Applying Internet of Things for Personalized Healthcare in Smart Homes

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***Abstract*—The paper advocates for applying Internet of Things (IoT) for personalized healthcare in smart homes. An IoT architecture is presented which enables such healthcare services. Continuous monitoring of physical parameters and processing of the medical data form the basis of smarter, connected and personalized healthcare. The core functionalities of the IoT architecture are exposed using RESTful web services to the consumers. The main contributions of the paper are: (i) providing a unified approach for discovery, management and interaction with physical devices, (ii) utilizing Machine-to-Machine Measurement (M3) framework to generate high level abstraction from wearable sensors, (iii) combining cross-domain sensor data using M3 and (iv) controlling home automation devices based on health sensor information. Prototype implementations and performance evaluations of the architecture components are discussed.**

***Keywords*—Internet of Things; M3 Framework; Personalized healthcare; Smart home.**

I. Introduction

It is estimated that the world population is set to grow by an estimate of 2.3 Billion by 2050[1]. Providing healthcare to them will become far more challenging. To better prepare for that, the current healthcare industry is under transformation. The industry is shifting from reactive approach towards health conditions to a more proactive approach in terms of early detection of conditions, prevention and long term health and wellness management. To realize the vision, health condition monitoring and management of individual wellbeing must be given the priority. To goals of providing better healthcare services and improve the quality of life of citizens automatically lead us to consider the Internet of Things (IoT) technologies. They will play a key role in envisioning, developing and maintaining smarter, connected and personalized healthcare services and solutions [11]. These services can enable continuous monitoring of physical conditions and their automated processing. This results in generation of processed events which could reveal conditions like high blood pressure, stress [12] etc. Devising appropriate storage mechanisms to store the processed events eventually leads to the formation of electronic health records (EHR) [1]. This further enables doctors and healthcare providers in better evaluating and facilitating early detection the physical conditions. As a result, a new era is being formed where IoT is combined with ambient intelligence to provide personalize healthcare services to the elderly and disabled persons in smart homes. This is known as Ambient Assisted Living (AAL). But the M2M devices deployed in smart homes or medical institutions are heterogeneous, multimodal, designed to be low cost and have limited resources. Hence these devices can not directly support complex data processing, discovery of necessary resources, keep a history of data, manage themselves autonomously or advanced security mechanisms. These create several challenges for applying IoT in personalized healthcare and the objective of the paper is to address them.

This paper provides an IoT architecture that enables smarter, connected and personalized healthcare and wellness services to the persons in smart homes. Continuous monitoring of physical parameters through wearable sensors is highly necessary. These sensors correspond to the eHealth domain. We also consider the sensors deployed in smart home domain in order gain deeper understanding of the person's environment. This in turn allows the architecture in combining sensor measurements from different domains. This could be utilized to provide solutions like automatically adjusting the room temperature of a person having fever which is deduced from (wearable) body temperature sensor. Semantic web technologies have been used to combine sensor data from different domains and generate actionable intelligence. This is accomplished using Machine-to-Machine Measurement (M3) framework [21]. The contributions of the paper are – (i) providing a unified approach for discovering, managing and interacting with heterogeneous devices deployed in smart home and eHealth domains, (ii) Utilizing M3 framework to generate high level abstraction from sensor data, (iii) combining sensor data from different domains to create novel healthcare solutions, (iv) controlling home automation devices based on the person's health, (v) interaction with M2M devices regardless of communication technologies.

The rest of the paper is organized as follows. The related works are analyzed in Section II. Section III presents a functional architecture to provide the personalized healthcare solutions. Section IV focuses on prototype implementation of the architecture and performance evaluation. Section V presents operational flows for a few use cases and finally the paper concludes in Section IV.

II. Related Work

A plethora of research works exist in the e-health and AAL domains as well as in semantic computing applied to healthcare services. We have summarized the related works and inspected their limitations in this section.

Authors Zuehlke et al identified a set of functional specifications for mobile health based systems in [1]. Electronic Health Records (EHR) are at the center of any healthcare systems. Other functions supported by such systems

[1] http://www.cisco.com/web/strategy/docs/gov/everything-for-cities.pdf

should include easy implementation & availability, cost-effectiveness, easy adoption etc. But the paper does not point out how to apply such requirements for consumer centric healthcare systems.

A survey of IoT based technologies applicable for healthcare is outlined in [2]. The authors point out that, among the current communication technologies, 6LoWPAN, Bluetooth Low Energy (BLE) and NFC are suited for various aspects of healthcare systems. NFC is useful for a patient to check his/her health status, BLE can be used to gather information of several patients and 6LoWPAN can communicate with any IPv6 enabled systems. The concept of connected healthcare using the Internet of Things is introduced in [3]. The paper takes a patient centric approach to provide useful services for ambient assistive living (AAL) for the elderly persons. Security is one of the key features addressed in this paper. Application of cloud computing in pervasive healthcare is explored in [4]. The proposed architecture includes wearable devices which collect patient data and they are transmitted to smartphones which act as intermediate gateway. These data are then transmitted to a remote cloud using RESTful web interfaces maintaining end-to-end security. The cloud computing platform is mainly targeted to manage patient data. But this method does not equip the patient to obtain high level abstraction from data obtained from wearable devices and does not utilize semantic web technologies. Similar e-Health solutions have been considered from the middleware perspective in [5]. A distinct point of the middleware is the use of XMPP as means of communicating the events. But interoperability with other middleware is not mentioned.

The interoperability and standardization aspects of eHealth communications have been addressed in [6]. Interoperability issues in medical systems are identified in depth in [7]. The paper adopts a semantic based approach for the interoperability issues. The authors described a framework which combines dialog game with a decision support system which leads to resolution of mismatching. But there is no discussion of how the knowledge can be utilized in software development for personal healthcare. Interoperability using semantic web technologies is further addressed in [8]. Jara et al. design healthcare applications exploiting a temperature sensor [9]. But they do not exploit semantic web technologies. The application is remotely accessible but not necessarily through consumer mobile devices. Lasierra et al. integrate semantic web technologies and provide web services for their healthcare scenario [10]. To the best of our knowledge, there is very few healthcare-based applications exploiting semantic web technologies directly on constrained consumer smart devices. Moreover, there is no work on cross-domain knowledge involving inter domains areas such as healthcare, smart home, affective sciences and weather forecasting. On a related note, we have further analyzed the limitations of current literature and have briefed them below –

- There is no inter-domain linking (e.g., food related to symptoms) or intra-domain linking (e.g., healthcare and weather forecasting) works for personalized healthcare services.
- There is a lack of semantic web best practices when designing ontologies or datasets for e-Health domain.
- The healthcare application development approaches and middleware solutions do not use any unified reasoning approach nor reuse the domain knowledge already designed.
- Although current literature identifies the advantages of using semantic web technologies for e-Health services, not many applications have integrated such technologies for consumer mobile applications.

III. IoT Architecture for Personalized Healthcare

This section initially concentrates on consumer centric and architectural requirements for IoT based smarter, connected and personalized healthcare services. These requirements are then translated into a functional architecture and a mapping of its components on physical infrastructure is provided. The architecture components are then described in detail as well as their novel aspects are highlighted.

A. Requirement analysis

- The first requirement of personalized healthcare architecture is the availability and integration of a data generation subsystem from where the physical parameters will be collected.
- The overall architecture system also requires a processing and storage subsystem since the data generating devices cannot support these functionalities due to limited resources.
- The processing and storage subsystem should be able to access the data generation subsystem regardless of communication technologies used in a network subsystem.
- The architecture also requires a consumer subsystem which will receive the personalized healthcare solutions.
- The consumer subsystem should support resource discovery to discover M2M devices present at data generation subsystem and select appropriate ones for data collection.
- A device management framework is necessary to keep track of the registered devices and their configurations.
- The processing and storage subsystem must incorporate mechanisms for generating high level abstraction from raw data. This forms the stepping stone for smarter, connected and personalized healthcare.
- Depending on the consumer’s demand, the processing and storage subsystem should be able to communicate raw data or processed data (high level abstraction).
- The interaction between the mentioned subsystems should occur in a stateless manner using RESTful principles.
- Proper access control policies should be enforced to allow authorized users avail the personalized healthcare solutions.
- The overall system should be able to provide subscription service for occurrence of a list of events which is notified using push notification.

- The architecture should allow the consumer to react to the smart home environment based on the received push notification. This requires the presence of an actuation subsystem.
- From the consumer aspects, the architecture must ensure low latency, high QoS, easy user interface and social network integration. Usability, recovery from errors and timely feedback are very necessary for AAL based systems.

B. *Functional archiecture for IoT based personal healthcare*

The above mentioned requirements reveal that there is a need to consider four main subsystems viz., data generation, processing & storage, consumer and actuation. Figure 1 represents the proposed functional IoT architecture.

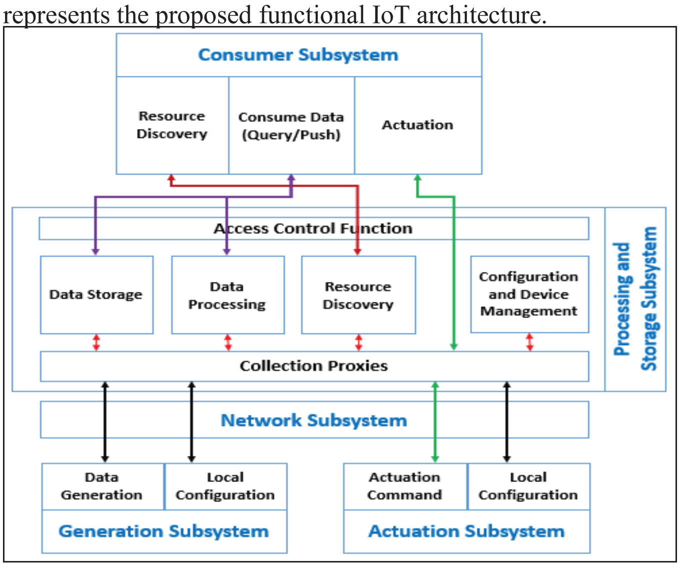

Fig. 1. Functional IoT architecture for personalized healthcare.

Figure 2 portrays functional architecture components mapped onto physical components. The generation and actuation subsystems are composed of wearable and other sensors and actuators. The components of processing and storage subsystem are broadly subcategorized into: (i) proxy manager, (ii) device management, (iii) discovery, and (iv) data processing and storage. They could be deployed in an M2M gateway or a personal cloud. The network subsystem forms an M2M area network (using Bluetooth Smart, Zigbee or low power Wi-Fi) with the M2M gateway, sensors and actuators. Finally the consumer subsystem is analogous to the consumer mobile devices like smart phones. To offer the personalized healthcare services, the core functionalities should be exposed to the consumers through RESTful web services. This is achieved by the service enablement layer. These components are described in subsequent subsections.

C. *Perception layer*

This layer is composed of generation and actuation subsystem i.e. M2M devices containing sensors and actuators. Continuous monitoring of a person's physical parameters is the first step towards a smarter and personalized healthcare. For this purpose, wearable devices with sensors are deployed to collect data about vital parameters of the person. At the same time, sensor and actuators are deployed to smart home with the purposes of (i) procuring deeper understanding of the person's environment as well as (ii) facilitating home automation.

These M2M devices exchange uniform metadata with processing and storage subsystem over the M2M area network. The sensor metadata are represented using Sensor Markup Language (SenML) and can be encoded using JSON or XML. The capabilities of SenML are extended to communicate actuator metadata also [14] [15]. This is a novel aspect of the architecture since it allows SenML and its extensions to provide uniform metadata exchange facilities which settles the heterogeneity and multimodality of physical devices. They also need to register themselves to the IoT architecture so that the processing and storage subsystem could collect data or send actuation commands. During the registration, the local configurations of the M2M devices are uploaded. The configurations of each device and associated sensors, actuators are represented using CoRE Link Format [16]. The configuration management API extracts the descriptions and store them at the configuration storage.

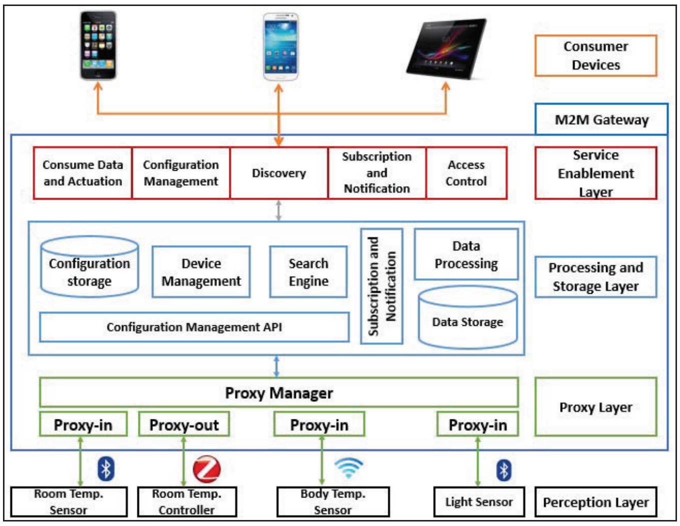

Fig. 2. IoT architecture components mapped onto physical components.

D. *Proxy layer*

The wearable sensors and other sensors and actuators for smart home may communicate over different communication technologies. The architecture employs a proxy manager which contains the necessary drivers for these technologies. The component is developed using RESTful web technologies to take advantages of: (i) ease of development and maintenance, (ii) proven interaction model with wide range of M2M and IoT applications and services, (iii) SenML metadata for sensors and actuators could be carried as the payload of HTTP or CoAP, (iv) directly access data generation and actuation subsystem through web interactions and (v) utilize the web standards to preserve interoperability in the IoT architecture and its components. The functionalities of the proxy layer also includes two distinct web services namely proxy-in and proxy-out. They manage sensors and actuators respectively [14] and could assist legacy M2M devices in generating and interpreting SenML metadata and create CoRE Link based configurations.

The proxy manager together with the proxy-in and proxy-out constitute the collection proxy depicted in Figure 1.

E. M2M Data processing and storage

The raw data generated by wearable sensors do not provide any useful information. There is also a lack of unified approach to: (i) interpret sensor data, (ii) combine sensor data generated at different domains, (iii) provide interoperability among M2M data as well as (iv) assist developers in accomplishing these tasks. The Machine-to-Machine Measurement (M3) Framework mitigates these challenges and help developers in building semantic web technology based IoT applications. M3 forms the main component in providing smarter and personalized healthcare through the IoT architecture.

M2M data processing utilizes the "naturopathy" scenario of the M3 framework. It contains a reasoning engine which semantically annotates sensor data (e.g., body temperature) to automatically infer high level abstraction (e.g., fever). The inferred data is then linked to related domain knowledge (i.e., ontologies and datasets of eHealth domain) to get additional intelligence. Then, such information is intertwined with cross-domain knowledge. For example, naturopathy dataset which explicitly describes that honey and lemon are recommended when fever is detected. Here, fever is a symptom in eHealth datasets and honey & lemon are recommended for fever in food datasets. M3 provides an easy way to combine such cross-domain knowledge and the computing is based on the Semantic Web Rule Language (SWRL). The naturopathy scenario also allows combining wearable sensor data to other external datasets provided by affective sciences [17] and weather forecasting [18].

The M3 framework is described in details in [19]. This paper briefly mentions the operational flow of the components using the Figure 3. To assist developers in building smarter healthcare applications, the SWoT Generator is conceived. This tool generates a template which consists of M3 ontologies, M3 datasets and M3 rules needed to interpret and enrich M2M data (generated by wearable sensors) with domain knowledge to build applications. The generator takes the wearable sensor data (e.g. body temperature) and the domain information (e.g. eHealth) as inputs to create the template for the developers. The next step concentrates on semantically annotating the sensor data. This step utilizes the M3 nomenclature and the M3 converter to make data coming from heterogeneous sources (eHealth and smart home domains) interoperable with each other and explicitly add the context. The M3 converter is compliant with the Sensor Markup Language (SenML) format in terms of sensor metadata description but could be extended to support other formats. The treatment of this phase generates data compliant with the M3 domain knowledge. Finally, to interpret data, Linked Open Vocabularies for Internet of Things (LOV4IoT) has been designed to reuse domain knowledge already designed by healthcare and home automation domain experts. Stemming from the 'Linked Open Data', the Sensor-based Linked Open Rules (S-LOR) has been designed to share and reuse interoperable rules to easily enrich IoT data by reusing domain knowledge from LOV4IoT. Due to interoperability issues, the M3 domain knowledge has been rewritten and is composed of interoperable ontologies, datasets and rules to enrich IoT data and provides inter-domain interoperability to easily build IoT applications. The actionable intelligence generated by the M3 framework are stored in the data storage along with a timestamp. This leads to formation of EHR which could enable the doctors and other caregivers assessing the person's medical conditions.

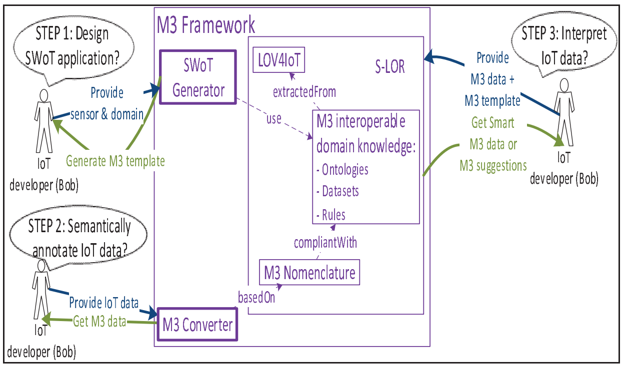

Fig. 3. Operational flow of the M3 framework.

F. Device management

Management of the devices deployed in smart home and eHealth domain is important. The device management module of the processing and storage subsystem keeps track of physical things associated to the IoT framework and periodically check their availability. The module also manages the mobility of wearable sensors, helps in provisioning phase and enforces access control policies to stop unauthorized access to the entire system. This is highly necessary from the consumer centric perspective of healthcare since the consumers should be aware of the managed devices and in charge of access control policies.

G. Resource Discovery

The consumer and processing & storage subsystem requires mechanisms for automated resource discovery. This allow them to discover if a desired sensor (e.g. body temperature sensor) or an actuator (e.g. room temperature controller) is currently registered to the IoT architecture. Also they learn about the properties, capabilities and URIs to access the M2M devices generating data about physical parameters. The novel aspects of the proposed resource discovery are: (i) integration of a lightweight search engine to provide "look up" facilities and (ii) discovery of devices regardless of used communication technologies. The module allows the consumers to discover the URI of a room temperature controlling actuator and send a command based on the derived intelligence of the M3 framework. The search engine component takes advantage of configuration storage to index the M2M devices. When a discovery request originates from the consumer, the search engine intelligently extracts keywords for search which are matched with the indices to retrieve a list of URIs of discovered devices. Similar to device management, this module is also dependent on the access control policies to limit discovery to authorized devices.

H. Subscription and notification

The subscription and notification module permits the consumers to subscribe to receive notifications about healthcare related events. These events are generated by the semantic reasoning engine in the M3 framework. The push notification is enabled by Google Cloud Messaging (GCM) for Android mobile applications and by Apple Push Notification (APN) service for iOS based applications. This module enables patients, doctors and relatives to receive notifications about health conditions which forms an important aspect of the personalized healthcare services. Actuation could also be performed based on the notification. For example, if fever is detected by the M3 framework and this event is pushed to the consumer, then the latter can choose to change the room temperature using actuation. This corresponds to controlling smart home equipment based on eHealth sensor measurement. This is another unique aspect of the IoT architecture.

I. Service enablement layer

The core functionalities of the processing and storage subsystem are exposed to the consumer subsystem through RESTful web services. This layer interacts with the consumers allowing them to: (i) consume data and send actuation command to the generation and actuation subsystem, (ii) add, update or delete configuration for device management [20], (iii) discover M2M devices and their capabilities, (iv) subscribe to push notifications and (v) enforce access control policies.

IV. Prototype Implementation and Performance Evaluation

The paper describes prototypes of an Android application deployed in the consumer subsystem and an M2M gateway which houses the processing and storage subsystem. The prototypes have been tested using real time sensor metadata coming from coming from a wearable body temperature sensor and other sensors deployed to a smart home. A room temperature controller actuator is also used.

A. Mobile application: Connect and Control Things

The consumer subsystems in this architecture are considered to be composed of Android powered devices. These devices are equipped a prototype mobile application called "Connect and Control Things" (CCT). The personalized healthcare services are provided to the consumers through CCT. Initially the application connects to the M2M gateway at a well-known entry point. Once its authorization is validated, it allows consumers to discover sensors and actuators registered to the gateway. Then the consumer can select a sensor from smart home to combine its metadata with body temperature sensor metadata. CCT also provides a list of events for which subscription to receive push notification is available. It also allows sending command to actuators. The sensor and actuator metadata are represented using SenML and its extensions and are encoded in JSON. The device management functionalities depend on CoRE Link Format based representation also encoded in JSON. This promotes interoperability with other healthcare systems.

B. M2M gateway

The web services of the M2M gateway are developed in python using Flask framework and are deployed in a constrained device in smart home. The main novel aspect is in integrating a lightweight version of M3 framework. Its actual version is deployed in a cloud system implemented using Apache Jena framework. The work has considered a lightweight version since only healthcare and smart home related knowledge and templates are necessary. For M2M device management, a lightweight framework for OMA LwM2M is used [20]. The discovery module integrates a search engine. The subscription and notification module works as shown in Figure 4.

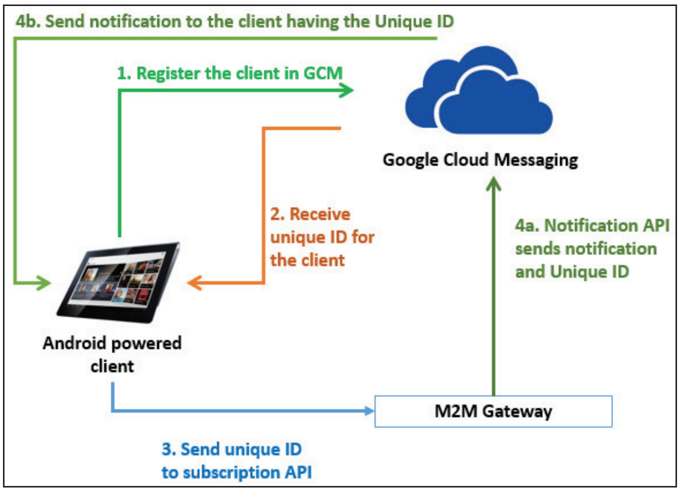

Fig. 4. Operational flow of push notification.

i. The consumer subsystem running CCT must register itself to GCM platform which assigns a unique identification (UID) number to each smart device.

ii. CCT communicates the UID to the M2M gateway along with the event to which the former subscribes.

iii. When the occurrence of the same event takes place (as determined by the M2M data processing unit), the gateway sends the event notification and UID to the GCM web service using HTTP POST method.

iv. GCM performs the push notification which results in CCT receiving a notification about the subscribed event.

The data and configuration storages are implemented using SQLite database.

C. Performance evaluation

The performance of the Android application is evaluation in terms of memory requirements, CPU usage and power consumption and the results are presented below.

- **Memory usage:** The application requires less than 3.5MB memory in Android powered devices. This establishes that the design and implementation of CCT is ultra-lightweight in nature.

- **CPU usage:** It is measured during four different phases of operations: (i) discovery, (ii) accessing sensors, (iii) device management related functionalities and (iv) actuation. The CPU load is found to be less than 2% as there is no complex computing involved. The overall CPU usage is less as it depends only on network operations and parsing JSON based metadata.

- **Power consumption:** The average power consumption is measured during the lifecycle of CCT. On a Samsung Galaxy S3 running Android KitKat consumes 298mW and 259mW when operated on mobile data and Wi-Fi respectively. For power saving, techniques mentioned in [22] [23] could be adopted.

The healthcare functionalities running on M2M gateway are essentially lightweight since the python script implementing the entire gateway is taking very minimal memory. The CPU load rises to 15%-19% only during the M2M data processing for healthcare and smart home sensors. Our future work is focused on performance evaluation about proactive monitoring of physical parameters of the users.

V. CONCLUSION

In a nutshell, the paper advocates for applying IoT architecture in providing smarter, connected and personalized healthcare solutions in smart homes. Their requirements for such healthcare services are analyzed and are translated into a functional architecture. Its components are mapped onto physical infrastructure. The components are described and their novel aspects are highlighted. The center of the proposed healthcare system is in M2M data processing using M3 framework. It employs a semantic reasoning engine to generate actionable intelligence from wearable sensor data and combine that with smart home sensors to create cross domain scenarios. Prototypes of the consumer mobile application and M2M gateway are described along with their performance evaluation results.

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REFERENCES

[1] Zuehlke, P.; Junhua Li; Talaei-Khoei, A.; Ray, P., "A functional specification for mobile eHealth (mHealth) Systems," e-Health Networking, Applications and Services, 2009. Healthcom 2009. 11th International Conference on, pp.74,78, 16-18 Dec. 2009.

[2] Lopez, P.; Fernandez, D.; Jara, A.J.; Skarmeta, A.F., "Survey of Internet of Things Technologies for Clinical Environments," Advanced Information Networking and Applications Workshops (WAINA), 2013 27th International Conference on, pp.1349,1354, 25-28 March 2013.

[3] Jara, A.J.; Zamora, M.A.; Skarmeta, A.F.G., "An Architecture Based on Internet of Things to Support Mobility and Security in Medical Environments," Consumer Communications and Networking Conference (CCNC), 2010 7th IEEE, pp.1,5, 9-12 Jan. 2010.

[4] Doukas, C.; Maglogiannis, I., "Bringing IoT and Cloud Computing towards Pervasive Healthcare," Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2012 Sixth International Conference on, pp.922,926, 4-6 July 2012.

[5] Bazzani, M.; Conzon, D.; Scalera, A.; Spirito, M.A.; Trainito, C.I., "Enabling the IoT Paradigm in E-health Solutions through the VIRTUS Middleware," Trust, Security and Privacy in Computing and Communications (TrustCom), 2012 IEEE 11th International Conference on , vol., no., pp.1954,1959, 25-27 June 2012.

[6] Aragues, A.; Escayola, J.; Martínez, I.; del Valle, P.; Munoz, P.; Trigo, J.D.; Garcia, J., "Trends and challenges of the emerging technologies toward interoperability and standardization in e-health communications," Communications Magazine, IEEE , vol.49, no.11, pp.182,188, November 2011.

[7] Ganguly, P.; Chattopadhyay, S.; Paramesh, N.; Ray, P., "An ontology-based framework for managing semantic interoperability issues in e-health," e-health Networking, Applications and Services, 2008. HealthCom 2008. 10th International Conference on, pp.73,78, 7-9 July 2008.

[8] Brandt, P.; Basten, T.; Stuiik, S.; Vinh Bui; de Clercq, P.; Pires, L.F.; van Sinderen, M., "Semantic interoperability in sensor applications making sense of sensor data," Computational Intelligence in Healthcare and e-health (CICARE), 2013 IEEE Symposium on , vol., no., pp.34,41, 16-19 April 2013.

[9] Jara, Antonio J and Zamora-Izquierdo, Miguel A and Gomez-Skarmeta, Antonio F, "An ambient assisted living system for telemedicine with detection of symptoms", in Bioinspired Applications in Artificial and Natural Computation, pp. 75-84, 2009, Springer.

[10] Lasierra, N.; Alesanco, A.; Garcia, J., "Designing an Architecture for Monitoring Patients at Home: Ontologies and Web Services for Clinical and Technical Management Integration," Biomedical and Health Informatics, IEEE Journal of , vol.18, no.3, pp.896,906, May 2014.

[11] Zhanlin Ji; Xueji Zhang; Ganchev, I.; O'Droma, M., "A personalized middleware for ubiquitous mHealth services," e-Health Networking, Applications and Services (Healthcom), 2012 IEEE 14th International Conference on, pp.474,476, 10-13 Oct. 2012.

[12] Massot, B.; Baltenneck, N.; Gehin, C.; Dittmar, A.; McAdams, E., "EmoSense: An Ambulatory Device for the Assessment of ANS Activity—Application in the Objective Evaluation of Stress With the Blind," Sensors Journal, IEEE , vol.12, no.3, pp.543,551, March 2012.

[13] Luigi Atzori, Antonio Iera, Giacomo Morabito, The Internet of Things: A survey, Computer Networks, Volume 54, Issue 15, 28 October 2010, Pages 2787-2805.

[14] Datta, S.K.; Bonnet, C.; Nikaein, N., "An IoT gateway centric architecture to provide novel M2M services," Internet of Things (WF-IoT), 2014 IEEE World Forum on, pp.514,519, 6-8 March 2014.

[15] Datta, S.K.; Bonnet, C.; Nikaein, N., "CCT: Connect and Control Things: A novel mobile application to manage M2M devices and endpoints," Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), 2014 IEEE Ninth International Conference on, pp.1,6, 21-24 April 2014.

[16] Datta, S.K.; Bonnet, C., "Smart M2M Gateway Based Architecture for M2M Device and Endpoint Management," Internet of Things (iThings), 2014 IEEE International Conference on, pp.61,68, 1-3 Sept. 2014.

[17] Hastings, Janna and Ceusters, Werner and Smith, Barry and Mulligan, Kevin, "The emotion ontology: enabling interdisciplinary research in the affective sciences," in Springer Journal of Modeling and Using Context, pp. 119-123, 2011.

[18] Paul Staroch, "A weather ontology for predictive control in smart homes", Master Thesis, 2013.

[19] Gyrard, A.; Datta, S.K.; Bonnet, C.; Boudaoud, K., "Standardizing generic cross-domain applications in Internet of Things," Globecom Workshops (GC Wkshps), 2014, pp.589,594, 8-12 Dec. 2014.

[20] Datta, S.K.; Bonnet, C., "A lightweight framework for efficient M2M device management in oneM2M architecture," Recent Advances in Internet of Things (RIoT), 2015 International Conference on, pp.1,6, 7-9 April 2015.

[21] Gyrard, A.; Datta, S.K.; Bonnet, C.; Boudaoud, K., " Cross-Domain Internet of Things Application Development: M3 Framework and Evaluation," 3rd International Conference on Future Internet of Things and Cloud, 24-26 Aug. 2015.

[22] Datta, S.K.; Bonnet, C.; Nikaein, N., "Minimizing energy expenditure in smart devices," Information & Communication Technologies (ICT), 2013 IEEE Conference on, pp.712,717, 11-12 April 2013.

[23] Datta, S.K.; Bonnet, C.; Nikaein, N., "Self-adaptive battery and context aware mobile application development," Wireless Communications and Mobile Computing Conference (IWCMC), 2014 International, pp.761,766, 4-8 Aug. 2014.

[2] http://www.agence-nationale-recherche.fr/?Projet=ANR-13-INFR-0008