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A Service-oriented Architecture for Ambient-assisted Living

Margherita PERUZZINI[a,1] and Michele GERMANI[b]
[a] *"Enzo Ferrari" Engineering Department, University of Modena and Reggio Emilia, via Vivarelli 10, 41125 Modena (Italy)*
[b] *Dept. Industrial Engineering and Mathematical Sciences, Università Politecnica delle Marche, via Brecce Bianche 12, 60131 Ancona (Italy)*

Abstract. Ambient-Assisted Living (AAL) is currently an important research and development area, mainly due to the rapidly aging society, the increasing cost of health care, and the growing importance that individuals place on living independently. The general goal of AAL solutions is to apply ambient-assisted intelligence to enable people with specific demands (e.g. handicapped or elderly) to live in their preferred environment longer by tools (i.e. smart objects, mobile and wearable sensors, intelligent devices) being sensitive and responsive to the presence of people and their actions. The research describes the design and development of a novel service-oriented system architecture where different smart objects and sensors are combined to offer ambient-assisted living intelligence to older people. The design stage is driven by a user-centred approach to define an interoperable architecture and human-oriented principles to create usable products and well-accepted services. Such architecture has been realized in the context of an Italian research project funded by the Marche Region and promoted by INRCA (National Institute on Health and Science of Aging) in the framework of smart home for active ageing and ambient assisted living. The result is an interoperable and flexible platform that allows creating user-centred services for independent living.

Keywords. Service-Oriented architecture; Smart Home; Smart Object; Ambient-Assisted Intelligence; Ambient-Assisted Living.

Introduction

Nowadays Ambient-Assisted Living (AAL) represents one of the most flourishing fields of application of Information and Communication Technology (ICT) and Service Engineering since the growing importance of assistive services. This phenomenon directly derives from the continuous global population ageing and the growing necessity to help people with specific demands (e.g. elderly) to live longer in their preferred environment by increasing their autonomy, monitoring its actions and providing care [1]. Indeed, developments in assistive technology are likely to make an important contribution to the care of elderly people in institutions and at home thanks

[1] Corresponding Author.
Margherita Peruzzini, University of Modena and Reggio Emilia
via Vivarelli 10, 41125 Modena (Italy), e-mail: margherita.peruzzini@unimore.it

to the adoption of the so-called ambient-assisted intelligence systems: remote monitoring, electronic sensors and equipment such as fall detectors or door monitors can improve older people's safety, security and ability to cope at home. Care at home is often preferred by patients themselves and is usually less expensive for care providers than institutional alternatives.

In the last years, some attempts have been made to explore the use of intelligent objects, also called Smart Objects (SOs), to provide assistance and monitor the users' wellbeing to support an independent living. In most cases, ambient-assisted intelligence can be added to traditional objects to create intelligent devices able to collect information about the environment and people living inside, and create high-level information to be re-used to design and configure products and services according to the users' needs. However, the main problem of AAL systems is their complexity and poor acceptability [2]. In this context, only starting from the analysis of the users' demands and requirements and adopting User-Centred Design (UCD) principles allow designing high usable systems able to collect the right set of data from both users and environment and optimize the human-machine interaction achieved [3]. Furthermore, only adopting a highly interoperable approach lead to design a flexible and scalable system with high performance [4, 5].

The present research proposes a new model to realize a service-oriented architecture for AAL: the system includes smart products, an ambient-assisted intelligence, and user-centred services to support active aging and independent living. The system is defined on the basis of an interoperable system architecture that manages every kind of product or service as a SO a priori, without knowing its specifications in advance or adhering to some specific communication standards.

1. Research background

The notion of SO describes a technology-enhanced everyday object equipped with sensors and memory to have communication and data exchange capabilities [6,7]. A SO is usually able to capture information about its surrounding, communicate with other devices and react according to previously defined rules [8]. Such information can refer to object properties (physical properties or text), interaction information (e.g. position of handles, buttons, grips), object behaviour (based on state variables) or agent behaviours (rules that an agent should follow when using the object) [9]. From an assistive point of view, a SO interacts with humans directly and supports the users to accomplish their own tasks in an intuitive way [10]. As applied to people with disabilities or frailties in general, a SO can be considered as "a device that allows an individual to perform a task that they would otherwise be unable to do" [2].

Nowadays numerous SOs are commercially available at low cost and many researchers are intensively working on their application to support elderly at home. The applicability of SOs in monitoring the users' conditions and providing the most appropriate support has been tested and demonstrated thanks to numerous EU projects: e.g. AGNES (Successful Ageing in a Networked Society) [11], HAPPY AGEING (A Home based APProach to the Years of AGEING) [12], PAMAP (Physical Activity Monitoring for Ageing People) [13]. At the same time in America the MIT Media Center is developing projects in this direction [14]. Furthermore, an inventory of the main characteristics and functionalities of such products for assistive purposes for elderly has been recently defined by [15]: it provides a useful overview for both researchers and designers about the potential application of SOs in supporting elderly people independent living and the main functional domains of activities that can be performed in a domestic environment with their support. However, an effective introduction of SOs into a real home environment is still hard to achieve. Acceptability and interoperability are the first two issues to solve.

At the same time, home automation industry is growing and its market is expected to expand for the next few years [16]. Forecasts estimate that the global market of home automation will reach $ 51.77 billion by 2020 with an annual growth rate of 17.74% from 2014 to 2020 [17]. However, the analysis showed that the application of large-scale and full implementation of home automation interoperable systems to create really smart living environments is still far from a reality. This is due to several factors: the lack of standardization, high costs for system integration and maintenance, and lack of interoperability due to the use of proprietary systems and closed communication protocols. In recent years, in fact, the number of applications that require the cooperation of several heterogeneous devices has grown very rapidly. Components, belonging to very different technologies and characterized by different complexity and products from different vendors, are often used together within the same home automation ecosystem. In literature different models of interoperability have been proposed [18]; they typically are organized into 3 levels (syntactic interoperability, network interoperability, and basic connectivity interoperability). An important aspect to ensure the intelligence of a home automation environment and to address the issues of interoperability is to appropriately model the heterogeneous information as environmental parameters, devices and their characteristics, the users and their preferences, the operating environment, etc [19, 20, 21]. Furthermore, a proper semantic description of the devices involved is fundamental to enable interoperability: it allows the devices' search and identification, and lets high-level services to be easily created and managed. Dibowski [22] provided a framework of ontologies to describe smart home devices as well as their functionalities, platform and producers in the domain of building automation. For instance, DogOnt has been specifically designed to model an environment describing intelligent home automation devices, their state, their functionality and notifications, and the architectural components [23]. Moreover, context-aware applications can use this information to support decision-making and to enable services to support users in their everyday activities (e.g. CONON ontology [24], CODAMOS ontology [25], Think Home [26], BONSAI ontology [27]).

2. The AAL system definition

2.1. The HicMO project

The HicMO project has been promoted by INRCA (National Institute on Health and Science of Aging) and funded by the Marche Region, in Italy. It involved 12 companies, both Large Enterprises (LEs) and Small and Medium Enterprises (SMEs), and 1 Research Centre; it started in February 2013 and has just ended (February 2015).

HicMO is the acronym of "Hic Manebimus Optime", a latin sentence by Tito Livio (i.e. Ab Urbe condita libri, V, 55) which stands for "here we will live very well" and express the general approach of the future users of HicMO technologies. It aimed to develop ICT system architecture able to manage smart products and services to support the active ageing by an ambient assisted living approach. The concept of SO assumes a great importance for the project purposes; in he HicMO context a SO is “any object or home device that is able to communicate its interactions with the user in order to monitor the daily activities, to understand the habits, to detect any abnormal behaviour that may highlight situations of hardship or danger, or the symptoms of some incipient illness”. The present research moves into the boundaries of the HicMo project and, in particular, defines the HicMO system architecture and describes the HicMO system prototype that overcomes the main limitations of the previous systems in terms of both usability and interoperability.

2.2. The project approach

In order to deal with usability and interoperability issues, HicMO is based on an Assistive Integration Platform (AIP) that allows both hardware and software integration and, in particular, enables communication between any product or service to create high-level AAL functionalities to support older people with their home environment. It is possible thanks to the abstraction of the SO concept and the adoption of a proper ontology to interpret and manage input/output data and information in a proper way. According to the HicMO approach, every entity can be represented as a SO independently from its specific characteristics, and can be described by a proper ontology. According to such ontology, new product functions and service applications can be created by ad-hoc system intelligence. The platform (AIP) is composed by a low-level layer and a high-level layer: the low-level layer allows to exchange input-output data with every SO connected to the platform, while the high-level layer interprets the collected data according to the defined ontology Interaction between the AIP and the SOs represents the core of the system. In particular, a Reference Model is defined to describe any SO entity and to manage any data exchange in different cases: data provider, data consumer, service provider, and service consumer. In this way communication between the AIP and any SO is enabled a priori, without exactly knowing the specific features of the SO in advance. A SO can be a physical entity or a virtual entity, also created by the aggregation of multiple sensors or devices. Similarly, also services can be managed by the AIP as a SO: they can be provided by means of products as well as web services and exchange data and information with the other entities connected to the system. Such architecture guarantees system flexibility, scalability, interpretability and configurability. Indeed, HicMO is not a closed entity but is a dynamic system able to configure its functions and services according to external conditions. Such conditions are directly defined considering the specific users’ needs.

2.3. The system design

The entities constituting the HicMO system architecture have been defined according to a UCD methodology, which combined Delphi and Quality Functional Deployment (QFD) technique. The method focuses on the analysis of the users’ needs and identification of the main system requirements as well as the selection of the most proper technologies and the definition of a suitable architecture to assure interoperability, configurability and high usability. The method consists of a double phase of evaluation involving experts in different disciplines according to the Delphi technique; method phases are organized in four steps and formalized according to the QFD approach to better highlight the data involved and the correlations required as described in a previous research work [28]. The former technique (i.e. Delphi) aims to facilitate idea exchange between experts thanks to the comparison among the different opinions and their progressive convergence on common key points allowing the identification of relevant topics from the natural convergence of opinions [29]. QFD allows the easy correlation between users' needs and technical specifications of the available systems and technologies in order to find out the best system design as demonstrated in [27]. The method steps are based on the following steps:

1. *Analysis of the users' needs*: it involves experts and uses interviews and ad-hoc questionnaires to depict a wide market analysis, identify the market segments and define target users and needs;
2. *Mapping of assistive devices' functionalities*: it involves technicians, designers and experts in SOs and ATs to define the functionalities that can be provided by the different technologies and their correlation with the specific devices by focus groups and brainstorming;
3. *Correlation between users' needs and functionalities*: it involves both experts and samples users to evaluate and compare how different functionalities can support the users' needs. It uses visible planning technique to support a pragmatic and effective discussion;
4. *Elicitation of the system requirements*: it relates the necessary functionalities with the technological parameters for system requirements elicitation by adopting the Design Structure Matrix (DSM) method.

In the present research, such a method has been applied to a wide user sample and a real system architecture has been defined (Figure 1). Technical requirements have been investigated to create a unique integrated platform; also communication exchange requirements have been analysed.

The architecture is based on following items: 1) an ad-hoc hardware data gateway able to concentrate heterogeneous data from different objects; 2) a set of adaptors able to make a simple object into a SO providing is a higher intelligence to exchange data with other systems, like smart plugs and smart adapters; 3) a dedicated software intelligence able to recognize and manage the different objects in an homogeneous way; 4) a set of local gateways able to exchange data with standard home automation protocols, such as Bticino, Konnex (KNX) and Modbus, as sub-systems.

In more details, the AIP is the core entity of the system: it includes a Low Level Gateway (LLG) to physically connect the SOs, and an High Level Service (HLS) to manage data exchange and SOs interrelations, thanks to a system intelligence to enable service functionalities and to coordinate the SOs actions and reactions. In this way, data are collected from and send to any SO by the LLG, while data exchange is coordinated by the AIP. The LLG manages a set of different home devices by different communication protocols, from Bluetooth to ZigBee and Wi-Fi. At the same time, the AIP is connected to external gateways by means of a router in order to exchange information with standard home automation protocols and manage devices also in these environments. In this way the AIP can create specific services and assistive functionalities, specifically tailored on the users' needs, by exploiting all the devices' single functions into an interoperable context.

As a result, the HicMO system allows to receive data from a wide variety of sensors (i.e. environmental, wearable, medical, etc.) and, at the same time, from commercial smart objects as well as standard home automation systems, and to interpret those data by creating a set of higher level information that can be used from the system objects and services to generate personalized reactions and provide ad-hoc functionalities according to the specific user needs and context-based conditions. In this way, such behaviour merges both assistive and home automation features. On one hand, typical home automation features refer to those functions based on the detection of environmental parameters and performed by independent devices that do not act directly on the person, but create a supporting environment. Indeed, the HicMO system includes a set of environmental sensors, which detect environmental conditions (e.g. temperature, humidity, air quality, lighting, infrared image) to provide measurements and generate alerts when needed (for instance, when fixed thresholds are exceeded or data processing highlights dangerous or abnormal conditions). Furthermore, the system includes a tracker that indirectly detects the user's position in certain places and during certain actions by placing the corresponding tag close to reference points (e.g. door handles or appliances, drawers, etc.) and its combination with an RFID tag worn by the user (on a ring). Also the presence of sensorized kitchen items, in particular hangings, drawers and intelligent household appliances (i.e. fridge), provides information about user accessibility and can be remote controlled according to the user's permissions. Furthermore, wearable devices such as shirt and shoes give information about their fit and user's positioning and motion. Finally, the integration with standard home automation systems like Bticino and KNX allows detecting environmental parameters (e.g. temperature, presence etc.) and controlling cabled devices (i.e. lighting system, home automation controls).

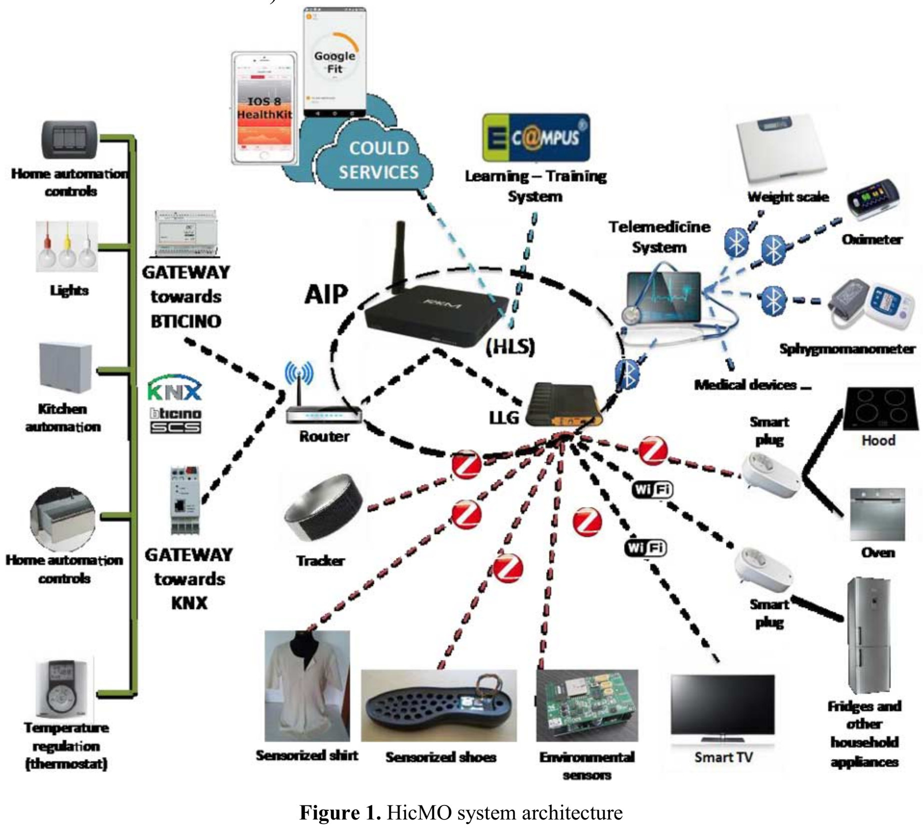

Figure 1. HicMO system architecture

On the other hand, typical assistive features refer to direct-monitoring functions that directly act on the users and their behaviours, such as monitoring vital signs or monitoring of the users' actions. Firstly, the HicMO system includes a telemedicine platform that allows measurements of vital signs through the integration of different devices: a digital sphygmomanometer to measure blood pressure (minimum pressure and maximum heart rate), a digital scale to measure the users' weight, a pulse oximeter to measure the oxygen saturation in the blood, an electrocardiograph (ECG) to measure the ECG waveform. Similarly numerous other devices can be added. Furthermore, a sensorized shirt provides data related to the user's movements (by means of an accelerometer and gyroscope) and his/her sweating by means of Galvanic Skin Response (GSR), and sensorized shoes measure the performed steps, the consumed energy, the duration and the frequency of the pitch and other parameters involved in the gait, which can be used to monitor the user's state of health. Data are exchanged and managed in an appropriate way by the AIP to create intelligent behaviours.

Interaction among devices is guaranteed by the following conditions:

1. all devices are seen as software entities (i.e. SO) able to communicate by http/https protocol, so that their low-level specifications are not important for the AIP;
2. any SO is implemented via web services and its interface is univocally described by its XML file, defined by a XSD (XML Schema Definition) file, which refers to common rules. In order to facilitate the creation of the XML files, an ad-hoc web form has been realized to guarantee the syntactic coherence.

3. The system prototype

3.1. System prototyping

The AIP consisting of HLS and LLG has been developed in its HW and SW components, as well as the specific gateways enabling communication towards Bticino and Konnex platforms. At the same time, also some new devices has been developed in both HW and SW parts by involving manufacturing companies producing the relative products and electronic companies developing sensors, firmware and software. Finally the system prototype is composed by:

- the *AIP*, that is made up of the local gateway (LLG) to connect SOs and the high-level service (HLS) to properly formalize and interpret SOs' data;
- a set of *commercial SOs monitoring environmental parameters* (i.e. temperature, air quality, humidity, lighting, energy consumption, infrared images);
- a set of *commercial SOs monitoring medical parameters* (i.e. oximeter, sphygmomanometer, electrocardiograph, scale, glucometer);
- a *telemedicine platform* to interpret data from the medical SOs and enable telemedicine services;
- a *learning platform* to provide training multimedia material to train the users into the correct use of the system devices;
- a set of *SOs specifically developed* for the HicMO project, such as the *sensorized shirt* measuring acceleration, speed values and GSR; *sensorized shoes* monitoring the user's movements and steps' quality; a *tracker* composed by a wearable part mounted on a ring and a fixed part that is attached to significant points or items (doors, handles, etc.); an *intelligent fridge* equipped with a refrigerated drug drawer inside where opening / closing and temperature are strictly controlled;

- two adapters, such as a *SmatTV adapted* to make the actual TV act as a system interface, and a *SmartPlug adapter* to make any object act as a smart objects by exchanging information especially about its use and energy consumption;
- two *local gateway* dedicated to connect the AIP respectively to Bticino and Konnex home automation systems, according to a Bus-to-Ethernet approach;
- a system interface to visualize data and manage system SOs by tablet.

Figure 2 shows some prototypes. Examples of intelligent behaviours are listed as follows:

- monitoring of the user's daily activities through data acquisition from SOs and processing of collected data;
- promoting correct lifestyle by providing reminders and monitoring the user's actions, such as remembering taking drugs or controlling vital parameters;
- generating alarms on the basis of the detection of high-risk events, such as fainting, falling or not taking drugs, or abnormal behaviours that may potentially indicate danger;
- improving comfort by the dynamic environmental configuration according to user behaviours, for instance by adjusting lights or temperature in a proper way when the user goes to rest or goes out;
- using multiple user interfaces or data views, thanks the management of alerts and reminders on different devices controlled by the same central intelligence, such as a SmartTV, a tablet, a smartphone or specific devices' interfaces;
- creating an interoperable environment by combining inputs and outputs from different SOs, such as smart objects, commercial home automation devices and sensorized items;
- integrating with commercial health application, like e-Health (iOS) and Google Fit (Android), where information derived from the system platform can be sent and used for more general purposes by other applications.

About security aspects, the platform allows to recognize the specific user (thanks to the HicMO Tracker) who is executing a specific action. As a consequence, data about that user are referred to the user and manage securely. A specific security protocol is then implemented by the Telemedicine system in order to certify the medical and vital data.

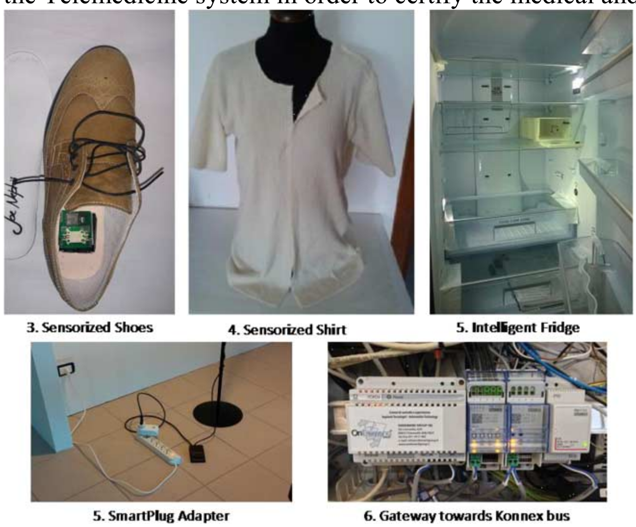

Figure 2. Example of HicMO SOs prototypes

3.2. Service use cases

The platform enabled four different services, which have been implemented as use cases. The services refer to the following aspects:

- *Accessibility control*: the system is able to enable or unable some actions (e.g. opening drawers, opening cabinets, opening doors or windows, starting some devices) only to authorized users. Users are automatically recognized by the HicMO Tracker and the system can enable/unable the SOs functions according to the user's rights;
- *Drug assumption*: the system control if each user, among those that need taking specific drugs, assumes the right drugs at the right time and, in case of failure, sends memos until sends advices to familiars and caregivers;
- *Vital signs monitoring*: the system is informed about the health condition monitoring required for each user, so it can remember to each user specifically when to control its parameters and which one (e.g. weight, blood pressure, glycaemia);
- *Environmental management*: the system is able to properly manage the home environment (e.g. lighting, temperature, alarm system) according to the users' needs and the occurring of specific situations (e.g. going to bed, waking up, watching television, doing physical exercises).

4. Conclusions

The paper presents a service-oriented architecture to support active ageing in the context of an Italian research project. The research described the project approach focused on interoperability, flexibility and scalability, the user-centred methodology to support the system design according to the users' needs, and the system prototype within the HicMO project. HicMO project is a valuable example of a successful system definition according to the specific needs of end-users and interoperability issues at the same time. For these reasons, it overcomes most of the current system architecture in the AAL context. Indeed, the HicMO system is highly flexible, since it can include any type of object or service coherent with the HicMO reference model, open due to the integration theoretically with any communication protocol and existing smart object, and scalable since it can be easily configured to be adapted to different contexts of application. Furthermore, it can be applied to modern houses as well as existing buildings. Future works will be oriented to test the system prototypes with final users in order to check the general level of system usability and user satisfaction as well as the specific functionalities of both products and services.

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