A Service Personalization System for Smart Homes Based on Semantic Web and Multi-Agents

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***Abstract*—The demographic change towards an aging society has led researchers to develop a range of assistive technologies to support the needs of the elderly and help them to have an independently and comfortably lifestyle in their homes. This work proposes a service personalization system based on the Semantic Web technologies and the multi-agent paradigm aimed to provide personalized assistance to people with disabilities and functional limitations within a smart home setting. In the proposed system, user's characteristics are represented through an ontological user model and a rule-based reasoning mechanism is used in order to infer additional information needed for tailoring the services available in the environment. The multi-agent paradigm is used to create a scalable, flexible, and distributed architecture where the agents use the user model and the reasoning mechanism to accomplish specific roles. The proposed system was validated through its integration with a Service Oriented Architecture and a demonstration of its use in three standard use cases.**

***Index Terms*—Context-aware, user centered, assistive technologies**

I. Introduction

DURING the last decades the average age of the world's population has increased. Furthermore, recent studies have shown that the speed of aging is likely to increase over the coming decades. In fact, by 2050 the percentage of global population aged 60 or older is expected to be 22% [1]. As a result, there is an expected increase of chronic illnesses and disability associated with old age [2]. This demographic change toward an aging society results in many social and health care system challenges to ensure that our physical and social infrastructures are able to foster better health and wellbeing to the elderly.

Given the fact that at least 80% of people older than 60 are living with one chronic illness and 64% of older adults prefer to stay in the comfort of their own homes, it is essential to develop technologies that help older adults not only to *age*, but also *live in place* i.e., independently and comfortably in their home [3]. Assisted living technologies based on ambient intelligence support the development of the Ambient Assisted Living (AAL) systems that are used for improving the quality of life of the elderly and people with functional diversity, anticipating their needs in specific situations and acting proactively in order to properly assist them to perform their Activities of Daily Living (ADLs) [4]

Smart environments users usually have different interests and preferences. This variability tends to increase within assistive technologies users, specially regarding to preferences associated with their functioning and disability levels. For instance, one with a mild vision impairment would need larger subtitles comparing to a user with no vision problems. Thus, the provision of personalized services capable of providing tailored assistance to a user based on their unique preferences, requirements, and desires is essential [5].

This work proposes a service personalization system which its main goal is to enhance users quality of life, specially the elderly and the ones with special requirements through the delivery of tailored assistive services within AAL environments. The system is based on two different technologies: the semantic web and the multi-agent paradigm. The former is used to build an user model ontology representing user's characteristics and his/her ambient and in the inference of concepts such as user's context and his/her preferences regarding the available services in the ambient. The latter is applied in a distributed architecture where the components use the information described in the user-model ontology and interact with each other in order to determine how and when the ambient services should be requested and to establish the communication between the service personalization system and the service oriented architecture available in the ambient.

II. Related Work

The main aspects within service personalization are the user modeling and the personalization mechanism. Semantic-based approaches are based on ontological user models and have been previously proposed in many research areas such as digital museum guides, knowledge management systems, and semantic web search engines [6]. The increasing adoption of semantic web technologies for user modeling is mostly due to its interoperability feature and ability to enable knowledge sharing and reuse over several application domains [7]. However, although many approaches have been proposed to properly assist users in AAL environments, most of them do not fully explore the potential of semantic web technologies for the personalization mechanisms.

M. Sutterer *et al.* [8] proposed the concept of dynamic user profiles to address the issue that user preferences and needs might change depending on the user context. Another important work concerning user modeling is the introduction of GUMO - a general user model ontology to provide an

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uniform interpretation of distributed user models in intelligent semantic web enriched environments [9]. Several user's dimensions such as user's heart beat, age, interests and abilities were represented in this ontology.

One relevant concern within ambient assisted living is the need of representing information about the user's health condition and limitations performing daily activities. In order to provide proper assistance for people with special needs through ambient adaptation, the correct representation of user's needs and capabilities is essential. However, since user models are designed to meet the requirements of a specific application, there is a lack of an uniform and consistent representation of user health condition, functioning and disability in most of the proposed user models.The Ambient Assistive Technology User Model (AATUM) ontology [10] was the first model to use the International Classification of Functioning, Disability and Health (ICF) framework [11] to model the user's functioning and disability levels in a consistent and internationally comparable way. In addition, user's disease or disorder diagnosis is properly represented using the International Classification of Diseases (ICD) code [12].

Service personalization related to AAL environments have been proposed in many ways. Authors in [13] proposed the use of embedded agents as a potential mechanism for enabling open, scalable and adaptive infrastructures upon which evolutionary AAL services can be delivered. R. Kadouche *et al.* [5] proposed the Semantic Matching Framework (SMF) for delivering personalized assistive services according to the user's needs and capabilities. D. Vergados proposed a generic platform named INHOME to provide the means for improving the quality of life of elderly people at home [14]. INHOME monitors individuals within their homes, enables remote control and configuration of home appliances, and provides error and status messages via a terminal or a television. MobileSage [15] aims to provide help on-demand services as the user moves between mobile environments based on the user's characteristics and his/her location.

III. Ontological User Model

In this work, the AATUM [10] ontology (Fig. 1) was updated to represent not only the user characteristics, but also the most important information about the user ambient. The class `Context` is used to represent where the user is located in terms of house's rooms and the activity being performed by the user. Classes representing the devices employed in the house were also included to allow the user's context to be inferred. For example, if the television status and the sofa pressure sensor values are represented in the ontology, it is possible to infer that an individual is watching a movie.

The class `UserProfile` contains a set of preferences related to the services most capable of helping the user in his/her ADLs within a smart home environment. Since user's preferences tend to change according to his/her context, the class `ConditionalUserProfile` is used to have a specific set of preferences for each context. All numerical preferences are represented as levels, ranging from 0 to 10.

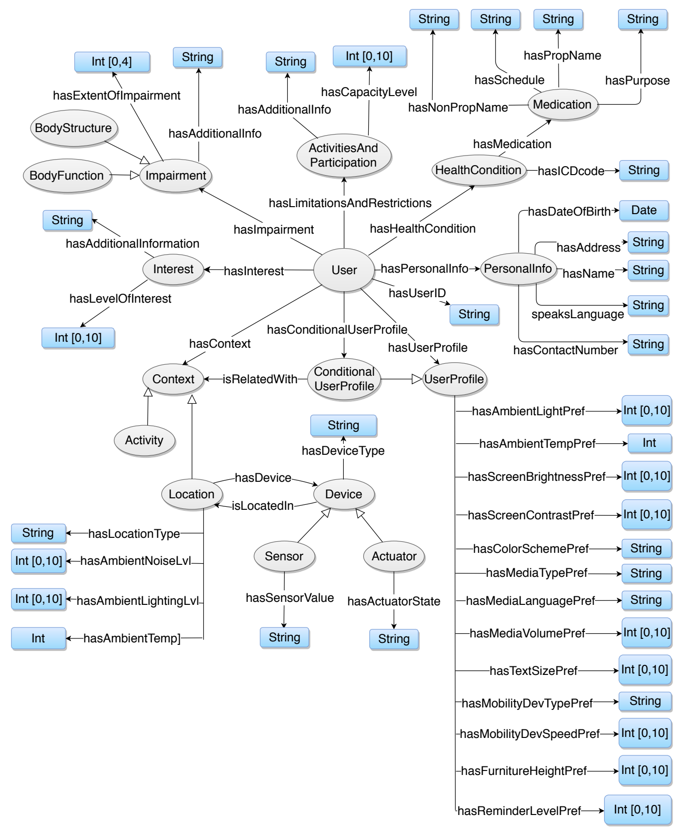


Fig. 1: The updated AATUM ontology

IV. Rule-based inference process

In this work we have used the Semantic Web Rule Language (SWRL) to enhance the personalization capabilities expressing additional concepts that cannot be directly obtained from the user model ontology. One of the main compelling features in rule-based reasoning is that it represents cause-effect relations is a very natural way, facilitating the understanding of the represented knowledge. Therefore, rule-based reasoning allows a more expressive method of inference when reasoning about user's information such as his/her preferences [15].

Three different set of rules were adopted: the first set is used to automatically infer default preferences according to user's impairments and disabilities described in the user's profile; the second is used to deduce user's coarse-grained activity based on the the sensors deployed in the ambient; the last is used to infer context-dependent preferences based on the default values previously inferred. Each of these sets is depicted below:

A. Default preferences

The default preference rules are used to deduce preferences values according to the user's impairments and limitations information described through the properties `hasImpairment` e `hasLimitationsAndRestrictions`. These are non-context dependent default values and will only change if the user update his/her personal information.

Even though the ICF is a well-known international model, no work relating levels of disabilities described in the ICF model and preferences values used to adapt smart-home services. Therefore, the relationships were defined empirically, based on the authors' analysis of how a preference can contribute to overcome the difficulties and to improve user comfort. Table I illustrates an excerpt of these relationships, formalized as mathematical equations and implemented as SWRL rules.

TABLE I: Relationships between user's disabilities levels and services preferences

Preference	Defined as
MediaVolume	Hearing + 5
TextSize	VisualAcuity + 5
AmbientLighting	VisualAcuity - LightSensivity + 5
ScreenContrast	ConstrastSensivity + VisualAcuity + 5
MobilityDeviceSpeed	10 - 2 * FineHandUse

B. Context reasoning

One of the main aspects of the proposed personalization mechanism is the capacity of having preferences related to user's context. Thus, a way to determine user's locations and activity based on data collected from the environment and stored in the ontology is needed.

Since smart environments usually have a great variety regarding the types of sensors deployed, we have used the ontology property `hasDeviceType` to indicate the sensor role within the ambient and `isLocatedIn` to express where the sensor is located. These two values are used along the identified user's id number delivered by the sensor to determine user's location, as shown in Fig. 2. Thus, the activity recognition mechanism becomes independent of the sensors types or methods used, as long the sensors are able to delivery the user's id identified by it. For instance, a RFID sensor could be used in the bathroom, a video-based system in the kitchen and a bluetooth signal strength-based method in the living room.

```
User(?u), Location(?l), hasUserID(?u,?id),
Sensor(?s),hasDeviceType(?s,"UserIdentification"),
isLocatedIn(?s,?l), hasSensorValue(?s,?v),
equal(?v,?id) -> hasLocation(?u,?l)
```

Fig. 2: SWRL rule used to infer the user's location

User's activity is inferred using sensor data and the previously deducted user's location. As in the location rule, activities rules use the properties indicating the sensor role in the ambient and the sensor's location. The ontology property `hasLocationType` which indicates the room type was also utilized to make the rules totally independent of the house structure . For example, the rule *"'if a user is over a bed located in a bedroom, and this bedroom' door is closed, then this user is sleeping"'* will properly infer the user's activities in a house with two bedrooms and one office as well in a second house with only one bedroom and no office.

C. Context-dependent preferences

Since user preferences tend to be different depending on the location or activity being performed, a third set of rules was used to adapt the default preferences values to more appropriate ones according to the user's context. Once the user context is inferred, the context-dependent preferences can be used to properly tailor the available services in the ambient.

In most of the cases this adjustment is made through the multiplication between the default preference value and a specific arbitrary coefficient. For example, if a specific user has the media volume preference set to 6, when the same user is sleeping the media volume will be adjusted to 3 (6 * 0.5). In another cases, such as `MediaType` preference, the value is simple switched to another possible value.

V. AAL Service Personalization Architecture

Fig. 3 presents an overview of the proposed personalization mechanism architecture. Each component in this architecture is implemented as an software agent and the tasks performed by these agents are implemented as their behaviors. The following subsections detail each one of the components.

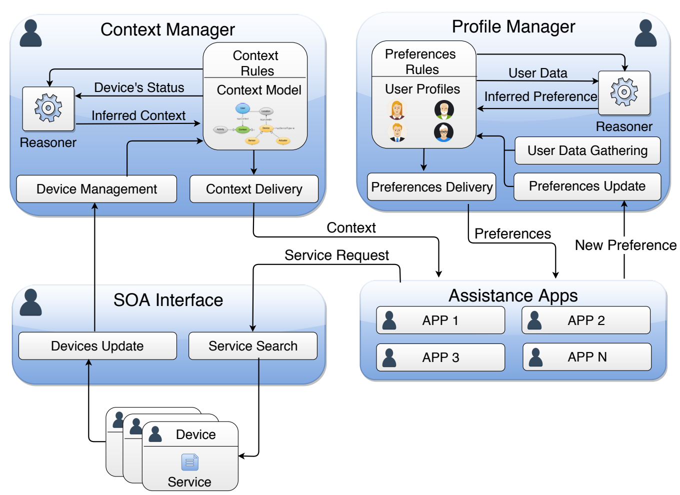


Fig. 3: AAL service personalization architecture

A. Context Manager

The Context Manager main function is to deliver correct information about the user's and ambient contexts. Ambient context refers to all device's information retrieved from the physical world, while user's context refers to user's location or activity. The combination of both contexts forms the Context Model.

Every time a device's state change (or a device is added on or removed from the environment), the Context Manager receives a message coming from the SOA Interface component and updates the Context model in order to keep it consistent with the physical world. Once all devices employed in the ambient are updated in the Context Model, the semantic reasoner is able to properly infer the user's context according to the strategy described in Section IV.

B. Profile Manager

The Profile Manager is the most important component in the proposed architecture. It is responsible for: **1)** Gathering the user data needed for populating the ontological user model; **2)** Inferring default preferences according to the user's impairments and limitations; **3)** Inferring context-dependent preferences; **4)** Delivering user's information to the AAL applications.

Data needed for populating the user model can be gathered during system initialization by the user or the caregiver through a mobile application or a RFID tag, or retrieved from a external source such as the user's doctor management system that also uses the AATUM or an aligned ontology. Once the basic user information is stored into his/her profile, the reasoning engine is able to infer the default and the context-dependent preferences using the rules described in Section IV.

The Profile Manager also allows the user to manually set any of his/her preferences. The user-informed preferences have higher priority compared to the inferred ones. Thus, when an AAL Application queries for the user's preferences in a given context, the Profile Manager first checks if some value has already been asserted for that preference in the user profile. If so, the asserted value is delivered; if not, the reasoning engine is called and the inferred value is sent.

C. AAL Applications

While the Profile and the Context Managers gather and generate information about the ambient and user's context, they are not responsible for taking decisions to control the ambient. All ambient control is made by the AAL Applications that receives the user and context information, processes it and then request available services to accomplish a specific function. For example, one application may be programmed to turn off all the house's lights when the user is sleeping while another can notify a caregiver in case of an emergency.

D. SOA Interface

The SOA Interface agent is responsible for integrating the proposed service personalization system and the service-oriented architecture existing in the environment. The main function of the SOA Interface is to interpret the requisitions coming from the AAL Applications and to search for the necessary services within the devices employed in the environment. Furthermore, the SOA Interface continuously checks the devices' states and inform the Context Manager in case of any change.

VI. System demonstration

This section demonstrates how the proposed system may be used to provide tailored assistance to smart-home users. First, the infrastructure utilized is introduced, followed by the description of the main features required by AAL environments implemented in this work. Then, the system's users are described and two use cases where the proposed system is utilized are narrated.

A. Infrastructure

Since a full smart-home facility was not available during this work development, a hybrid infrastructure composed by a simulator linked to a commercial automation was utilized. The simulation software has four main functions: (1) to allow the management and simulation of virtual devices, represented as agents in the Service Oriented Architecture in the same manner as the real devices; (2) to communicate with the Service Oriented Architecture to get the state of all real and virtual devices; (3) to display the state of all devices in a graphic interface, similar to a supervisory system; (4) to simulate a person that can be moved through the simulated house.

Using this software, a scenario based on the DOMUS lab smart-home[1] was created. The devices employed in this work and their distribution are described in Table II.

TABLE II: Devices employed in the system validation

Room	Device	Simulated/Real
Living room	RFID reader	Simulated
	Sofa pressure sensor	Simulated
	Smart TV	Real
	HVAC	Real
	Electric curtain	Real
	Dimming lamp	Real
Bedroom	RFID reader	Simulated
	Bed pressure sensor	Simulated
	Smart TV	Real
	HVAC	Real
	Door contact sensor	Real
	Dimming lamp	Real
Kitchen	RFID reader	Simulated
	Stove on/off sensor	Simulated
	Rug pressure sensor	Simulated

B. Required features

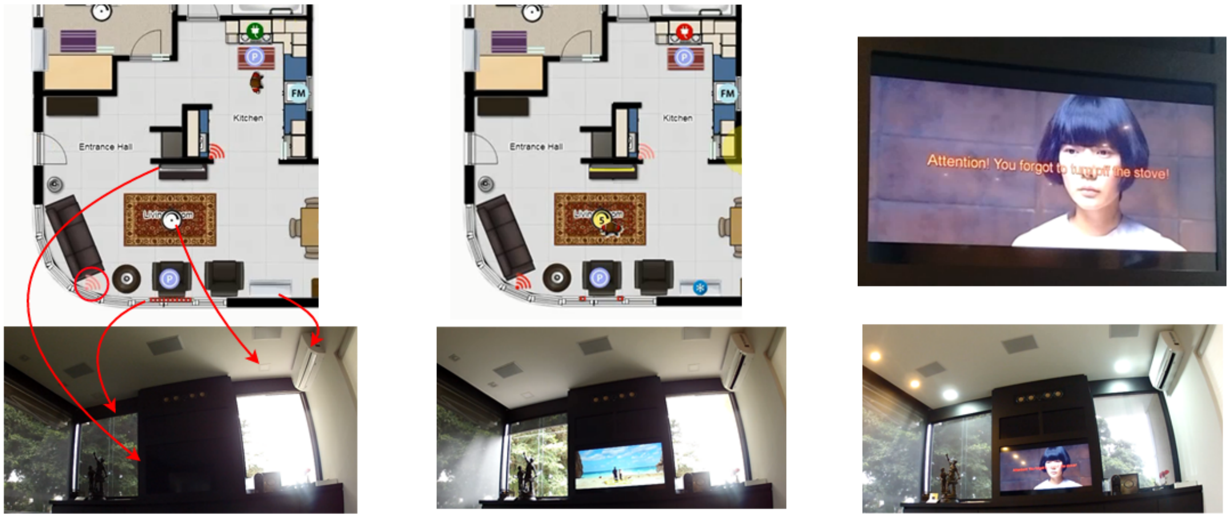
The AAL Joint Programme project "Action Aimed at Promoting Standards and Interoperability in the Field of AAL" [16] identified a set of fundamental features that should be present in AAL environments to meet its main purposes, i.e., to compensate difficulties caused by mental function disabilities and to assist the user with his/her communication activities. Some of these features are:

Behaviour Monitoring: user's location and activities should be monitored through non invasive sensors deployed in the house. Depending on the identified situation, the system must notify the user, his/her caregiver and/or sound an alarm. Furthermore, the system may control actuator such as lamps and curtains to guide the user to the bathroom during the night.

Calendar Service: it is a system focused on users that frequently forget appointments, social activities and particularly, to take medicines. The system must act as a smart calendar that reminds the user about scheduled appointments, daily activities not performed (e.g. taking shower, eating), and when the medications need to be administered.

Smart TVs interaction: smart TVs can be used a central communication unit at home, offering communication through

[1] http://domus.usherbrooke.ca/



(a) (b) (c)

Fig. 4: View of the simulator and the real environment during the system demonstration

video conference, chat and even online gaming. Furthermore, a Smart TV can be controlled by an application installed in a smart phone, facilitating its use and offering additional functions such as remote display.

C. Users

Two fictitious users were also defined based on the results of the project "'Action Aimed at Promoting Standards and Interoperability in the Field of AAL'':

Jane Miller *is an 85-year old lady who still lives independently in her own apartment. Despite several chronic diseases that require her to take many different drugs three times a day, she is doing relatively well. However, recently she has started to forget things and make mistakes that were unheard of before. The family doctor has diagnosed her with a mild cognitive impairment that may or may not worsen over time.*

Peter *is a 83-year old person living in the suburbs of a big Brazilian city. His wife died 4 years ago and his son has moved to another city about 200 km away. One of the main difficulties in Peter's daily life is to read small texts and images displayed on his Smart TV and smartphone. Furthermore, Peter has a mild listening difficulty.*

D. Use case 1 - Comfort control and behavior monitoring

Three AAL applications were developed to meet the required features previously identified: the first monitors the user behavior and acts if a dangerous situation is detected; the second is responsible for adjusting the ambient lighting and temperature to ensure safety and comfort to the user; finally, the third is used to control multimedia devices from a smart phone.

Using the simulation software, Jane Miller's character is moved to the kitchen, turns on the stove and then goes to her bedroom. When she enters the bedroom, the lighting is adjusted to 50% and the temperature is set to 22 °C, according to her preferences stored in her ontological user profile and delivered by the Profile Manager.

After that moment, two scenarios are reproduced. In the first, Jane closes the bedroom door and lays in her bed to get some rest. Since Jane adjusted the bedroom lighting to 10% a few days ago during the same situation, now the system automatically adjust the bedroom lighting to this value every time she closes the door and lays in the bed. In addition, the temperature is changed to 18 °C due the context-dependent preferences inferred by the Profile Manager. After a few minutes, the Behavior Monitoring Application identifies the danger situation and acts to keep Jane safe, setting the bedroom lighting to a maximum level and reproducing the sound message "'Attention! You forgot to turn off the stove!'' using a volume level of 80% (value inferred based on her listening capability level).

In the second scenario, Jane closes the bedroom door and sits in a chair to read a book. As in the previous scenario, after a few minutes the system issues an alert to notify Jane about the dangerous situation. However, since Jane is not sleeping, the alert is delivered according to her preferences inferred by the reasoning process - in this case, since she has a severe hearing impairment, the alert is delivered though a text message in the Smart TV. This message is displayed in her language (English) and with a font size inferred from her visual capability information. After delivering the warning message, the Behavior Monitoring App waits until the stove is turned off. Since this never happens, the application decides to alert Jane's family using the contact information stored in her ontological profile. This is accomplished through a service request that is executed by the Smart TV in her bedroom.

When the same situations were reproduced with the user Peter, the message alerting the stove was left on was presented through an audio in Portuguese, since this is the only language spoken by Peter. Moreover, the audio was reproduced using the volume level inferred based on his listening capabilities. The full demonstration of this use case can be watched in http://www.mauriciofv.com/archive/paDemo1.mp4

E. Use Case 2 - Comfort control and behavior monitoring

This use case is very similar to the first one. Jane goes to the kitchen, turn on the stove (Fig. 4 (a)) and goes to the living room, where the lighting and temperature are properly adjusted according to her preferences. Then, she uses an AAL application installed in her smart phone to request a movie to be played on the closest Smart TV and sits on the sofa. The movie is reproduced using the language, volume level, screen contrast and brightness according to the preferences inferred from her capabilities information. At this moment, the system identifies her new context and adjust the lighting to improve her comfort (Fig. 4 (b)). After a few minutes, the system identifies the dangerous situations and issue an alert message in the same Smart TV she is watching the movie (Fig. 4 (c)). Again, the text size and the language were inferred by the profile manager based on her personal information. The full demonstration of this use case, including the user Peter can be watched in http://www.mauriciofv.com/archive/paDemo2.mp4

F. Use Case 3 - Medicine notification

In the last use case, an AAL application was created to communicate with a service calendar containing the users' medicine schedules. When the application identifies that it is time to take a medicine, a personalized notification is sent according to the user and his/her context.

When Jane Miller was in her bedroom, the notification was delivered through a text message in the Smart TV("'It's time to take your medicine: Namenda 5mg"'), once again tailored according the language spoken by Jane and the font size informed by the Profile Manager. When the situation was reproduced with Peter, who was sit in the living room, the alert was delivered in a completely different way: the Smart TV played an audio message in Portuguese, using the volume level indicated by the Profile Manage to compensate his hearing difficulties.

VII. Conclusion

In this paper a service personalization mechanism in the field of AAL was proposed. Our approach, based on semantic web technologies was applied to three use cases defined by the Assisted Living Joint Programme to demonstrate how the personalization mechanism is used along a user model ontology and a service-oriented architecture to properly assist users with special needs with their activities of daily living in a smart-home.

The use of semantic web technologies has been increasing throughout the last years due its interoperability and knowledge integration and extraction features. However, most of the approaches within AAL environments don't explore the full potential of combining OWL ontologies with SWRL rules to build personalization mechanisms. In addition, most of the user models within AAL fails in the representation of user health condition, functioning, and disability, which are essential components to properly adapt the ambient to provide optimum assistance for the elderly and for people with special needs. In the AATUM user model, the World Health Organization's framework for health and disability is used to represent user's functioning and disability levels in a consistent and internationally comparable way. Also, the ICD code is used to properly describe the disease or disorder diagnosis.

Our proposed service personalization system is based on rule-based reasoning, which allows a more expressive method of inference when reasoning about user's information such as his/her impairments and preferences. Using the three defined set of rules, the personalization mechanism is able to infer and to provide crucial information such user's preferences, current activity and location to AAL Applications. Future work is needed to evaluate the proposed system and the preferences rules by elderly people and/or people with special needs in a complete smart-home setting.

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