ON THE DEVELOPMENT STRATEGY OF AN ARCHITECTURE FOR E-HEALTH SERVICE ROBOTS

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ABSTRACT

This paper presents a service robot architecture based on the principles of a Service-Oriented Architecture (SOA), whose modularity design maximizes the benefits of multidisciplinary contributions from researchers of different areas. The diagram of the proposed architecture is presented and discussed in terms of its development strategy, oriented towards the creation of societal and economical impact. Services are supported by an intelligently managed database, storing personal profiles and preferences towards an active and personalized assistive care. The Entity-Relationship schema is described in detail, giving an overview of how the different types of information are related, e.g., relating preferred activities with specific locations and with preferred friends to take part. It is virtually impossible to identify all elderly needs in advance, since their fragile condition leads to constantly changing needs. The proposed methodology fosters services adaptability. It allows them to continuously fit elderly specific needs efficiently and improve the quality of a service without requiring redeveloping it entirely. By applying the proposed architecture, a service robot can, for example, actively look for an elderly person to inform him about the daily lunch menu, advising him according to their food preferences, or even perform specific actions, in a personalise manner, when the elderly is found in a certain status (felling sad, bored, etc.). This work is developed within the context of the Social Robot project, funded by the FP7 Marie Curie Programme IAAP.

KEYWORDS

Service Robot, Elderly Care, Development Architecture, Behaviour Perception, Information Database.

1. INTRODUCTION

This paper presents a service development strategy for a mobile social robot. The main goal is the continuous proactive provision of personalized assistance to elderly people, towards improving their quality of life and independence. The proposed schema is supported by an intelligently managed database of user profiles and preferences, promoting personalized care provision. Population ageing is a problem that the world is currently facing. It is motivating research efforts towards the creation of technologies which are able to continuously assist and support elderly people in their daily lives. The Ambient Assisted Living (AAL) research area is dominated by service providing robotic platforms and/or environments, in which the scope of this work is developed.

Robotics and ICT technologies are being taken up by the market as health and social care profitable solutions in terms of deliverance and efficiency [Broek, Cavallo and Wehrmann, 2010]. Using robotic technologies to improve monitoring and assistive services has been target of keen research by different groups and with a strong support of the European Commission. In fact, the EU funded different specific research programmes, such as the Ambient Assisted Living – Joint Programme, amongst others. One major research branch has been the development of mobile robotic platforms for assistance and monitoring. This study covers all the aspects of service provision, from the technological considerations to the end-user feedback, so as to measure the acceptability and requirements of these systems. Some examples of these projects are MOBISERV [MOBISERV, 2009], which developed a robot to support the daily living of seniors focusing on health, nutrition, well-being and safety, including the capability to monitor vital signs or detecting falls. The KSERA [KSERA, 2010] aimed assisting elderly with Chronic Obstructive Pulmonary Disease through monitoring their psychological, behavioural and environmental data and providing embedded entertainment. FLORENCE [FLORENCE, 2010] aimed to improve the well-being of the elderly by providing connectivity, reminding, fall detection, encouraging activities, gamming and interface with some home devices. Notable technological mentions on the field of assistive service robots are the Care-O-Bot [Care-O-Bot] and the Robot Maid [Robot-Maid].

Let us take a closer look over two specific service robots for elderly care which we believe being representative of the current state of the art in AAL and that were developed within the European Research projects, the Companionable [COMPANIONABLE, 2008] and the Echord – Astromobile [ASTROMOBILE, 2011]. Hector was developed within the FP7 Companionable project. Some of its care support services include diary management, memoire services (e.g., reminders for taking medicines on time) and social networking communication. It encompasses a fall detection capability, which the system can use to detect emergencies. Hector can assist a remote control centre to assess the gravity of the fall so that an appropriate action or emergency team is needed. This remote control centre is supervised by humans, which benefit from this basic awareness to optimize their resources. Simon, on the other hand, has been developed within the FP7 Echord-Astromobile project [Cavallo et al., 2013]. This robot also interacts with users in an indoor environment, with the purpose of assisting them in their daily life or working activities. It uses natural speech recognition, for which they exploit the Open Source Speech-Recognition Software Simon. Originally, Simon was developed to deal with persons suffering from physical disabilities but whose speech capabilities were intact. Some of the supported services include medicine delivery, stand support, reminder alerts and entertainment. Its design integrates a smart environment for better localization services.

A common characteristic of these (and other service robots) is that they are pre-programmed with specific services and knowledge at the manufacturing stage. Consequently they fail to properly exploit the rapid technological advances and also to cope with the constantly changing needs of elderly people. Because of this fast time-to-market oriented strategy, these technologies, as products, become obsolete in the sense that new products with new capabilities will be available at an increasingly faster pace. What if these technologies could profit from the scientific advances through a modular architecture, allowing a seamless integration of new modules and capabilities? This would create social and economic impact. From a societal perspective, a user could expand an existing platform with new functions, knowledge and services to continuously meet its needs. Economically speaking, buying a technological solution that could be expanded, without having high replacement costs or even buy a new one, presents a clear economic benefit. This manuscript presents a development oriented architecture, which is strategically designed with these two issues as its driving pillars. The presented concepts and architecture are currently being developed and applied within the Social Robot project [SOCIALROBOT, 2012], for developing a mobile platform for personalized care provision.

2. SOA-BASED DEVELOPMENT STRATEGY

The proposed strategy intends to provide a scalable framework through seamless plug and play integration. We propose a hierarchical approach where complex servicing tasks are recursively broken down into simpler operations. For its multidisciplinary oriented development, the following paragraphs introduce four key definitions, which are adapted from the SOA concepts so as to be better understood by a broader audience.

Method *A method is a low level process of basic complexity, which operates over the raw data or interacts, through a driver, with peripherals such as input/output devices or databases.*

Function *A function combines two or more methods. It provides a set of logical operations that are*

	too complex to be considered a method. They are categorized into Robotic, ICT and Behaviour Analysis.
Service	*A service orchestrates two or more functions in a process where the robot actively interacts with a user and whose main purpose is to assist him, fulfilling an expectation.*
Scenario	*A scenario corresponds to an event or sequence of events where the robot provides one or more services to an end user, so as to fulfil a given contextual goal or goals.*

From the definitions, it is easy to understand that methods correspond to the lowest level computational processes and that functions depend on these methods to provide answers to problems of additional complexity. These functions alone do not directly fulfil a user expectation, yet they are relevant in the sense that they gather the required information used for an empathic and personalized experience. There are two key differences between a function and a service. (1) A service has to be explicitly experienced, which means that it is provided by the platform in order to fulfil an expectation from the user side. *For example, reminding a user about its personal daily schedule and recognizing who the user is, are two complex problems. However, unlike the first, the recognition does not fulfil an expectation on its own, yet it provides the needed identity information so that the system can automatically retrieve the correct person's schedule.* Thus, (2) a service is an orchestration of two or more functions, requiring performing different operations at different levels, such as communication through output devices or intelligently managing information in the database.

2.1 Architecture of the Social Robot System

The development strategy for designing the architecture is conceptually implemented based on the SOA principles, from which we get a modular system comprising different abstraction layers (see Figure 1):

Hardware	*It is composed of physical components corresponding to the input/output technologies available on the mobile platform. For an immersive interactive experience, they include Touch Screen, Display, VoIP, Sound Speakers, Microphones and Video Cameras. These are complemented with a Laser Rangefinder for autonomous navigation purposes.*
Operational	*This layer contains methods which require low-level capability procedures to perform their objectives. It includes modules for basic data processing, querying data from sensors, forwarding data to output devices, a clock and parameter parsing.*
Functional	*The functional layer includes algorithms with decision-making and cognitive reasoning capabilities. Action and emotion recognition, navigation with obstacle avoidance, selecting the appropriate information to display or establishing communication are some examples. The main purpose is to assist with the discovery of information needs, provide an adequate solution and intelligently manage information.*
Workflow Engine	*The workflow engine is responsible for the interpretation of a service, orchestrating a sequence of required functionalities to fulfil the associated expectation for that service. It can include a failsafe module, which is responsible to determine alternative solutions in case of an error from the functional layer.*
Service	*The service level is designed so as to allow non developers to be able to define new services themselves. It holds XML format descriptions of a service, which are defined as a sequence of functional modules adequate to assist an elderly. The main categories are Care & Wellness, Guidance and Mobility Monitoring.*
Database	*The database is a key element in our framework. It is a knowledge repository containing organized personal information, including user preferences, event and medicine calendar, behaviour profiles and Virtual Care Teams (VCTs). A VCT is a list of associated family members, caregivers, friends or neighbours which constitute a social pool for contacting in case of emergency or socialization purposes.*

The proposed development architecture is illustrated in Figure 1. The hierarchical abstraction layers and modules clearly represent the concepts that have been introduced so far. Inter-layer communication is minimized, such that it is limited to adjacent layers, *e.g., functional processes can only access the hardware via the operational methods*. The communication between different modules is done through messaging systems. In the specific case within the Social Robot project we are exploiting the Robotic Operating System (ROS) to exchange information. However, other messaging platforms can be used instead. This architecture aims to establish a clear separation between service design and low-level development. The following paragraphs discuss how the proposed design can address the two initially identified objectives.

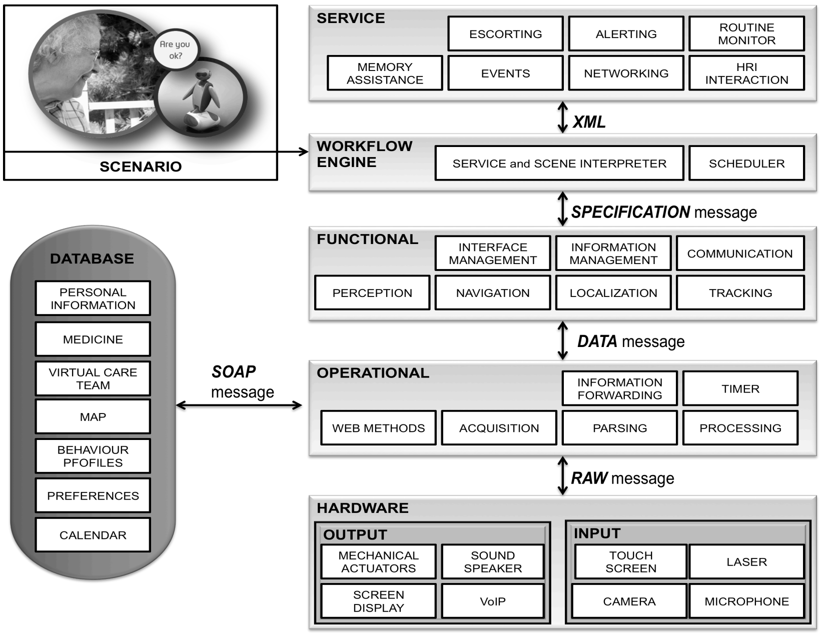

Figure 1. Social Robot Architecture

OBJECTIVE 1 (Adaptable Service Orchestration): Unlike other known service robots, our architecture offers an intuitive XML-based service orchestration, minimizing the need for expert developer intervention. To define a service, we only need to select some functions and specify their execution order. Then, during the first stage of a service interpretation, the workflow engine is responsible to assess service integrity, which means it has to verify that the functional sequence meets input/output requirements (see Algorithm 1).

Algorithm 1. Pseudo-code representing the steps used in the workflow engine to complete a service.

	Workflow Engine Runtime Steps
Input	Service XML file
1:	Parse service to functional sequence
2:	Verify input/output requirements to ensure service integrity
3:	**Try**
3:	**for 1:n** such that *n=number of required service call back functions* **do**
4:	prepare input data;
5:	execute function; **/* At the for cycle we can combine any functions we see fit to fulfil a goal. */**
6:	request output data;
7:	**end for**
8:	**end try**
9:	**catch exception**
	report fail log **and do**
	repeat **or**
	Alert Virtual Care Team member and enter sleep mode
	end and
10:	**end try**
11:	**if** *sequence=success* **then**
12:	request new service;
13:	**end if**
Output	Scenario status

OBJECTIVE 2 (Platform Usefulness and Longevity): The proposed modularity clearly benefits the longevity of the platform. In fact, methods and functions can be seamlessly replaced to cope with the scientific research and technological advancements. The integration of new modules only needs to ensure compliance with the defined communication input/output message structures.

Example: *Let the system have an operational module for identifying faces based on Method 1, whose input is an Image and the output a String with the name of the identified person. Let a new Method 2 be developed, which is able to provide better identification results. A developer's only concern needs to be the encapsulation of Method 2 such that the input/output pair is still an Image and a String and that the encapsulation requests and publishes such information in the correct message topic.*

This example illustrates that this strategy will, at least, prevent the platform from being easily outdated, maximizing thus a long and useful existence at an elderly home. Exploiting the proposed paradigm, we aim to go one step further in the way service robots interact and assist the elderly. An intelligently managed database is presented, where elderly information and profiles are exploited for personalized service provision.

2.2 SoCo-Net: An Intelligently Managed Database

The Social care Community network (SoCo-net) constitutes a core component of the Social Robot solution. It is an elderly centric, web-based virtual collaborative social community network that enables the effective administration and coordination of the user (Person) profiles and Virtual Care Teams (VCTs) around the elderly person (see Figure 2). *A VCT* consists of people (members) of different ages (young and old) and roles (relatives, friends, neighbours, care professionals, etc.) that can assist, collaborate and actively communicate with the elderly. SoCo-net services' main objective is to ensure that the elderly, through the ageing process, will have a unique personalized profile of disabilities and abilities, special needs and preferences thus promoting personalized care provision. In order to promote modularity, the SoCo-net components and schema are designed, developed and maintained independently from the robotic platform. Information management is mainly maintained by *VCT* members, which have the ultimate responsibility of ensuring data correctness. From the robot's perspective, there are methods responsible for retrieving and storing the required data for service provision and, when necessary, update the database table contents.

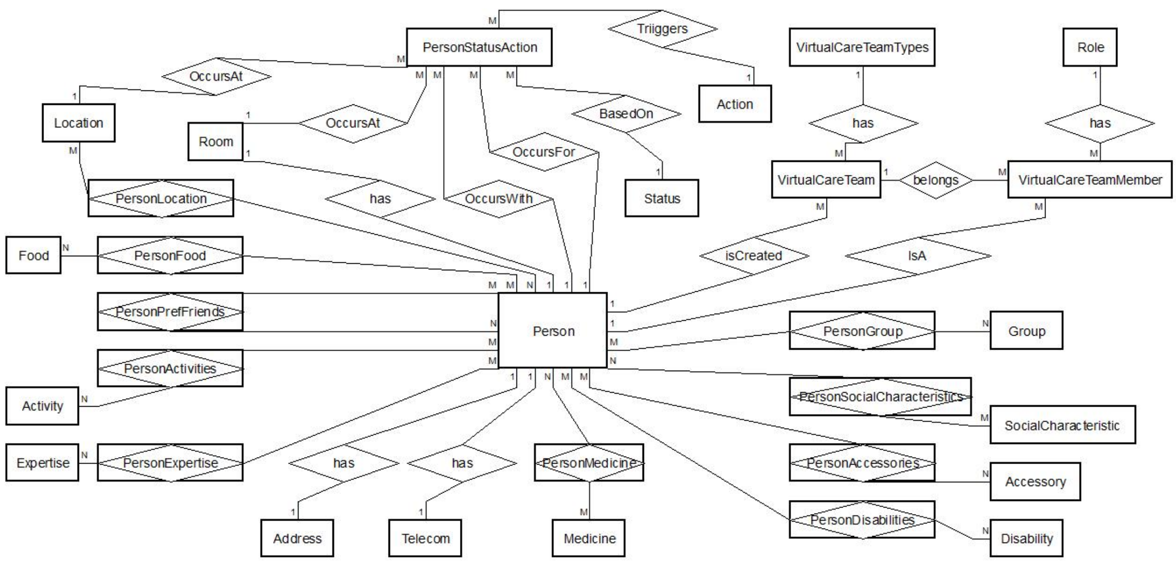

Figure 2. SoCo-net Database Entity-Relationship (ER) schema.

The SoCo-net's Entity-Relationship (ER) database schema is provided in Figure 2. It includes the tables storing Persons' personal information like name, address, telephone number, birth date, email, etc. The Person Profile tables create associations between a Person and his/her preferences related to activities he/she would like to perform, preferences related to the food he/she likes, certain disabilities he/she may have, etc.

The VCT tables contain members associated to a specific Person, their roles and so on. A more detailed description of each table included in the SoCo-net database is provided in Table 1.

Table 1. Descriptions of the SoCo-net's database tables.

Table Name	***Description***
Person	*Stores general information about all the users of the system.*
Address	*Stores the information about an address of a Person or a Location included in the system.*
Telecom	*Stores the telecom information of the Person (Prefix, Phone number, etc.).*
Room	*Stores, information about all the rooms that are included in the elderly house.*
Activity	*Stores information about all possible activities a Person may carry out within a day. Such as playing cards, chess, walk in the park, trips, swimming, eating in restaurants, etc.*
Accessory	*Stores information about all possible accessories a Person may need. Such accessories can be eyeglasses, walking sticks, cars, mobile phones, umbrellas, coats, medicine, etc.*
Disability	*Stores a list of all possible disabilities a Person may have (hearing problems, sight problems, walking problems, etc.).*
SocialCharacteristic	*Stores a list of all possible social characteristics that the Person may have. Such social characteristics are for example (does not like water activities, does not like outdoor activities, does not like to see very handicapped people, etc.)*
Expertise	*Stores a list of all possible expertise a Person may have in a certain domain (electrical engineering, doctor, sports, gardening, etc.).*
Location	*Stores a list of all possible locations (specific locations) that a Person may like or do not like to visit (i.e., the park, the hospital, the cinema, etc.).*
Group	*Stores a list of all possible groups that a Person can belong to (i.e., Golf group, Dancing Group, Photograph Group, etc.).*
Food	*Stores a list of different food that can be included in the food menu.*
Action	*Stores a list of all possible actions (call, visit, talk, etc.) a Person would like to perform (or the Social Robot should perform) when the Person is found in a certain status (i.e., depression, sick, pain, etc.).*
Status	*Stores a list of different status (i.e., depression, sick, pain, etc.) a Person might be in.*
Medicine	*Stores a list of all possible medicine that a Person may take.*
PersonStatusAction	*Associates a Person with the specific action that he/she would like perform (or the social robot should perform), the member of his/her VCT he/she would like to perform the action with, and the room that he/she would like the action will take place, in case the Person is found in a certain status (depression, sick, pain, prolong immobility, etc.).*
VirtualCareTeam	*Stores information about a Virtual Care Team (VCT) built around an elderly user.*
VirtualCareTeamTypes	*Stores a list of all possible team types that can be built around the Person (relatives, social workers, friends, neighbours, care professionals, etc.).*
VirtualCareTeamMember	*Stores information about members that belong to a certain VCT and the Role that the members hold in the VCT. A member can be in different VCTs with different roles.*
Role	*Stores a list of all possible roles a member can obtain in a Virtual Care Team (friend, neighbour, daughter, son, caregiver, occupational therapist, etc.).*

One key innovation behind the design and the development of SoCo-net's database is the intelligent management techniques (algorithms) that SoCo-net supports, which dynamically adapt the content, included in the database, throughout the elderly ageing process. These are statistical analysis techniques, applied to event logs containing a history of past events and other related history information acquired by the robot through the process of the elderly daily monitoring. Based on event frequency and detected changes, the system can update preferences, VCT member priorities, its routine and so on. Such approach promotes personalized care provision and a means to adapt service provision as the elderly needs change. It aims to keep him/her stimulated and motivated to always retain interest in making use of the Social Robot services.

Personal data is the core resource that the SoCo-net services are built on. For this reason, security and privacy is important for SoCo-net, as it is crucial for the users to feel that the system does not allow unwanted privacy intrusions and to ensure that they are in control of the services offered to them. Thus, the key objective is to protect resources through a set of security controls, both preventive and detective. The most prominent aspect is that only authorized users may access and use sensitive data or invoke services.

3. SERVICE PERSONALIZATION AND ADAPTABILITY

Existing robots are built to provide limited services which have been programmed *a priori*, upon analysis of end-user group requests. It is virtually impossible to pre-define a service that will be capable to continuously fulfil elderly people's needs throughout their ageing process, mostly because these needs are constantly changing. Moreover, services are often limited to monitoring and reminding. Think of a scenario where such a system is deployed in a multi user environment. Under the current paradigm, it will repeat the same service provision over and over again, which reflects in a decrease of user acceptability and loss of interest. Additionally, these platforms usually operate on request, that is, the user is often the party responsible for initializing the interaction process. By exploiting personal information, we propose an active service providing strategy which is best explained through a simple example scenario.

Scenario*: Let the robot detect that Mrs. Johnson is feeling sad and decides to approach her. Upon detecting such behaviour state, it queries the database for a list of Mrs. Johnson preferred actions, which are associated to this "sad" state, that when performed will change her state to "happy". So, in fact, from the knowledge base of personal profiles, the robot knows the certain actions that are likely to influence Mrs. Johnson current state. Therefore, it takes the initiative and actively suggests her if she would like to establish a Skype call with her daughter, or engage on a social activity of her liking, which will take place a few minutes later.*

The presented solution to solve this scenario maximizes the exploitation of the information in the database. Preference and priorities for different persons allow each user to have an engaging and personalized experience with the robot, which is different from all the others because it satisfies their personal needs based on their own preferences and behaviour profiles. In Table 2, we have a clear example of how a scenario can be parameterized into services and which functions are required to complete it.

Table 2. An example of a partial scenario taken from the *Social Robot project*, with required services and functions.

Scenario Description Parameterization	Required Service	Functional Requirements
(...) Now with the presence of the Social Robot, half an hour before the meal, Social Robot considers the menu and the meal preferences of each elder. By comparing the menu and the meal preferences of Andreas, Marios and Antonis, Social Robot noticed that Andreas does not like the menu but Antonis and Marios love it.	***Daily Routine monitoring and assistance***	***1. Preference Assessment 2. Task Guidance***
SocialRobot goes to the room of Andreas, Antonis and Marios	***Robotic***	***1. Localization 2. Navigation***
to inform them about the menu, and save Andreas from walking in the eating room and also remind Antonis and Marios not to skip the dinner because the food today is their favourite. The three men were discussing that the care staff is so overloaded with the more severe sick people in the centre, that they always ignore them thinking that they can still do most of the things alone and that only Social Robot looks for them. (...)	***Human-Robot Interaction***	***1. Face Recognition 2. Speech Analysis 3. Speech Synthesis***

One of the major challenges concerning this approach is the learning phase, which is the problem of associating preferences and priorities to a specific person. Presently, this information is supervised by members of the elderly VCT or obtained from elderly feedback during the interaction phase. One key difference of this approach is that the database can be accessed remotely and has a friendly user front-end allowing credentialed members to manage this information along time. Moreover, the robot by itself maintains a history of information, which from time to time it uses to automatically update the Person Profiles, *e.g., frequently attended activities will gain priority over others.*

4. DISCUSSION AND CONCLUSION

This manuscript presented a development strategy for a modular architecture of a service robot, targeting a societal and economic impact. We argue that this abstraction strategy between different conceptual layers, will allow the system to be constantly and seamlessly integrated with new functionalities and devices. The nature of the service design, using an XML structured description, allows new services to be composed and tested in short time. In fact, it provides an intuitive and fast way to add new servicing capabilities to a robot so as to fulfil new elderly requirements, while simultaneously cope with the technological and scientific advancements, requiring only a set of simple restrictions. This means that when acquiring an expensive robotic platform, one knows in advance that it can be easily extended without additional high costs. The system evolves its capabilities during its lifelong durability. In order to better provide personalized assistance, the system encompasses a database of personal information which is intelligently managed. This is also a key aspect in the proposed system, because it means that behaviour profiles and preferences of a user can be synchronized with current elderly conditional status. Consequently, the system is capable of adapting its services accordingly, thus easing the take up of this technology by an elderly as being its own, because of the empathic and personalized assistive interaction. In addition, a continuous (timely) analysis of elderly information allows the robot to actively engage a user, which extends its assistive usability. We conclude that the presented concepts and discussion constitute an alternative, appropriate strategy for developing new service robots which will have a longer and efficient lifelong usability.

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