An Integration Platform for Private Assisted Houses

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Keywords: Ambient assisted living, Smart Environments and Housing, Home Care Monitoring Systems, Remote Monitoring, Assistive Technology and Adaptive Systems.

Abstract: A Private Assisted House aims to define a novel care model focusing on the changing needs of people to promote active life expectancy. This raises the need of personalization in the design and development of Smart Home, so starting from users requirements we stress the need of integration suitable to support such changing requirements. In this paper we discuss Private Assisted House integration platform focusing on its conceptual model and reference architecture. The platform is defined around a set of smart objects managed by a home gateway that communicate with a Cloud Center. This organization provide two kinds of processing: (i) local to the house, and (ii) remote. The local processing involves events, triggers, commands and automations managed directly for the gateway. The remote processing implies communication from the house to the Cloud Center that can provide intelligence to the house using high-level applications that use data correlation to perform specific tasks.

1 INTRODUCTION

Italy is one of the European countries holding highest ageing index rate. This implies an exponential growth of the costs of care for the elderly in the foreseeable future. According to recent demographic projections in Italy, over-65s in 2020 will be 22.5% to reach the threshold of 32.6% by 2065. Even more significant is the increase of the over-80s, which will increase from the same period from 2.8% to 3.7% and 10% (source: www.demo.istat.it) and the perspective of longevity and active elderly population is growing quickly. At the same time people, at least in Italy, like to spend their elderly time in her/his home, a place where she/he can continue to carry out usual activities both in the case of independent living or life in the family.

From this context rise the need to provide population with an adequate home care and risk prevention. To do that technology evolution is a driver and make possible guarantee the same level of care according to budget constraints given among the others by the economical crisis. Technology is able to guarantee also a certain level of personalization since elderly profiles are different from person to person and at the same time they change from time to time.

In this paper we present a software integration platform suitable to support a personalized care model in their private home with the benefit of innovative and content-based services made by user-friendly technologies. This means that different levels of service are enabled by a flexible software integration platform that is introduced with this work, and it is adequate for people with different degrees of aging and/or disability according to the DfA "Design for All" paradigm (Mace et al., 1990).

The platform is based on the concepts of Internet of Things (IoT) (Gubbi et al., 2013) with the ability to measure, infer and understand environmental indicators in a private house while rely on the power of cloud computing and big data technologies to provide a virtual infrastructure that integrates monitoring devices and analytics tools. We based our model on a platform that can integrate and coordinate home automation, tele-care solutions and smart-objects responding in a personalized way to concrete needs of automation, prevention, safety and communication. This new class of Ambient Assisted Living (AAL) technology will bring new capabilities such context awareness, anticipatory behavior, user friendliness and flexibility (Nehmer et al., 2006). Moreover, we extended our model with advanced monitoring func-

Corradini F., De Angelis F., Re B., Anceschi E., Callisto De Donato M. and Iddas P..
An Integration Platform for Private Assisted Houses.
DOI: 10.5220/0005436000450052
In *Proceedings of the 1st International Conference on Information and Communication Technologies for Ageing Well and e-Health* (ICT4AgeingWell-2015), pages 45-52
ISBN: 978-989-758-102-1

tionality by applying a probabilistic framework based on the Bayesian networks in order to further improve behavioral analysis based on the data incoming from the house.

The development of the platform was conducted within the Pass (Private Assisted House Project) project. It is part of an regional public financed initiative for the development and implementation of real life diffusion of Ambient Assisted Living systems (Rossi et al., 2014).

The paper is organized as follows. Section 2 describes the development of the conceptual model. After this Section 3 introduces the integration platform reference architecture. Section 4 presents a real scenario with reference to the solution in practice. Finally, Section 5 introduces relevant related work and Section 6 draw some conclusion.

2 PRIVATE ASSISTED HOUSES CONCEPTUAL MODEL

The conceptual model of the Private Assisted house (PAss) is characterized by a multilevel structure with a strong decoupling in data processing, both in the implementation of basic functionality directly available in the house, and in the implementation of the advanced features through methodologies and technologies that are located at the cloud level. It is reported in Figure 1.

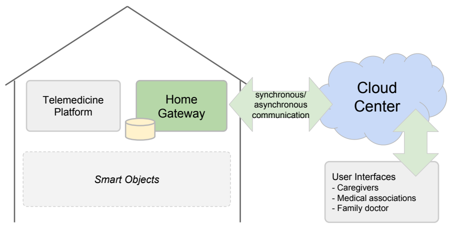

Figure 1: The main components of the Private Assisted House.

The architectural model defines the following functional components.

- **Smart Objects**
  A smart object is an object able to describe its interactions with the physical world (Kortuem et al., 2010). It has both physical properties and information related to them. In addition to this, it is endowed with the ability to communicate with other objects and with the environment to which it belongs with the aim to interact with other objects and coordinate the execution of complex actions.

  Under the PAss project several smart objects have been developed including: doors and windows with automation functionalities, a liquid-screen window with programmable opacity, motion sensors, light controls, temperature controls, wearable sensors for monitoring vital signs, etc.

- **Home Gateway**
  The home gateway component implements the business logic for the local management of the house. It uses data coming from the smart objects and from external entities such as, for example, the Cloud Center (CC) or the telemedicine platform. In the architectural model, this component consists of an embedded system developed with open source technologies.

- **Cloud Center (CC)**
  The CC component implements a higher level of processing that involve data coming from the house. This allows storage, normalization and analysis according to a logic that is not usually available in the local environment of the house. The component is built using technologies that enable the management and persistence of data like in a typical big data scenario.

The conceptual model outlined above is the starting point for the definition of an integration platform within the PAss house. The house will be equipped with a software platform that offers integration features for domestic devices in a communication network inside the house. This provides integration capability with the outside towards the CC that is able to realize complex functionalities that usually are not available within a classic home automation. The platform objective is the implementation of welfare scenarios that could evolve over time involving devices and automation inside the house while exploiting complex functionalities made available outside.

The presence of objects, home gateway and cloud center respond to the needs to have a physical interaction with user and two level of processing, one related to the house with small, simple actuation and one able to introduce in the house new configuration over time to respond to the changing needs of the users. New configurations are built in the CC automatically from algorithms specific for the disease/disability under control or by a human physician that control the house environment.

The high-level view of the integration platform software revolves around five key concepts: (i) detection, (ii) processing, (iii) actuation, (iv) interaction, and (v) communication. The goals we want to achieved is to provide an assistive environment with a non-invasive approach. We offer a single system with

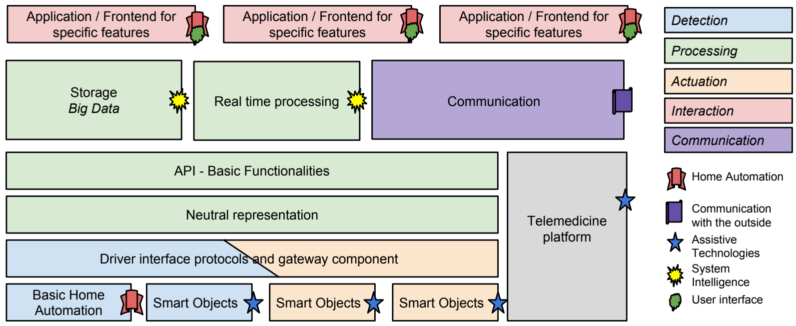

Figure 2: The architecture of the PAss platform.

many different functions and the opportunity to increase them through the applications deployed in the Cloud Center located outside the house.

The Figure 2 describes the features that are implemented in the platform through the use of components based on open source frameworks or through development from scratch during the project.

The lowest layers of the system are responsible for detection and actuation capabilities. Here the system integrate both legacy devices for basic automation (already commercially available), and new smart objects (developed in the project) aimed to introduce assistive technologies in the house. The former are integrated using well-known protocols (i.e. KNX, Bticino) while the latter are built to a higher level, agnostic transport protocol, through the definition of payload in textual format (using the JSON notation). Both categories of objects must be represented in a neutral manner with respect to the underlying protocol. In this sense, the object is generalized with respect to the specific protocol in a neutral representation that is based on the functionalities of the object (for example a switch will exhibit the functionality of on/off, and so on).

In a higher level to provide the platform with a neutral representation, we use some abstractions to ensure independence from the lower layers and to enable the ability to interoperate. In this regard, the platform will incorporate the Open Source product Freedomotic (Freedomotic web site, 2014), a software component that has a flexible and scalable architecture that can interact with best-known protocols of building automation as well as custom solutions. Freedomotic exploits modern enterprise integration models and architectures of distributed computing, along with the APIs used for its extension. It was chosen as a reference after a phase of scouting for home automation technological platforms with the requirement of extensibility, open source philosophy, technological maturity and the ability to provide APIs to other system components.

The Freedomotic component is placed side by side with a telemedicine platform. Telemedicine allows the query for medical information and the administration of devices that collect such information. The data gathering is made using REST web services with payload described using the JSON notation. We can reach the following measuring instruments to assess vital signs supported by the system: (i) BPM Blood Pressure Monitor, (ii) PFM Peak Flow Meter, (iii) BGM Blood Glucose Monitor, (iv) VSM Vital Signs Monitor, (v) HWS Health Weight Scale, (vi) BCM Blood Coagulation Monitor, (vii) ECG ECG Monitor, (viii) PO Pulse Oximeter.

The communication layer is provided by the MQTT (Mqtt web site, 2014) protocol. This provides a flexible infrastructure to publish and subscribe messages with the ability to discriminate them using their *topic*. Each publisher sends content to specific topics, while each subscriber retrieves them subscribing for updates related to that topic. The platform will provided two kinds of processing: (i) local to the house, and (ii) remote.

The local processing involves the use of a model based to events, triggers, commands and automations. The events are generated by the smart objects and delivered towards the integration platform where they are related with the triggers in the system. The triggers detect particular conditions from the events content. This activate commands to the actuations of the house. In this sense, the automation expresses a correspondence between one or more triggers and one or more commands. At this level, simple domestic automations are possible in the form of *if-then-else* rules.

The remote processing implies communication from the house to the outside to send information about its state and retrieve commands to be executed. It refers to what happens in the CC that provides information persistence to high-level applications that can provide automation to the house. At this level there are domestic automations whose implementation is defined by a correlation of high-level data that cannot be achieved in the home gateway.

The CC represents the intelligence of the system enabled by big data storage and analysis features. In particular, the open-source distributed framework Hadoop (http://hadoop.apache.org/) based on the well-known MapReduce framework (Dean and Ghemawat, 2004) and the non-relational database HBase (http://hbase.apache.org/) based on Google's BigTable (Chang et al., 2006) provide the ability to retrieve data and correlation about the house and its occupants. This provides the ideal knowledge base for the realization of applications whose functionalities are based on inferences and correlations. At this level, the information retrieved from the house and from the telemedicine platform are related to achieve a specific assistive goal (i.e. check the normal everyday life of an elderly at home).

The solution chosen in PAss is the use of applications based on *Bayesian networks* (Pearl, 1988) that allow the platform to perform correlations between incoming data from the house and other external components (for example the telemedicine platform) in order depict facts from which produce actuations to be executed in the home to support such scenarios. A Bayesian network is used to model a domain containing uncertainty in some manner. In our case this uncertainty can be due to imperfect understanding of the domain or incomplete knowledge of the state of the domain at the time where a given task is to be performed. Indeed, the measurement process of the physical quantities that defines the state of the system is made by a distributed sensor network that act in a asynchronous fashion: in every moment of time some of this observation of the physical world will be characterized by uncertainty.

Bayesian networks have been used since they are a representation of a probabilistic model, which is for us the reproduction of a probability distribution over a set of variables to support the implementation of advanced features for the house. This approach, which combines statistical methods and artificial intelligence, it is a useful tool in many ways, including the ability to simulate and replicate complex situations. Moreover, Bayesian networks are able to highlight the structure of a phenomenon by means of an intuitive graphical representation allowing the non-expert in the field to understand relationships. Using this approach it is possible to learn information from the data and, at the same time, to introduce in the analysis an expert judgment (medical, etc.).

Based on this approach, in the PAss house we are able to correlate information about the state of the environment with information about the vital signs supported by the telemedicine system in order to state what are the condition of normality when living in the PAss house besides conditions that could lead to dangerous state as explained in Section 4.

3 PRIVATE ASSISTED HOUSE INTEGRATION PLATFORM

3.1 Reference Architecture

The architecture of the integration platform is made by several components represented in Figure 3.

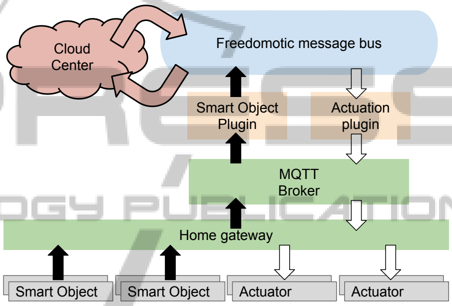

Figure 3: Communication flows of MQTT messages.

The system consists of five basic parts:

1. A network of sensors whose task is to collect data and send them to the home gateway.
2. The home gateway based on Freedomotic, that manage the house and the flow of incoming messages from the sensor network and the CC.
3. A broker for messages that redirect the received messages to the subsystems that require them.
4. The PAss database that is responsible to store data from the network of sensors and the events detected by Freedomotic. It maintains the local history of messages coming from the CC.
5. A CC that store and analyzes the collected data from the house by using the Hadoop framework and Bayesian networks. It generates the actuations for the home gateway in the house.

The data streams managed by the system are essentially two:

- In black arrows, we highlight the data collected by the sensor network that are sent through the broker messaging system to Freedomotic. Data is analyzed and redirected in three directions: (i) to the PAss database in the home gateway; (ii) to the user interface that update the graphical objects with the values collected by them; (iii) to the remote CC.

- In white arrows, we highlight the messages coming from the CC implementation which are forwarded to the home gateway system. The local system update the graphic interface of the actuators for which the CC sent information. The system forwards the commands to the real actuators inside the environment.

3.1.1 PAss Data Model

Within the platform for the PAss house there are two main data sources. The telemedicine platform, which is an autonomous system with its own data model and the data model specifically developed for the smart objects. This model is divided into three parts corresponding to the three types of messages that can be managed by the platform:

- **Measurement Payload.** The data sent from the smart object follow a data model that is used for the local processing in the home gateway, for the update of the user interface, and for the CC. The standard data that are sent from each smart object contain: the date and time of the measure, the type of smart object that carried out the measure, the address associated with the object, its unique identifier within the network of sensors, a Freedomotic name and address. These data are generated at each measure. The specific data collected from the single sensor is sent as a tuple with the name of the collected measure, its value and its measurement unit.

- **Actuation Payload.** The messages with an actuation payload from the CC are addressed to the actuators available in the house. These messages shows what the objects must perform according with the data gathered from the environment. The payload contains information such as the time stamp of the message, the unique identifier of the actuator, the name and type of the objects and finally the command that it must perform.

- **Configuration Payload.** The messages with a configuration payload from the CC contain a description of the triggers and controls that the house should be able to run autonomously to respond at changing conditions in the environment. These are messages used to reconfigure the home gateway due to a change in the assistive scenario. The content foresee a timestamp related to the message generation and a list of triggers to be installed (or removed) form the actual configuration of the home.

3.1.2 Local Applicative Model

The PAss is locally managed through the home gateway based on Freedomotic. Freedomotic adopts a messaging system based entirely on events. Any change in the environment or interaction with the software by users generates an event (click on the graphic interface, changing a value on an object, etc.). These are published on defined channel and intercepted by triggers. In turn, each trigger can be associated with one or more commands defining a reaction. In other words, when a sensor communicates any change in the environment, an event is generated on a specific channel, and if the event is consistent with the trigger, then one or more commands can be sent to the actuator that can run them.

This mechanism allows the creation of rules for automation in a very simple way. The rules are expressed using the template ”if THIS then THAT” where the part THIS corresponds to a trigger, and THAT is made by one or more commands executed in sequence (similar to the popular approach in https://ifttt.com/). The rules system allows to hide the implementation details of the triggers and controls on virtual objects allowing their use for inexperienced users. They can manage the house to create automations via the user interface of the system.

The use of local rules is not enough for the PAss house. Instead, we must use an ”intelligence” located outside the house that should be able to aggregate data from multiple sources, including telemedicine platforms. The integration of different data in the home allows the derivation of configuration and actuation messages for the house.

3.1.3 Remote Applicative Model

In the remote Cloud Center, the application model of the integration platform of the house is extended with an external logic. The data coming from the house are stored, normalized through big data technologies and made available for processing with the Bayesian networks to enable applications that detect abnormalities and predict hazardous conditions.

To meet these requirements, the sensor data must be integrated and interpreted using proper models and technologies able to deal with uncertainty conditions, for example some sensors could not sent the measurements due to a technological problem, and we will work in a non-deterministic but probabilistic setting. For this we need a tool that models situations involving uncertainty as, indeed, the Bayesian networks.

To sum up, the system for scenarios recognition consists of the following elements that communicate using the same messaging system described above.

Physical sensors (Smart Objects): sensors that detect what happens inside the house and provide the raw data for the CC applicative model; *Virtual sensors*: software components that aggregate and filter raw data by using mathematical models to avoid erroneous readings and to describe measurements as a sample in a stochastic process; *Bayesian networks*: component that recognizes system states and scenarios to reach a high-level goal; *Actuators*: components that make decisions and allow the system to react autonomously in the house environment.

In the CC we place all the components needed to make the management and monitoring of smart homes (for example by caregivers, medical staff, welfare associations), the management of the configuration of the PAss integration platform, and the exploitation of the telemedicine platform.

4 A DAY IN THE PAss HOUSE

In order to validate the integration platform different use cases has been identified focusing on different levels of care. We assumed a light scenario, an intermediate scenario and one advanced scenario. In the following we refer to an intermediate scenario as a good example of what the house can do to support the daily routine.

> ”Mark is a retired person of 65 years old, married with no children. He had an ischemic stroke with paralysis of the right upper and lower limbs 14 months ago. The relevant aspects of his health condition can be synthesized as: right hemiparesis with a flexion contracture of the upper limb, aphasia and dysphagia; high blood pressure; severe tendinopathy of the subscapularis muscle of the left shoulder; prostatic hypertrophy. While there is only a minimal chance of a functional improvement, there is a real danger of regression, both in the motor functions and in the cognitive one. In particular, we want to avoid the loss in the ability to walk and the worsening of flexion contracture of the upper limb. Mark was discharged from the rehabilitation center three months after the stroke, and then he continued to rehab in Day Hospital (DH). Once evaluated his socio-health situation, the physiatrist and social services have suggested Mark and his wife to move to a PAss house, more suited to the needs of the family.”

By showing this use case we will also focus, in subsections 4.1 and 4.2, on two particular situations that may occur in the house.

> ”His day begins at 8 am. After waking up, he is able to get out of bed due to its integrated automation system and with the help of his wife. Mark is able to walk short distances with orthosis and a stick support and can reach quite easily the bathroom where he can wash in a bathtub with a rising platform, always with the help of a caregiver. Moreover, if the transfer should occur in the absence of caregivers the presence of a motion sensors system reveal any falls, ensuring a call to the rescue.”

In this situation, the system will use the motion sensor Passive InfraRed (PIR) located inside the house (usually one for room) to detect the movement. These sensors trace the movements within the home environment and, together with the pressure sensors located on the sittings, we can monitor the activities carried out identifying abnormalities. As outlined in the previous sections, these conditions will be monitored through the Bayesian network framework where the network states use the data incoming from sensors in order to establish the conditions of normality and abnormalities.

The normal condition implies that at least one sensor registers the presence of the person through the recognition of a movement (with the exception of the person that is not in the house). Terms of inactivity (for example, TV watching, sleeping) are considered normal if they involve the use of furniture such as chairs or bed with a pressure sensor that detects the use. Abnormality conditions can depend on: (i) Fall or prolonged inactivity: PIR sensors do not detect movement for a long period of time and/or is not recognized the use of chairs/bed; and (ii) Malfunction of the sensors: the absence of data or conflicting data that would result in uncertainty in the assessment of the scenario.

> ”Mark can reach the kitchen in an autonomous way. The morning is the part of the day dedicated to rehabilitation aimed primarily at preventing complications due to hypomobility of limbs and to increase physical performance. During this phase, as for the rest of the day, it is very important to measure vital parameters through a wearable system of sensors. This is aimed to monitor at a distance the condition of hypertension.”

While the environment is monitored, the person is constantly controlled by wearable sensors that are able to detect vital signs (heart rate and respiration, activity level and posture). These information are involved in the assessment of the condition of normality/abnormalities through the Bayesian network framework. If the system detects a situation of inactivity, the condition of normality can be detected through the vital parameters measured by the wearable sensors. Moreover, the sensors are able to detect the posture (vertical or horizontal) and the acceleration along three axes. This is useful to determine emergency conditions such as the occurrence of a fall (always considering the data provided by the other sensors in the house).

> ”The afternoon is the time for relax and the presence of a caregiver within the home is not essential. Mark, using a simplified interface, can provide for the regulation of temperature and brightness, enabled by the presence of liquid-screen windows to mitigate sunlight.

Here, the environmental sensors (light meter, temperature/humidity, gas) monitor the conditions inside the house. The supplied data are used to adjust the conditions of brightness and temperature in the environment either automatically, or manually by the user through an interactive graphical interface. The data collected from the monitoring system are correlated with information from other sensors in the house (PIR, pressure) again by applying the Bayesian network framework. For example, if at a certain time of the day the person is in the living room and the light meter registers an excessive lighting, the system can respond automatically activating the darkening of the liquid-screen windows.

4.1 Fall Recognition

In the unpleasant situation of a fall, we can have the intervention of several sensors: motion (PIR) and pressure (chair) sensors as well as wearable sensor (posture) giving the following information: (1) Movement in the kitchen and chair use, (2) Movement in the bathroom, (3) No movement in any room, with speeding down, person in a horizontal position, (4) Movement in bath, speeding down, person in a horizontal position.

In the above cases, we outlined two different levels of emergency that can be summarized in a Bayesian network: (i) The person is still and may have lost consciousness; (ii) The person moves (detected by the PIR in the bathroom). The condition of horizontal position and the detection of a downward acceleration are considered fundamental situations because they are considered an abnormality inside the bathroom.

4.2 Adjustments of Environment

Some scenarios can involve environmental monitoring sensors (temperature/humidity, light meter), motion sensors (PIR, pressure), an interactive panel, a graphical interface and the liquid-screen window. For example, in a bedroom the data provided can be the following: (i) Movement in the bedroom, not enough room lighting (the system responds by turning on the light in the room); (ii) Movement in the kitchen, temperature below the average (the system performs a temperature regulation modulating heating); (iii) The operation of the window is performed manually by the user to answer a particular need.

5 RELATED WORK

In the context of Internet of Things and Ambient Assisted Living much interest has been placed into the home environment to address issues related to medical care and for the comfort and welfare of the inhabitants. Several projects and works have been developed, each with different characteristics and target. We report some works that are most close to our.

In (Kaldeli et al., 2013) the authors report the effort made in the European project SM4ALL that aims to build a smart home able to exhibit complex functionalities build over a set of services offered by real objects and the environment. The system is characterized by a composition of services made using planning techniques that deals with devices that evolve over time exposing new functionalities or disappearing from the environment. In such high dynamic context declarative goals are stated by the user (or inferred by rules) and then a plan of actions is made by the planner and realized by the pervasive layer of object in the house.

The MavHome Smart Home research project equips the house with the ability to make decisions based on predicted activities looking for pattern of device utilization and movement in the house (Rao and Cook, 2004). Actions of the inhabitants are modeled as states in Markov models to provide automation and adaption to the inhabitant’s needs.

In (Pellegrino et al., 2006) an architecture of a home automation gateway is presented. This approach supports the integration of heterogeneous devices and uses an enhanced run-time engine to generate events at run-time basing either on events coming from the house or by inferred rules to prevent annoying or dangerous situations.

Some efforts are also made by the Ambient Assisted Living Joint Programme (http://www.aal-europe.eu/. The problem of monitoring vital signs is faced by EMOTION-AAL (http://www.emotionalaal.eu/) and H@H (http://www.health-at-home.eu) projects that aims to build integrated platforms for collecting data from a variety of bio-sensors for the permanent monitoring of the state of health of the users. Fall detection is also investigated, among others we can mention CARE (http://www.care-aal.eu) and ROSETTA (http://www.aal-rosetta.eu/). They provide a way to monitor, analyze and interpret the behavior of the elderly at home (such as falls or loss of consciousness), and automatically generate an emergency call.

6 CONCLUSION

This work is the results of a public financed action for the development and implementation of an integration platform for Ambient Assisted Living to monitor activities of daily living and to detect any abnormal behavior that may represent a danger, or highlight symptoms of some incipient disease. According to the need of elderly people, Private Assisted House is also an enabling technology for the development of a novel care model that considers the changing needs of users using an highly configurable integration platform aimed to support their daily life.

Our future works will go in several directions: (i) the prototype and care model will be evaluated in rehabilitation institutions of Marche Region (Italy) to allow an experimental evidence of the working system and to provide feedback for further technical developments; (ii) we want to extended out platform over time with new components to solve specific problems or address the needs of a specific category of people (or disabilities, or disease) integrating also the development of specific tools and smart object; (iii) we intend to further improve the application of the Bayesian networks in order to implement a scenario where the system changes over time, by learning or by changing conditions of normality and abnormality based on habits of the subject who lives in the PAss house; (iv) we want to work on a care model suitable for Marche Region institutions to bring AAL to the user's house.

In this respect, this work represent the core of an infrastructure that will be used in real scenarios and a special attention will be devoted to the result obtained not only form the technological perspective but also from the quality of life perception form the end-users.

ACKNOWLEDGEMENTS

The project PAss ”Private Assisted House” (www.projectpass.eu) is co-funded by the Marche Region administration, under the action ”Smart Home for Active and Healthy Aging”, so we thanks to Marche Region and all the partners of the project.

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