the collected data and the health-related knowledge. As can be seen from Figure 1, the architecture of the proposed IoT-based healthcare system comprises mainly four parts: From bottom to top, we distinguish the sensing layer which is the main data source that represents the context. It allows access to distributed platforms (Smartphone, Pc) and different sensors and devices (Temperature sensor, Pressure sensor, Glucometer, Heart beat sensor,Humidity sensor,...) to collect multiple types of personal information and data related to patient's health and his surroundings. The networking layer allows communication and data exchange between the sensing layer and the middleware. The middleware management layer is the backbone of the proposed architecture and it comprises:

- Acquisition and extraction engine: collects information from sensors and other data sources such as patient profile and extract features to send them to the knowledge manager. It also communicates appropriate information to actuators.
- Knowledge manager : comprises the ontology-based context model that formulates data representing user and environmental context and the related rule-based reasoning model.
- Query engine: handles queries received from the application layer.
- Reasoning Engine: checks the context consistency and deduces the high-level context from low-level context.
- Patient database: stores the low-level context collected from sensors and high-level context deduced from the reasoning engine. Data stored can serve for a historical summary.

The application layer presents the interfaces of our system that provide multiple kinds of healthcare services to the end users (doctors, patient, nurses, and family members).

IV. Ontology-based context model

In this section we will describe the whole concepts and their relationships that constitute our ontology-based context modeling approach. Context is defined as any information that can be gathered and used to infer and describe the situation of an entity that is relevant to the user and the application [15]. Contextual information can be static or dynamic. The static context consists of the unchangeable data that are provided by the user such as personal profile, user characteristics while the dynamic one represents data that change dynamically such as the data collected by sensors.

The proposed model allows the representation of static and dynamic context related to elderly patient and the environment where he exists. This contextual information is useful to ensure him a continuous and ubiquitous health monitoring. They should be taken into consideration when reasoning in order to provide the appropriate healthcare services. This model ameliorates and secures the patient's health and life.

Our Ontology is developed based on an ontology engineering methodology detailed in [16]. We start by acquisition of knowledge. We revise and adopt a number of evidence-based clinical guidelines available for health diagnosis, and management in order to define the domain knowledge. The major guidelines include the World Health Organization (WHO) and the Agency for Healthcare Research and Quality (AHRQ). The domain includes several different types of knowledge, such as knowledge about patients' context including physiological and behavioral context, knowledge about medication and etc. The next step consists on the revision of existing ontologies in order to provide a common understanding of this domain and reconcile heterogeneous knowledge sources. Our ontology was built by extending health-based standard such as SNOMED CT [4] and (ICD)-10 [5] with IoT based ontology such as SSN ontology [8] and SOSA [9]. We also added some concepts from Time ontology [17] which presents temporal concepts, for describing the temporal properties of resources in the world or described in Web pages. FOAF ontology [18]is also integrated into our model. This ontology includes all possible aspects of a general profile of a person, such as health history, gender, and height. we also added new concepts/properties to fit monitoring of the elderly patient in IoT environment. The designed ontology includes all these aspects which are presented in figure 2. The main concepts of this ontology are:

- **FOAF:Person**: saves information related to the user. Each user is associated with several properties such as *FamilyName*, *Age*, *Gender*, etc. In healthcare field, Person can be **Patient**, **Doctor** or **Nurse**.The property *HasLocation* links person to his environment which can be a home, a hospital or outside. **Patient** class is associated with multiple properties: *HasProfile* links a patient to his static profile represented by his interests, hobbies, historic diseases and his capabilities. *HasSymtom* is used to represent patient's symptoms, *UsePhysicalObject*, *HasHealthCondition* ,

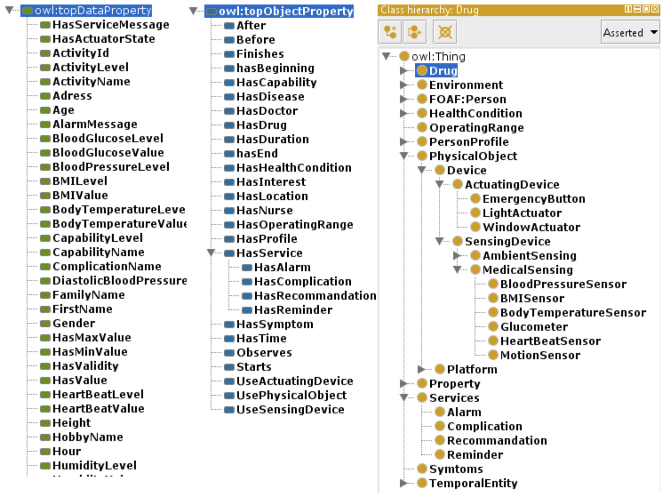

Fig. 2. Main classes, objects, data properties of the Healthcare IoT-based ontology

HasService link patient respectively to his physical Objects, his actual health condition and the services needed.

- **HealthCondition**: defines the patient health condition deduced based on the detected measurement. If the patient condition is healthy, the system informs the patient to maintain his health. If the patient condition is moderate, the system automatically recommends drug using decision-making rules and can also inform patient about complication that can occur. If patient condition is serious, the system sends alarms to medical staff and recommends different drugs.
- **ssn:PhysicalObject** concept represents all objects used to monitor Patient's health and his environment. It has **Platform** sub-class that refers to platforms used to receive recommendations and feedback such SmartPhone, and **Device** sub-class that presents all devices using by Patient in his smart home or nursing room. **Device** concept has two sub-classes: **sosa:SensingDevice** and **sosa:ActuatingDevice**. **sosa:SensingDevice** can be ambient used to detect ambient measurements such as temperature and humidity or medical used to measure vital signs such as Glucometer, Blood Pressure Sensor,BMI device and etc. **sosa:ActuatingDevice** refers to objects used to change a state in patient's environment such as Window Actuator, Smoke Alarm and Emergency Button. The property **sosa:observes** links **sosa:SensingDevice** to his observations. The property **ssn:forProperty** defines the actuations made by **sosa:ActuatingDevice**.
- **ssn:Property** has two sub-classes: **ObservableProperty** class represents the data captured from the connected sensing devices. This class has two sub-classes **MedicalProperty** that defines medical parameters such blood pressure and blood glucose etc, and **AmbientProperty** that represent ambient information such as temperature and humidity. **ActuatableProperty class** represents actuations done by actuators such Open/CloseWindow and TurnOn/OffLight. **HasTime** property is used to define the time at wihich observable Properties are detected.
- **OperatingRange** class defines the predefined ranges of the observable properties.
- **Service** determines the services provided by our system according to the health condition of patient. It has four sub-class of services. **Reminder**, **Recommandation**, **Alarm** and **Complication**.
- **Drug**: describes the drug that should be taken by patient. Drug can be insulin or oral medication such as metformin, Sufonylureas, Diuretics, etc.
- **time:TemporalEntity** class details the time in which observations are taken or Actuations are applied. it can be **Instant**, **Interval** or **duration**.

V. Rule-based reasoning

The reasoning is performed using the predefined ontology and a rule-based knowledge base. The proposed rules are written based on clinical guidelines and a set of efficient prescriptions offred by several medical professionals. Rules are triggered every context data update in order to infer further information for the care situation. They are used firstly to verify the availability of medical and ambient devices and the validity of the collected data and then in the diagnostic and decision making : Sensor data often contain inconsistencies and errors due to diverse internal and external factors such as hardware failure and environmental factors and so on. That is why, verifying the validity of data collected is very crucial as it allows providing reliable health services and improving the quality of patient's monitoring. Each measured data is characterized by a data range defining the threshold that must not be exceeded. The next rule is used to verify the validity of each observable data.

Rule 1: SensingDevice(?s) ˆ ObservableProperty(?o) ˆ Observes(?s, ?o) ˆ OperatingRange(?r) ˆ HasOperatingRange(?s, ?r) ˆ HasValue(?o, ?v) ˆ HasMaxValue(?r, ?maxv) ˆ HasMinValue(?r, ?minv) ˆ swrlb:greaterThanOrEqual(?v, ?minv) ˆ swrlb:lessThanOrEqual(?v, ?maxv) -> HasValidity(?o, true)

After verifying the validity of the collected data, next step consist on its analysis in order to deduce the status of patient's health or his environment. Several SWRL rules are proposed. Ones rules are proposed to define the actual situation of the monitored patient through vital signs observations by generating feedbacks, deduce the risk situation if the observations exceed the normal range and trigger the appropriate health services. Some typical vital signs and their normal range according to the medical rules are presented in table V .

TABLE I
NORMAL RANGE OF SOME VITAL SIGNS MEASUREMENTS

vital signal	normal range
Blood Glucose	70 mg/dl to 140 mg/dl
Blood Pressure	Systolic: 90–120mmHg Diastolic: 60–80 mmHg
Heart beat	50–100 beats per minute
BMI (Body Mass Index)	18.5 to 24.9
Temperature	36.1–37.9 C°

According to rule 2, if the blood pressure detected by the blood pressure sensor has systolic value upper than 140mmHg and diastolic value upper than 90mmHg than the patient has High blood pressure.
Rule 2: Patient(?p) ˆ BloodPressureSensor(?x) ˆ UseSensingDevice(?p, ?x) ˆ BloodPressure(?b) ˆ Observes(?x, ?b) ˆ HasValidity(?b, true) ˆ DiastolicBloodPressureValue(?b, ?d) ˆ SystolicBloodPressureValue(?b, ?s) ˆ swrlb:greaterThan(?d, 86) ˆ swrlb:lessThanOrEqual(?d, 90) ˆ swrlb:greaterThan(?s, 131) ˆ swrlb:lessThanOrEqual(?s, 139) -> BloodPressureLevel(?p, "High Blood Pressure")
Rule 3 verify the level of blood glucose if the value detected by the glucometer is between 140 and 180 mg/dL.
Rule 3: Patient(?p) ˆ Glucometer(?x) ˆ UseSensingDevice(?p, ?x) ˆ BloodGlucose(?b) ˆ Observes(?x, ?b) ˆ HasValidity(?b, true) ˆ HasValue(?b, ?v) ˆ swrlb:greaterThan(?v, 140) ˆ swrlb:lessThanOrEqual(?v, 180) -> BloodGlucoseLevel(?p, "Elevated Blood glucose")

Rule 4 allows the generation of emergency services, the actuation of an emergency button and the deduction of the appropriate drug which is 'Diuretics' if the level of blood pressure is high. Services include the generation of an alarm to call the doctor and the deduction of the complication that can occur which is Heart attack.

Rule 4: Patient(?p) ˆ BloodPressureLevel(?p, "High Blood Pressure") ˆ Alarm(?a) ˆComplication(?c) ˆEmergencyButton(?e) ˆUseActuatingDevice(?p,?e)-> HasAlarm(?p,?a) ˆ HasServiceMessage(?a, "You are in danger, Call a doctor") ˆ HasActuatorState(?e,"On") ˆHasComplication(?p,?c) ˆHasServiceMessage(?c," Heart attack ")ˆ HasDrug(?p, Diuretics)

Our reasoning model can also generate reminders such as medication reminder that indicate to the patient that is time to take his prescribed medication. Rule 5 is one example .
Rule 5: Patient(?p) ˆHasDrug(?p,Diuretics)ˆ HasTime(?m,?t)ˆ HasDuration(?t,?d)ˆHour(?d,12)ˆReminder(?r)->HasService(?p,?r)ˆHasServiceMessage(?r,"It is time to take your Diuretics drug")

VI. Prototype Implementation and evaluation

The proposed system aims to provide chronic-care elderly with personal home care services, in order to reduce the demand for caregivers, to lessen the time, money, and resources dedicated for care. Based on its functionalities, the proposed system is organized in three module: Data analysis and decision-making module which allow interpretation of collected data and generation of feedback and treatment, device management module which allow real-time monitoring of device attached to the patient, and alert management module that responsible for notifying caregivers when an emergency occurs. Our implementation focuses only on data analysis and decision-making module. The two other modules are out of the scope of this implementation.
In our work, we developed the Acquisition and extraction engine, Knowledge manager, the query engine, the Reasoning Engine, the database, and the user application. Acquisition and extraction engine collects various sensing data such as Blood Pressure, Blood Glucose, BMI, humidity, Ambient Temperature and so on, as well as patient profile and lifestyle data, stores them in MySQL database and extracts features to send them to the Knowledge manager. Knowledge manager comprises knowledge ontology database that is implemented using Protégé and a set of SWRL rules that are used for the classification of patient health parameters. The reasoning is performed by Pellet reasoner based on the knowledge manager and features extracted. The query engine is based on SPARQL query which is a semantic query language that is able to retrieve and manipulate data stored in RDF format. The Reasoning engine is based on JENA API which is an open semantic web java framework that supports ontology language. This API is used in our system to extract the data of the user's context and compiles the RDF graph in order to generate a high-level context based on the developed rules. Results generated after reasoning are also stored in our database for further use. User Application is developed using J2EE language, EJB, JSF, and Primefaces frameworks.
The web application is intended for caregivers and patients that should first be identified. Healthcare caregivers can visualize the list of authorized patients and edit their profile, physiological and ambient parameters, create patient, add devices and examinations test, and consult alerts. The system allows patient monitoring their health conditions by querying for sensors data and send them to the server in order to receive real-time feedback and recommendations. Figure 3 illustrates the interface allowing the patient to follow up his health status. The system enables also patient to visualize historical data in order to understand his health as shown in figure 4.

VII. Conclusion and perspective

In this paper, an IoT-based Healthcare system is proposed for continuous monitoring of chronically ill elderly.

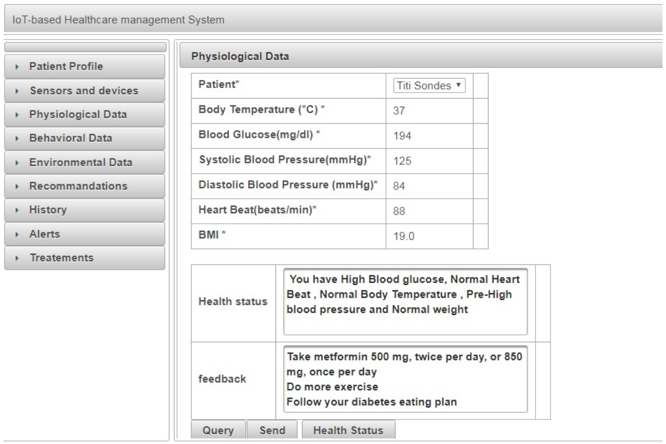

Fig. 3. Physiological measurements monitoring interface

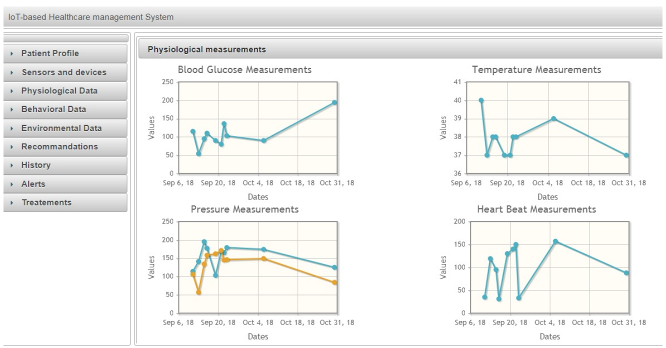

Fig. 4. User interface showing the historical summary of vital signs measurement

In this system, an ontology-based context model has been developed for modeling health and environmental data. The ontology is constructed by reusing multiple ontologies relevant to IoT and Health domain. This work has also focused on rule-based reasoning based on SWRL language in order to infer the health status of the patient and detect the emergency situations. As a continuation of this work, we are aiming to develop the complete other modules constituting the system. We will also continue to work on some benchmark that can help us evaluate the performance of our system and make a comparative study with other works in this area.

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