POSTECH's U-Health Smart Home For Elderly Monitoring and Support

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***Abstract*—With the increase of the aging society worldwide, hospitals, medical practitioners and health insurers are now increasingly seeking ways to reduce the cost of healthcare while maitaining its quality. One solution subject to attention from gouvernement and healthcare providers is the U-Health Smart Home that aims to provide non-intrusive and non-invasive monitoring and assistance to the elderly directly in their own home. At POSTECH, the U-Health Smart Home project is focused on building a smart home along with an autonomic system to monitor the home as well as the inhabitants to provide intelligent support and assistance in any situation at anytime. This paper presents our initial results from this project. The first contribution is a general framework for the U-Health smart home and the second one is an initial semantic model that can be used in the autonomic system to provide autonomic support to the elderly.**

Keywords-U-health smart home architecture; ontology, semantic web; reasoning

I. INTRODUCTION

The smart home concept was first introduced in the early 1980s as an intelligent building. At that time, the smart home was only designed for user convenience. This meant that the smart home contained several different devices to analyze the current status of the home environment. However, it became very difficult to manage these devices efficiently because each device uses different protocols and data models. A separate, but related concern is developing the role of the computer to help improve one's quality of life.

In the last decades, the elderly population has increased significantly and healthcare providers are predicting a possible collapse of the existing healthcare system if no significant actions are taken to develop more cost-effective solutions. A key challenge is to reduce costs with little or no degradation in the quality of service provided to patients. Fortunately, the U-Health Smart home has been identified by many governments as one feasible solution to reduce the cost of healthcare for the elderly, by keeping them in their own home and providing them with "intelligent" technologies to assist them as needed.

In this paper, we present some advances that have been achieved at POSTECH (Korea) in building a Smart Home and deploying hardware and software solutions to assist the elderly in their home. The software solution aims at specifying architectures to monitor the elderly using wireless sensor technologies and to control the appliances and other components in smart home components as needed.

One aspect that is central to this architecture is the knowledge-based (KB) concept. KB aims at capturing the concepts in a U-Health Smart home that are necessary to develop an autonomic solution to support the elderly. The KB architecture uses semantic web technology to define the meaning of information that is necessary to identify the appropriate action to perform in the U-Health Smart home depending on the user's situation and the context.

The aims of the Knowledge Based system are two-fold:

1. First, to capture the semantic of all information related to the state of the smart home and the status of elderly residents such as localization and elderly health parameters.
2. Second, to develop an autonomic decision-making system that can use this semantic model to reason about the situation of the elderly and take the appropriate actions.

These are the motivations behind the specification of an autonomic system to control and assist the elderly inside their home.

The structure of this paper is as follows. Section II introduces state-of-the-art smart home projects and related work. The following section introduces the U-Health Smart Home initiative at POSTECH and its motivations and challenges. In this section, the ontology model, SHOM, is introduced along with the creation principle and the use of CIM features and reasoning behind SHOM. In Section IV, we focus on the autonomic system part of the project and on the knowledge-base definition. The development environment and use cases of the autonomic decision-making system are also

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described. Finally, in Section V, the conclusions and some perspectives for future work are presented.

II. LITERATURE REVIEW

This section outlines a few recently reported projects related to the construction of a smart home to support the elderly (and other residents) in their daily life. The AILISA Project [1] is a French initiative that promotes an experimental platform to evaluate technologies for remote monitoring and assistance to elderly persons at home. It aims to set up interdisciplinary platforms for the evaluation of these technologies at three levels - technical, medical and ethical. So far, the AILISA system focuses more on the human assistance and not on a computer based system. The objective of the project in [2] is to develop a telemedicine information monitoring system. This project is more focused on the integration of a variety of wireless vital sign monitoring technologies using an OSGi healthcare gateway. The project suggests an efficient way to merge and manage this variable information. However, it does not provide any autonomic decision flow. The UbiSense Project [3] aims to develop an unobtrusive health monitoring system for elderly persons. It differs from existing approaches by using embedded smart vision techniques to detect changes in posture, gait and related activities, and aims to capture signs of deterioration of the patients by analyzing subtle changes in posture and gait. To analyze the activities of a user or a subject, it uses subject-specific information, called personal metrics. This project also concentrates on monitoring, and does not provide any autonomic functionality.

III. AUTONOMIC SYSTEM FOR U-HEALTH SMART HOME AT POSTECH

Autonomic Computing [4] is an initiative started by IBM in 2001. Its ultimate aim is to develop computer systems capable of self-management to overcome the rapidly growing complexity of computing systems management, and to reduce the barrier that complexity poses to further growth. In other words, autonomic computing refers to the self-managing characteristics of distributed computing resources, adapting to unpredictable changes while hiding intrinsic complexity to operators and users. An autonomic system makes decisions on its own, using high-level policies. In the context of the smart home for U-Health, autonomic computing technology has an important role as it aims to monitor the elderly continuously in any part of the home and provide to healthcare specialists accurate data about their behavior and health state. Hence, elderly will not have to visit the Healthcare specialist as often as they use to do while they could be contacted in emergency cases if the system detects any serious anomaly. It is worthy to notice that the aim of the autonomic system is not to replace medical practitioners, but rather to perform some time intensive tasks to help the elderly in their daily activities and providing them with a continuous care they can only have in dedicated expensive structures.

To be efficient, an autonomic system needs to collect all the information relevant to the situation of the elderly at home. All these information allow the system to build what is called context information that is required to understand what is happening in the smart home and react accordingly. The system needs also to have some control over these entities through actuators (e.g. on/off of home appliances), or in the near future, some medical actuators connected to the body of the elderly person to provide some drugs (e.g. insulin for diabetics). We have identified several layers of the global U-Health Autonomic framework as depicted in Fig. 1. The different layers highlight the functional requirements to setup the U-Health smart home solution. At the lower level of the framework, we find all the hardware components that are needed to monitor and control various entities in the smart home such as wearable devices on the elderly, home appliance or home objects, via sensing and actuating mechanisms. An actuator is the component or mechanism that can control devices such as lights, opening or closing of windows, or starting and stopping an oven. Sensors are devices that can be installed anywhere in the smart home to collect environmental information such as temperature, humidity or lighting condition. Body sensors can be carried on the elderly to monitor their health status, e.g. ECG, pulse rate, SpO2, etc.

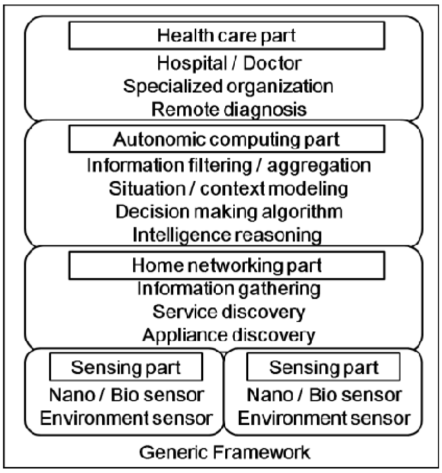

Figure 1. U-Health smart home Framework

All these sensors and actuators are connected to a device with wireless communication capabilities that are able to form a Wireless Sensor Network (WSN). The WSN consists of many heterogeneous sensors, possibly organized as separate networks that can communicate with each other to collect information and send them to a “fusion” node that is connected to the home network. Devices on the body of elderly can form what is called a Wireless Body Area Network (WBAN). And appliances in the home can also be equipped with wireless communication capabilities to form a Wireless Area Network (WAN) using any wireless technology such as 802.11, Bluetooth or ZigBee.

The information gathered by the sensors are then sent through wireless and/or wired links to the computer that runs the autonomic system. Information is filtered and directly aggregated along the path by the autonomic system, and then transformed into knowledge that is injected in the Knowledge Base (KB). The autonomic system can therefore use the KB to reason about the situation in the smart home and the elderly, and then decide if any action is required to fulfill the fixed objectives. The U-Health smart home is controlled by a health provider such as a hospital or doctor, who defines the objectives of the system and also information collected in any situation that could not be handled by the smart home itself such as emergency situations requiring a doctor to assist the elderly.

In Fig. 2, we present a photo of the smart home that has been built at POSTECH for the purposes of the project. This smart home is equipped with several types of sensors, actuators, and wired and wireless systems to test functionality and assess practical issues related to the smart home.

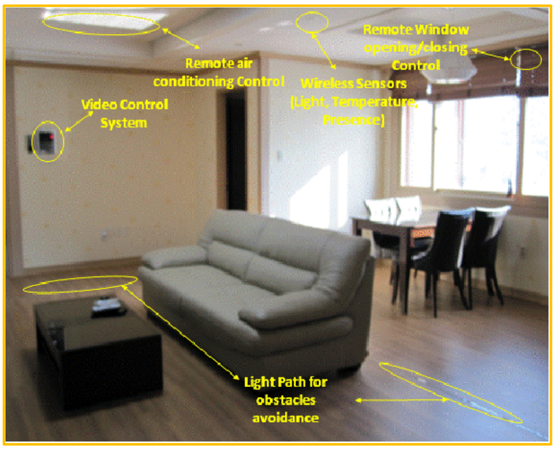

Figure 2. POSTECH Demo Smart Home

We have deployed two types of sensors at depicted in Fig. 3: Environmental wireless sensors from HyBus [19] and ECG monitoring medical sensor from Uheart [20]. The ECG sensor is composed of two parts, the sensor part that is installed on the elderly body in the heart region and a receiving base that is connected to a Hybus Wireless sensor via a USB connection. The sensor part contineouly senses the heart beats and sends an ECG signal to the base part using RF. Along with sensors, remote controllable appliances and LEDs have also been deployed. LED paths from the sleeping room to bathroom and the kitchen have been installed on the floor to help elderly to find safely their direction during the night avoid any contact with furniture and walls which may cause them injuries in case of falls. These are automatically switched on when the smart detect that the elderly has moved out his bed.

Figure 3. Uheart ECG sensor and Hybus Wireless Sensor Base

IV. KNOWLEDGE BASE AND SEMANTIC REASONING

The knowledge base is at the heart of the decision-making system in the U-Health Smart Home. The role of the knowledge base is to model all the concepts related to the U-Health Smart Home and the relationship between them. The semantic of the concepts as well as their relation should be defined in a precise way. Without a complete and semantically rich knowledge base, it is difficult for any system to perform activities that replace humans. The starting point of this work is the DMTF Common Information Model (CIM) [5]. It is a standard that defines how managed elements in an information technology (IT) environment are represented as a common set of objects and relationships between them. CIM provides a common definition of management information for systems, networks, applications and services, and allows vendor extensions. The motivation in using CIM is that it is widely used in the industry and is available for free. However, CIM has many limitations. For example, CIM does not have any semantic that could help a system to reason. For that, we first need to transform the CIM model into an equivalent semantic model while trying to manually incorporate the semantic in the subsequent model. In order to achieve this, we decided to use ontology to define an equivalent semantic model.

Ontology is a widely accepted concept for the modeling of information. In computer science, ontology is a formal representation of a set of concepts within a domain and the relationships between those concepts [7]. It is used to reason about the properties of the domain, and may be used to define the domain. The representational primitives are classes, attributes, and relationships, while the definitions of the representational primitives include information about their meaning and constraints on their logically consistent application. The Web Ontology Language (OWL) is an ontology language specified by the W3C RDF and XML to represent information in a manner suitable for processing by computers [8,9]. OWL ontology may include descriptions of classes, properties and their instances. Given such ontology, the OWL formal semantics specify how to derive its logical consequences, i.e., facts not literally present in the ontology, but entailed by the semantics. This represents the main motivation of using it in this project. Hence, OWL provides three increasingly expressive sub-languages designed for use, OWL-Lite, OWL-DL and OWL-Full. In our work, we use OWL-DL as it provided the necessary properties for reasoning.

In the following sub section, we highlight the CIM and the rationale behind the selection of the set of classes. The following sub section presents the SHOM ontology model we propose as a foundation for the Knowledge Base of our project.

A. *Using CIM Classes and Relations*

CIM introduces several models and several classes in each model [5]. The first task was to identify the set of classes which are useful for our solution.

CIM_Core: The Core model establishes a basic classification of the elements and associations of the managed environment and the class hierarchy begins with the abstract ManagedElement class. Our model expands in several directions, addressing many problem domains and relationships between managed entities. Note, however, that we are not using all of the classes and relationships that are defined in the Core model. For example, we are not using the eight recursive associations defined in this class. This is because these classes and relationships are either not relevant for our model, or because they introduce semantic ambiguities. Following the CIM_Core document,

CIM_Device: The CIM_Device model describes the functionality provided by hardware, as well as providing configuration and state data. The components which are represented in a CIM_Device typically describe a hardware specification. However, there are several concepts related to CIM_LogicalDevice, which is an abstraction of a hardware entity that is logical by nature, such as paper sizes supported by a Printer. This is captured in the CIM model by a relationship that enables the Physical Element to "realize" the LogicalDevice. Especially, we used the CIM hierarchy of the Sensor and Alarm. To use the Sensor class, the hierarchy is: Thing – ManagedElement–ManagedSystemElement– LogicalElement –EnabledLogicalElement – LogicalDevice – Sensor. The Sensor class is under the LogicalDevice class, which means the Sensor class will be realized by some physical sensor because of the realization relationship described above. We divide the sensors into two types: BodySensor and EnvironmentSensor. The BodySensor generates user health information, and the EnvironmentSensor generates the information about the smart home context like fire, light, motion, temperature, etc. So, in our model, several classes, which are pairs of PhysicalElement and LogicalDevice, are created.

CIM_System: The CIM_System defines computer-system related abstractions. Many of the concepts related to a computer system derive from the CIM_System abstraction in the Core model.

CIM_User: The focus of the CIM_User/Security model includes (1) general contact and white pages information for organizations, organizational units and people, (2) services "users", and (3) the related security information to authenticate and authorize a "user". So, we create a SmartHomeUser class which is under the User Entity class. UserEntity class is an abstract class that represents users – their names, contact data and similar information. We do not want to change any information about existing classes in CIM, so we create more meaningful classes about users. The added class hierarchy is that UserEntity – SmartHomeUser – MonitoredUser and UnMonitoredUser. MonitoredUser means a user that uses a body sensor for monitoring to prevent accidents or to provide convenient service. With respect to the security issue, we do not want to use this model because the special component in distributed framework of smart homes can provide faster and more robust security level.

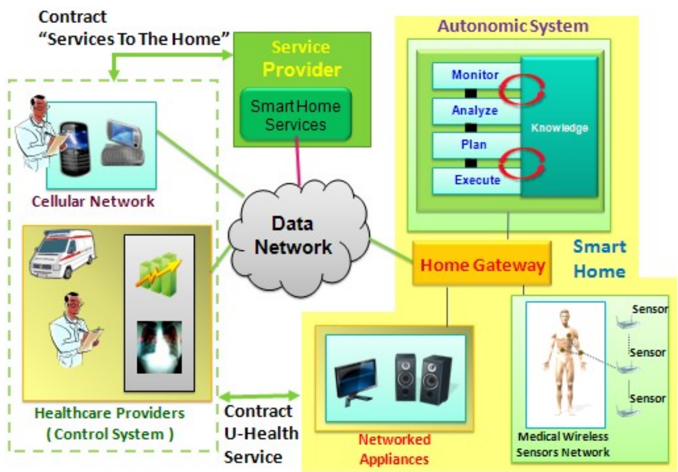

Figure 4. General system architecture

PhysicalElement class: Subclasses of CIM_PhysicalElement define any component of a System that has a distinct physical identity. Under the PhysicalElement class, PhysicalComponent, PhysicalConnector, PhysicalLink, PhysicalPackage classes are defined in CIM, enabling us to represent all physical elements in a smart home. For this reason, we create Room and Apartment classes to answer questions such as - where is the smart home user. The positions of the Apartment class and SmartHome class (which is subclass of Apartment class) are under the PhysicalElment class and the isBelongTo relation is created between the SmartHome class and POSTECHSmartHome class, which is a subclass of Organization. This means that the SmartHome belongs to POSTECH. POSTECHSmartHome class does not indicate an actual home; rather, it is a conceptual class. It is possible to build many smart homes in POSTECH. For the previous example question, the locality of devices is defined in our model. We created PhysicalSensor and PhysicalAppliance under the PhysicalElement, and also LogicalAppliance under the LogicalDevice to make a pairing between PhysicalElement and LogicalDevice. In the case of Sensor, the Sensor class under the LogicalDevice is already defined in the CIM model. PhysicalSensor has two subclasses, which are BodySensor and EnvironmentSensor.

UserActivityState class: The state of the smart home user can be associated with a main activity in the smart home, such as watching TV or sleeping in the bedroom. The smart home management system needs to define the semantics of each user activity for making appropriate autonomic decisions. In our model, there are several classes that can be used to define user activity and behavior. These classes are used in conjunction with reasoning rules to determine one or more appropriate actions to take in certain situations. For example, if the smart home user is in a sleeping state and in the bedroom, then the light that is in the living room and the bathroom do not need to be turned on except in special situations. And OtherActivityState can be used to extend the UserActivityState to express more user activities in the Smart home.

Attributes: Every new class has its own attributes to describe details about the class and/or managing objects created from the class. For example, a smart home user has two different types of states, which are the activity and health states. The activity state is defined as a class, but the health state is defined as a set of attributes, because the health state of the user is classified as one of Critical, Warning, and Normal, and every user is defined to be in one of these three states. Thus, it should be defined as an enumerated attribute, not a separate class, since every smart home user has this state.

Relationships: In the case of new classes, new relationships between new classes and new or existing classes may need to be created. The relationships are important to properly represent how different entities in the smart home work together to model a user or a situation that occurred in a smart home.

B. *SHOM: Smart Home Ontology Model*

The proposed semantic model to build the Knowledge Base that is mandatory to perform autonomic decision-making in the U-Health Smart home is called Smart Home Ontology Model

(SHOM). As previously mentioned, several parts of SHOM are introduced as an example of a generic approach to build a semantic model. The SHOM model has 103 classes and 73 relationships. Two of the main strengths of the SHOM are its scalability and flexibility. If a required concept is related to a CIM concept that is associated with a component in an IT environment, then it is possible to create unused classes and relations that are defined in the CIM model. Alternatively, if a required concept is a new concept, then there are many different classes in the SHOM model that can serve as a superclass to this new class. For example, the UserActivityState class has a class called OtherActivityState for scalability.

1) Converting CIM classes and relationships into the OWL SHOM model

There are several efforts to convert the CIM model into an ontology model, that is, to translate CIM into OWL [10, 11,12]. In [12], the authors highlight the difficulties in translating CIM to OWL and why different approaches could be implemented. Despite any standard solution to this translation, the authors of [12] present a table-based solution for this mapping which has been useful in our work. Although we use their solution, it was nevertheless necessary to overcome several limitations. Readers can refer to [10,11,12] to obtain more details about the transformations.

2) OWL properties characteristics in Protégé

To create the SHOM model, we have used the Protégé 3.4.1 and 4.0 tools. In Protégé, OWL properties represent relationships between two individuals. There are two main types of properties, Object properties and Datatype properties. Object properties link an individual to an individual. Datatype properties link an individual to an XML Schema Datatype value or an RDF literal. OWL has also a third type of property called – Annotation properties. Annotation properties can be used to add information to classes, individuals and object/datatype properties to useful information such as labels, comments, creation date, author, or references. In the case of object properties, there are four characteristics; Inverse, Functional, Transitive, Symmetric properties. Reasoning

Reasoning is responsible for checking for inconsistencies and implied relationships in the ontology, and testing and checking the rules to understand the context. There are two kinds of approaches - ontology reasoning and user-defined role-based reasoning. Ontology reasoning is used to check the ontology itself, such as looking for inconsistencies between classes and relations. User-defined role-based reasoning is based on first order logic, and computes the inferred reason using user-defined roles. We used both approaches. For ontology reasoning, we used functionalities of the Protégé tool. In Protégé, we can easily check class inconsistencies by selecting an appropriate reasoner. So, we used user-defined roles using SWRL (Semantic Web Rule Language) to take advantage of inference.

3) Ontology reasoning

Ontology reasoning uses transitive, inverse, symmetric, subclassof, subPropertyOf, disjointwith, and other properties or axioms to reason about the consistency of the ontology. For example, the relation Realize in the SHOM model is an inverse property between PhysicalElements and LogicalDevice. If there is some physical element, such as a physical sensor, then the physical sensor must realize the logical sensor. A logical sensor is realized by a physical sensor. In case of usage of subclassof, because the physical sensor and physical appliance are subclasses of PhysicalElements, those also have a Realize relation.

4) User-defined role-based reasoning

For example, consider the two very simple, and probably not too realistic, rules which are defined just for the experimentation or illustration.

If the elderly is on his bed and the TV is off and the light is off, then the elderly person is sleeping. If the elderly person is sleeping then set the temperature in the room to 23 degrees Celsius.

A corresponding SWRL formal specification is now provided.

SmartHomeUser(?x) ∧ isInRoom(?x, bedroom) ∧ hasApplianceState(tv_bedroom, false) ∧ hasApplianceState(light_bedroom, false) → hasUserActivityState(?x, sleeping)
hasUserActivityState(?x, sleeping) ∧ TemperatureSensor(?y) → changeTheValue(?y, 27)

The first part of this SWRL specification defines rules for reasoning, while the second part defines appropriate actions to take. For example, hasUserActivityState(?x, sleeping) means user X is presumed to be sleeping. In this project, information about user behavior is obtained from the system.

V. EXPERIMENTATION AND USE CASES

A. Tesbed Implementation

The CIM model, which version is cim_schema_2.23.0_final, is used as a foundation of our ontology model. However, only parts of the CIM are useful for our ontology. Those parts are the CIM_Core, CIM_Device, and CIM_System. To make an ontology model, we used the open source tools - OWL language and Protégé [13], to create and edit the ontology. The OWL API [14] is a java interface and implementation for the World Wide Web Consortium OWL. This API, version 2.2.0, was used to communicate between the ontology and the decision making system, and manipulate the ontology according to the information collected from the network. For reasoning, the Pellet API [15], version 2.0.0, was used. Pellet is an OWL 2 reasoner and provides standard and cutting-edge reasoning services for OWL ontologies. To use these API, Eclipse SDK, version 3.5.1, and JAVA version - JAVA SE Runtime Environment 1.6.0_17 were used.

For the first attempts, Protégé 4.0 was used as a tool to create ontology for OWL 2. However, to test the SWRL rule, Protégé 3.4.2 is also used (Protégé 4.0 does not provide as easy way to use the SWRL). The current version of SHOM is made by Protégé 3.4.2 using OWL 1.

B. Use Cases

To explain the use of the SHOM model on the autonomic decision system, we present several use cases scenarios. There are two kinds of use cases. The first is to provide convenience for elderly persons, and the second use case is to detect any health problems and then take proactive action.

1) Use Case 1. Smart Home Energy Management

Most elderly persons spend a lot of time home alone. Sometimes, they leave their home. At that time, they may forget something - turning off the lights or the gas cooker, locking the door etc. In these cases, the decision-making system in our project knows that the elderly person goes out and the smart home is empty. According to defined rules, our decision-making system will automatically turn off the TV or light for energy reduction, turn off the gas cooker for safety, and lock the door for security. In addition, environment-, body- and other bio- sensors [17, 18] do not need to send information to the system, so they change their mode to sleep mode to reduce their energy consumption, except the motion detecting sensors for security.

2) Use Case 2. Elderly Health Monitoring

This use case represents one of the most important situations for elderly persons. In the smart home, an elderly person must use body sensors to monitor their health status. In particular, an ECG sensor can detect serious problems such as danger of an imminent heart attack. This use case is for this example or other emergency situations. If the system detects dangerous signals generated by the ECG sensor, then it checks whether the elderly person is currently using that sensor or not. If the answer is yes, then it changes the status to emergency and makes an emergency call. If not, for example, the elderly takes the sensor off, and then it changes the status to warning until the system receives enough information from other sensors to verify the status of the elderly person.

VI. CONCLUSION AND FUTURE WORK

In this paper, we reviewed the goals of our research [18]. We highlighted the open problems for the research community in U-Health and we described related work on smart home projects, autonomic systems and semantic web technologies.

Then, we introduced the proposed general architecture and autonomic decision making system for the U-Health smart home. The requirements for the U-health smart home system were discussed and the SHOM model for the smart home at POSTECH described. The principles used to create the SHOM and the reasoning of SHOM and the usage of CIM features were presented. We also showed the development environment and presented examples of use cases and implementation.

Although SHOM was defined, it can be enhanced in different ways such as making the model and reasoning components more complete, or for the reasoning part to support more intelligent decisions and actions. To enhance the model and system, testing will be performed in the POSTECH Smart Home. This will allow us to better understand and predict the user behavior at home and to test the possible medical care services. Using these tests, the autonomic system will learn about the user's behavior, and the SHOM model will be made more suitable.

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REFERENCES

[1] Norbert Noury, Pierre Rumeau, "Ambient Multi-Perceptive System for Residential Health Monitoring Based on Electromic Mailings", HEALTHCOM 2006, 17-19 August 2006, pp. 95-100

[2] Chih-Jen Hsu, Chiou Yii-Tay, Chang Cheng-Lii, Hwang Jlng-Huei, Jone-Chiung, "Telemedicine Information Monitoring System", HEALTHCOM 2008, 2008

[3] UbiSense project, http://www.doc.ic.ac.uk/vip/ubisense/home/home.html

[4] IBM Corporation, "An architectural blueprint for autonomic computing", April 2005, http://www.ginkgo-networks.com/IMG/pdf/AC_Blueprint_White_Paper_V7.pdf

[5] Common Information Model Standard, http://www.dmtf.org/standards/cim/

[6] P.Horn, "Autonomic Computing: IBM`s Perspective on the State of Information Technology", IBM Corp., October 2001, http://www.research.ibm.com/autonomic/research/papers/AC_Vision_Computer_Jan_2003.pdf

[7] John Strassner, "Knowledge engineering using ontologies", Handbook of Network and System Administration, chapter 3, section 4, pages 425-457

[8] OWL Web Ontology Language Overview, http://www.w3.org/TR/owl-features/

[9] Berners-Lee, T., Hendler, J. and Lassila, O., "The Semantic Web", Scientific American, May 2001

[10] Daniela Berardi, Diego Calvanese, Giuseppe De Giacomo, Giuseppe Santucci, Antonio Perrone, Guido Vetere, "Using the CIM Conceptualization in Autonomic System Management the System Management Ontology Project", DSOM 2003, Heidelberg, Germany, October 20-22

[11] Dennis Heimbigner, "DMTF – CIM to OWL: A Case Study in Ontology Conversion", SEKE2004, Canada, 2004, pp.470-474

[12] Marta Magewska, Bartosz Kryza, Jacek Kitowski, "Translation of Common Information Model to Web Ontology Language", Lecture Notes in Computer Science, Volum 4487, 2007, pp.414-417

[13] SWRL: A Semantic Web Rule Language Combining OWL and RuleML, http://www.w3.org/Submission/SWRL/

[14] Protégé, http://protege.stanford.edu/.

[15] OWL API, http://owlapi.sourceforge.net/

[16] Pellet: OWL 2 Reasoner for Java, http://clarkparsia.com/pellet

[17] M. Waleed Shinwari, M. Jamal Deen and Dolf Landheer, "Study of the Electrolyte-Insulator-Semiconductor Field-Effect Transistor (EISFET) with Applications in Biosensor Design", Microelectronics Reliability, Vol. 47(12), pp. 2025-2057 (December 2007).

[18] M. Waleed Shinwari, David Zhitomirsky, Imran A. Deen, P. R. Selvaganapathy, M. Jamal Deen, and D. Landheer, "Microfabricated Reference Electrodes and their Biosensing Applications", Sensors – Special Issue on ISFET Sensors, Vol. 10(3), pp. 1679-1715 (March 2010).

[19] Hybus, http://www.hybus.net/

[20] Uheart, http://www.uheart.kr/