Ambient Assisted Living Ecosystems of Personal Healthcare Systems, Applications, and Devices

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Abstract

Personal health monitoring aims to empower citizens' for their healthcare and wellness. The healthcare devices, connected with healthcare applications, clinical information systems, tele-medicine services, and national medical record systems are evolving into ambient assisted living (AAL) personal healthcare ecosystems. Accordingly, the research and development is gaining significant momentum and expanding multidisciplinarily, addressing functional, quality-of-service and quality-of-experience aspects. However, most of the current research in AAL focuses on specific aspects of AAL in isolation, lacking overall system design, integration and quality perspectives. Consequently, the evolving solutions fail to achieve one or more essential requirements such as interoperability, integration, usability, security, and dependability. To bridge the gap between requirements and technical services, this paper presents a conceptual framework providing a holistic view of AAL ecosystems. Besides, the system architectures and technology standards are discussed for the proposed CareStore platform for seamless deployment of AAL applications and devices.

Keywords: Ambient-assisted living, personal health monitoring, healthcare systems integration and interoperability

1 Introduction

Ambient-assisted living (AAL) offer personalized healthcare and wellness services supported by medical sensors/actuators, personal health monitoring applications, tele-medicine systems, communication networks, and health information systems. Current research in AAL addresses one or more aspects in isolation lacking a holistic AAL ecosystem perspective, which should consider business, organizational, technological, user-experience and quality-of-service aspects all together. Besides, there is a lack of conceptual frameworks, providing a complete view of AAL ecosystems. Some of the frameworks such as universAAL [1], SOPRANO [2], MonAMI [3], and ecosystems such as Continua [4] address various aspects of AAL systems. However, those focus mainly on resolving technological differences among medical sensors and healthcare systems through standards, i.e., IEEE 11073, HL7, EN13606, and ASTM F2761. The objective of this paper is to present the *OpenCare Conceptual Framework* for AAL ecosystems of personalized healthcare systems, applications and devices. The proposed framework is an extension to our previous research related to *OpenCare Project* [5]. In this contribution, we will extend the *OpenCare Platform* as an *OpenCare Conceptual Framework* providing a holistic view of AAL ecosystems, to bridge the gap between AAL services and technological platforms. We will also discuss the high-level system architectures of the proposed *CareStore Platform* [6]., which is our ongoing work realizing the *OpenCare framework.* The paper is organized as follows. Section 2 briefly presents the related research in AAL systems and solutions. Section 3 presents the proposed conceptual *OpenCare framework*. The framework is realized by the *CareStore Platform*, which is discussed in Section 4. This section further elaborates the internal architecture of different subsystems of the *CareStore Platform*.

2 Related Work

The scientific and business ventures are joining hands to reduce healthcare expenses by empowering the citizens in their personal healthcare. The consortia, conceptual frameworks and technical platforms are striving to bridge the wide gap between AAL services and technologies [1-3]. Technology standards i.e., IEEE 11073, HL7, EN13606 are struggling to resolve interoperability and integration issues among AAL medical devices, applications and systems. Whereas, the regulations i.e., HIPAA, IHE, EU-Directive are devoted for providing guidelines to achieve integration without compromising security, privacy, compliance, and usability. The AAL solutions ensuring QoS attributes i.e., usability, data accuracy [7], security/privacy [8], and availability [9] are leading the rest. Besides, the QoE (Quality of Experience) evaluation significantly contributes in identifying the concerns of potential AAL users to evolve better usable systems [10]. Other research also closely related to our work is [11, 12]. [11] has mainly focused on sensor, middleware, and interface layers, whereas [12] considers the high-level business services in AAL4ALL framework. In comparison, our proposed *OpenCare framework* identifies more conceptual levels, i.e., device and application marketplace, quality attributes, technology standards and external systems.

3 Material and Methods

We investigated ambient assisted living domain through academic research and practical experience. We conducted an extensive survey of existing AAL system and platform to evaluate the existing solutions and identify the major aspects of AAL solutions. Besides, we have been working with local industry and caring homes in Denmark and Germany to elicit the business and non-functional requirements of AAL systems through user-centered and participatory research. For user participation, initially we developed small-scale prototypes to connect the personal healthcare devices such as glucose meter and weight scale with the homecare platform. The users of different age, background and education level were selected to evaluate to prototypes. Based on the rigorous investigation and analysis of existing AAL platforms, and evaluation/feedback gathered through user experience, we propose a conceptual *OpenCare Framework*, which identifies the major aspects of AAL systems. Moreover, the high-level system architecture of proposed CareStore platform and detailed architectures of its subsystems are also elaborated.

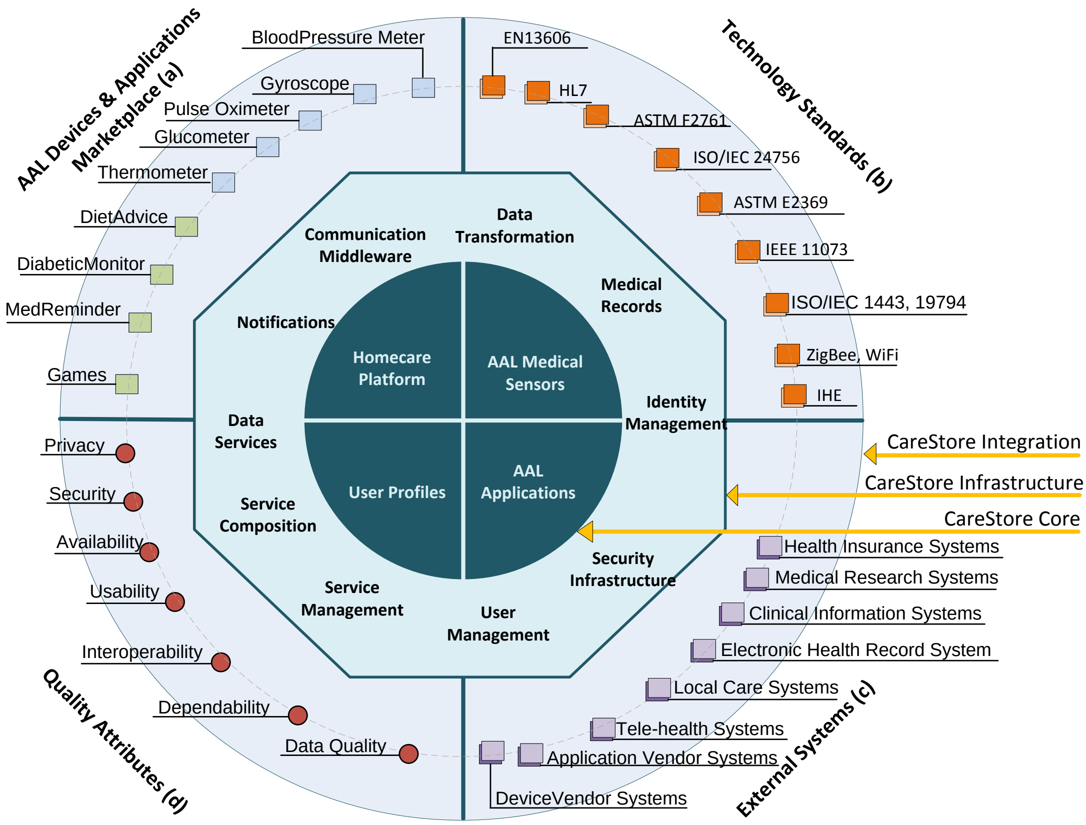

Figure 1: *OpenCare Framework* for AAL Ecosystems of personalized healthcare systems, applications and devices

4 OpenCare Framework for AAL Ecosystems

AAL ecosystems are complex, multidisciplinary, and personalized in nature. Therefore, it is important to understand different aspects of the AAL systems considering business services, quality attributes, usability/accessibility concerns, integration requirements, and technology standards required for implementation. The proposed *OpenCare* framework defines various aspects of AAL ecosystems to meet its complex requirements. *OpenCare* framework is divided into three conceptual levels including *OpenCare Core*, *OpenCare Infrastructure* and *Open Care Integration*, as shown in Figure 1 and discussed subsequently.

4.1 OpenCare Core:

OpenCare Core identifies very essential components of AAL ecosystems consisting of the *homecare platform, AAL medical sensors, AAL applications* and *user profiles*. The homecare platform is user's personal computer, which connects with AAL medical sensors and deploys AAL applications. The user profiles are created at the homecare platform, so that access to AAL applications and remote healthcare services is granted based on the user profile attributes. User profiles store personal, identity and healthcare data which includes social, credential, device/application information of citizens at a local or remote computer depending upon the system architecture.

4.2 OpenCare Infrastructure:

OpenCare Infrastructure represents infrastructural subsystems and components of AAL ecosystems. It consists of the applications, subsystems, communication middleware and data stores required for AAL ecosystems. The *Data Services* is the set of business services offered by an AAL system such as add new device, add new application, view blood pressure report and download device driver services.

The data services can be atomic services offered by a single organization or composed services from two or more services involving more organizations. For instance, configure homecare platform service will invoke the services to authenticate the user, download updated version of homecare platform, and install updated homecare platform before configuring it for a particular user. The composition will be performed by the *Service Composition component*.

The *Service Management* component will be used by a system administrator to manage business services. The service management activity includes service packaging, deployment, updation and monitoring. Moreover, the administrator uses the *User Management* component to add and manage users in the AAL system including citizens, caregivers, device vendors, application vendors, and system administrators. *Notifications* are used to send and receive messages among systems and subsystems for the subscribed events. AAL ecosystems are composed of the internal and external systems subscribing for events of interested topics. For example, the homecare platform will be interested to receive an update notification, when a new version of the platform is available at the central repository. Similarly, the homecare platform can subscribe for notifications from vendor systems to receive updates for AAL device drivers and applications.

The *Middleware* infrastructure provides many services to integrate technologically diverse applications and systems using protocol transformation, message exchange (i.e., mediation, filtering and routing), and monitoring and management of business services. AAL systems rely on a middleware to provide message-based communication to integrate and interoperate AAL devices, applications and systems. The *Data Transformation* component is responsible for receiving data from a source system or device, and transforming into the required format/protocol of the destination system or device to achieve interoperability. For example, the vital signs data created by IEEE 11073-compatible devices can be transformed to HL7-CDA format to store medical records in a central database. The *Medical Records* is an important healthcare IT concept in today's globally connected healthcare databases. There are voluminous standards and specification spotlighting several aspects of medical record systems. An *Identity Management* component deals with user identities, which are created as digital certificates, user name passwords, and biometric features. Whereas, the *Security Infrastructure* consists of security mechanisms, architectures, databases, and protocols to ensure data confidentiality and integrity.

4.3 OpenCare Integration:

The external fold of the OpenCare framework diagram in Figure 1 shows the integration perspective of AAL ecosystems. Integration is concerned with connecting the devices, applications, databases, subsystems and systems to accomplish an AAL ecosystem. The four quadrants in the figure show the major aspects of the integration perspective, which are discussed below.

a) *AAL Devices and Applications Marketplace*: There is a growing trend of purchasing AAL products and services from online stores or marketplaces of medial sensors/actuators, mobile health apps, and health monitoring apps. Medical sensors/actuators are used for the measurement of physiological health parameters of the citizens such as temperature, pulse rate, blood pressure, motion, and glucose levels. The medical devices i.e., gyroscope, pulse oximeter, glucometer and others are used for collecting vital signs. The health and wellness applications such as Diet Advice, Medicine Reminder, Diabetic Monitor, Sleep Cycle, and Stress Check are installed on the homecare platform.

b) Technology Standards: The AAL ecosystems rely on technological standards in different system lifecycle phases. The IEEE 11073 standard defines a common framework for personal health medical devices data in a transport-independent manner to achieve interoperability. The ASTM F2761 standard focuses on safety requirements in using medical devices in integrated clinical environment. The HL7, EN13606, and IHE standard also address interoperability, integration and security requirements but at a broader level of healthcare systems.

c) External Systems: AAL system business workflows span across the boundaries of AAL subsystems for integration with external systems. AAL systems integrate with *application* and *device vendor* systems to download the device drivers and applications from the vendors' online marketplace. *Tele-health systems* will interact with AAL systems to provide home-based services through tele-medicine applications. *Electronic Health Record Systems* are the centralized medical record databases at regional or national levels. *Clinical Information Systems* receive citizens' medical data and enable physicians or specialists to access it for diagnosis and medication. *Medical Research Systems* collect the citizens' medical data from AAL systems to conduct research on specific diseases or medicine. Finally, *Health Insurance* organizations would be involved in health data to validate health insurance claims.

d) Quality Attributes: Quality attributes including quality-of-service and quality-of-experience are crucial factors in AAL. *Interoperability* is a key requirement to bridge the semantic and technical gap among personal healthcare devices, applications, networks and systems. *Usability* is critical as AAL systems are also used by elderly users or users with health impairments. User-centered development methodologies involving fast prototyping and interactive feedback from user space helps extensively to achieve better and more usable systems. *Availability* is concerned with many parameters including availability of devices (and their drivers), applications, network resources (network hardware and bandwidth), technical expertise and trainings in the AAL domain. Availability is increasing with growing global marketplaces (i.e., online stores) and technical infrastructure (i.e., web, grid and cloud solutions) ensuring high availability of resources. *Security* and *Privacy* are major concerns to protect the medical data against unauthorized access by eavesdroppers and misuse of personal data for commercial or criminal causes. *Dependability* is attributed to reliability, which encompasses system availability, performance, safety and integrity. Equally important is *Data Quality*, because inaccurate and erroneous data mishandled by the systems may result in severe and unfavorable consequences to the health and life.

Having discussed the conceptual *OpenCare* framework; we will present the *CareStore* platform, which realizes the concepts defined in the framework.

5 The CareStore Platform

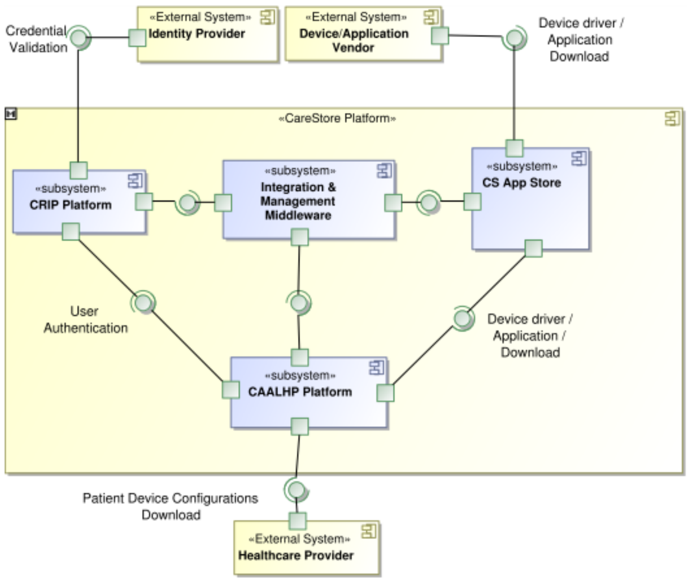

Figure 2: The System Architecture of the *CareStore Platform*

The CareStore platform is developed with the objectives to develop an open platform for seamless deployment and installation of medical devices and applications, and create a marketplace for downloading device drivers and applications. Besides, integration of the homecare platform with the external vendor systems is one of the major targets to be achieved. Security is provided by an integrated subsystem of the platform for user identification (through biometry and RFID) and device recognization (through RFID) [6].

Figure 2 shows the high-level system architecture of CareStore platform as a UML component diagram, which shows the internal subsystems of the platform i.e., *Common Ambient-assisted Living Homecare Platform* (CAALHP), *Common Recognition and Identification Platform* (CRIP), *Integration and Management Middleware* (IMM) and *CareStore AppStore*. The CAALHP subsystem provides the core AAL services to the end user; CRIP subsystem is responsible to authenticate the user; IMM subsystem is the infrastructural and communication middleware and CS AppStore subsystem is the repository of device drivers and AAL applications. The subsystems and external systems of CareStore system architecture are integrated with each other in a service-oriented way through services offered and services required by the subsystems and external systems, which are shown in system architecture using UML notations of circle (for service offered) and semi-circle (for service required). The CAALHP subsystem depends upon the services offered by other subsystems. For example, when a user interacts with CAALHP, it invokes the security services offered by CRIP to authenticate the user. The CRIP on the other hand depends upon the credential validation service offered by an Identity Provider.

Similarly, CAALHP invokes the device driver/application downloading services of the CS AppStore for deployment at the homecare platform. The *PatientDeviceConfigurations* are downloaded by CAALHP through the services offered by (external) Healthcare Provider. The *patientDeviceConfigurations* are the configurations of a particular medical device for a particular citizen created by a healthcare service provider i.e., therapist/physician/specialist using *Healthcare Provider System*. The idea is that a therapist creates (and uploads) a prescription for a particular citizen (or patient) to use a particular medical device with prescribed settings (e.g., ergometer load control settings, infusion pump settings for remote health monitoring. As soon as new configurations are uploaded, those are pushed to the homecare platform resulting in seamless configuration of remote health monitoring devices. Accordingly, the IMM subsystem, which is the communication and infrastructural backbone of CareStore platform offers services to CAALHP, CRIP, CS AppStore subsystems and external organizations, so that those can exchange business, security, notification and updation messages to each other in a loosely coupled component-based architecture. We will present more detailed internal architectures of different CareStore subsystems in the subsequent part of this section.

5.1 CareStore AppStore:

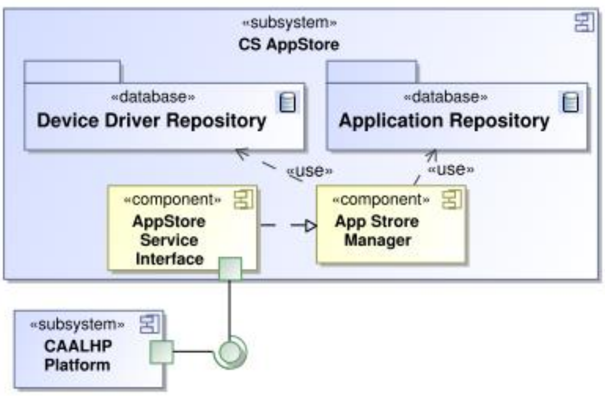

Figure 3: *CareStore AppStore* Subsystem

The registered device and application vendors will upload their products at the online CareStore AppStore subsystem, so that the same can be downloaded automatically by the CAALHP subsystem when a particular device is recognized by the homecare platform or an application is requested by the end-user. The technical design of the CareStore AppStore is shown in Figure 3. The AppStore services to download drivers and applications are offered by an *AppStore Service Interface*, which connects to the *AppStore Manager* component to retrieve the required artifacts from corresponding repositories.

5.2 CAALHP: The homecare platform represents the homecare subsystem of the *CareStore* platform. It consists of the core part of the platform called i.e., CAALHP, which offers AAL services to the end-users and platform administrators. CAALHP offers services to (seamlessly) add new devices, install health monitoring applications, send vital signs, update platform and register users.

The internal design of the CAALHP subsystem shown in Figure 4 consists of the CAALHP Interfaces i.e., *User Interface* and *Admin Interface*. The user interface offers AAL services to the end-user, whereas, the admin interface is used by the platform administrator to register new users, add/remove vendors, and update the platform. The *CAALHP Interfaces* are connected to the *CAALHP Services* component, which deploys the business logic of AAL services. We have separated the service interfaces from service implementation to provide integration of technologically diverse components for scalable and extensible systems architectures.

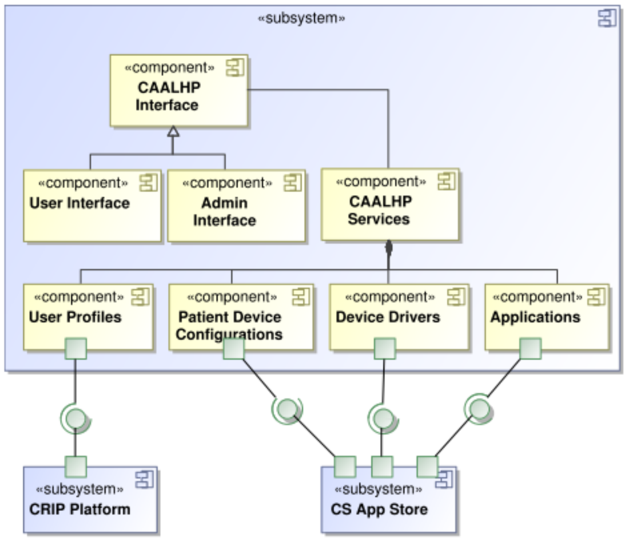

Figure 4: The homecare platform CAALHP

The *Applications* and *Device Drivers* components maintain the repositories and configuration information of different devices and applications installed at the homecare platform. The *Patient Device Configurations* component stores device configurations prescribed by a physician or doctor for a particular patient. The *User Profiles* component stores the profiles and identity details of users. The identity information is maintained with the help of CRIP platform, which is responsible to authenticate the users.

5.3 CRIP: The CRIP platform offers a set of security services required by the CareStore platform. The internal design of the CRIP subsystem is shown in Figure 5. CRIP stores the RFID data of medical devices, so that those can be recognized when added to CAALHP subsystem. The *Device Validation* component uses RFID data for device recognition. The *Encryption* and *Digital Signature* components provide functionality to use data protection algorithms (i.e., AES, DES, DSS, MD5) to ensure data confidentiality and integrity. The *Authentication* component validates user credentials, whereas, the *Authorization* component validates user roles and authorization policies. The authentication component relies on a local *Identity Store*. The user identities are verified by an external system i.e., Identity Provider, whereas, the access rights are verified through access control policies database. The *Non-repudiation* component ensures auditing and stores evidences of communication with internal and external systems.

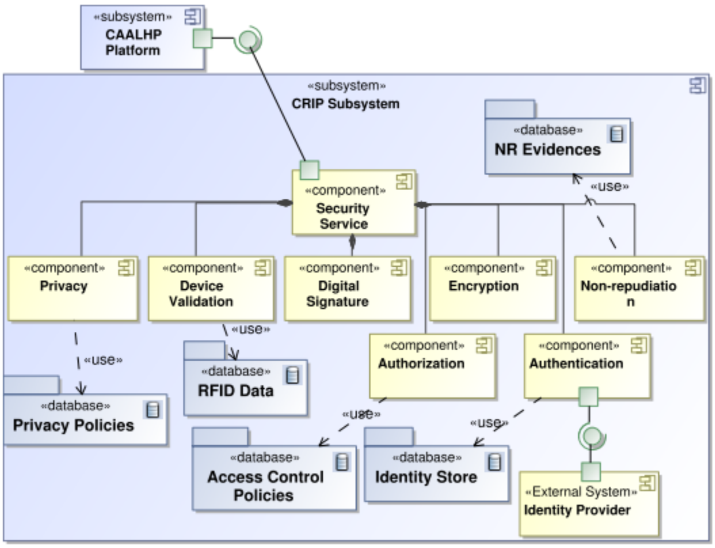

Figure 5: The CRIP Subsystem of CareStore AAL platform

The evidences are stored in *NR Evidence* database. Finally, the Privacy component evaluates the dissemination of data from CAALHP to external system. The privacy preferences of citizens are stored in the privacy policies database so that the same should be forwarded along with data when medical data is sent to the external systems.

Conclusion

Our theoretical analysis and real-world experience led us to the results that most of the current platforms and solutions are not easy to use in personal health monitoring and telemedicine scenarios. The conceptual frameworks are more ideal than practical, whereas the available solutions are still facing plenty of challenges such as interoperability, usability, dependability/availability, and security. In current status, the end-users still require significant technical support and continuous supervision from skilled IT and medical staff, which on one hand hinders their 'independent-living' and on other increase the cost for the (elderly) citizens with limited budget. Besides, it puts lot of economic pressure on the government and health insurance providers to meet the expenses. More validation and user experience studies are necessary to improve the systems with user feedback and participatory development. Based on the requirements identified through analysis of contemporary AAL systems and user experience evaluation the proposed CareStore platform aims to provide a technical solution for seamless deployment of medical sensors/actuators and AAL applications. CareStore is an ongoing project; currently we have preliminary prototype implementation to connect blood pressure and weight-scale devices with the homecare platform. We are extending the platform and it services to evolve as an open AAL platform for connecting devices and applications in a vendor-neutral way and integrate the AAL subsystems with tele-health and medical record systems.

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References

[1] M. Tazari, F. Furfari, Á F. Valero, S. Hanke, O. Höftberger, and, et. al., "The universAAL Reference Model for AAL", *Handbook of Ambient Assisted Living - Technology for Healthcare, Rehabilitation and Well-Being,* Vol. 11, pp. 610-625, 2012.

[2] A. Sixsmith, S. Meuller, F. Lull, M. Klein, I. Bierhoff, S. Delaney, and R. Savage, "SOPRANO - An ambient assisted living system for supporting older people at home", In *7th Int. Conf. on Smart Homes and Health Telematics,* Tours, France, 2009, pp. 233-236.

[3] A. Ibarz, J. L. Falcó, E. Vaquerizo, L. Lain, J. I. Artigas, and A. Roy, "MonAMI: Economic impact of mainstream AAL open platform in home care", In *Ambient Assisted Living and Home Care,* Springer, 2012, pp. 127-134.

[4] R. Carroll, R. Cnossen, M. Schnell, and D. Simons. "Continua: An interoperable personal healthcare ecosystem". *Pervasive Computing 6(4),* pp. 90-94. 2007.

[5] S. Wagner and C. Nielsen, "OpenCare project: An open, flexible and easily extendible infrastructure for pervasive healthcare assisted living solutions", 3rd Int. Conf. on *Pervasive Computing Technologies for Healthcare, 2009*, pp. 1-10.

[6] S. Wagner, F.O. Hansen, C.F Pedersen, M. Memon, F.H. Aysha, M. Mathissen, C. Nielsen, O.L. Wessby, "CareStore platform for seamless deployment of ambient assisted living applications and devices," In *7th Int.Conf. on Pervasive Computing Technologies for Healthcare,* Venice, Italy, May, 2013.

[7] A. J. Jara, M. A. Zamora, and A. F. Skarmeta, "An internet of things-based personal device for diabetes therapy management in ambient assisted living (AAL)", *Personal and Ubiquitous Computing,* vol. 15, pp. 431-440, Apr, 2011.

[8] M. Ziefle, C. Rocker, and A. Holzinger, "Medical technology in smart homes: Exploring the user's perspective on privacy, intimacy and trust", In *35th Annual Con. on Computer Software and Applications (COMPSACW),* 2011, pp. 410-415.

[9] G. N. Rodrigues, V. Alves, R. Silveira and L. A. Laranjeira, "Dependability analysis in the ambient assisted living domain: An exploratory case study", *J. Syst. Softw.,* Vol. 85, pp. 112-131, Jan, 2012.

[10] R. Beringer, A. Sixsmith, M. Campo, J. Brown and R. McCloskey, "The acceptance of ambient assisted living: Developing an alternate methodology to this limited research lens," In *9th Int. Conf. on Smart Homes and Health Telematics,* Montreal, Canada, 2011, pp. 161-167.

[11] M. J. O'Grady, M. Walsh, R. Tynan, C. Gurrin, M. Dragone, and G. M. O'Hare, "Managing diversity in practical ambient assisted living ecosystems", In *The AALIANCE: The European Ambient Assisted Living Innovation Alliance Conference Malaga, Spain. 11-12 March 2010,* 2010.

[12] L. M. Camarinha-Matos, J. Rosas, A. I. Oliveira and F. Ferrada, "A collaborative services ecosystem for ambient assisted living", In *Collaborative Networks in the Internet of Services,* Springer, 2012, pp. 117-127.