Assistive Home Platforms
From Guidelines to Technology Selection and Reasoning Applications

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1 STAGE OF THE RESEARCH

The assistive home technology described in this paper is already available as a Proof of Concept (PoC). Some aspects, such as, infrastructures and data acquisition are more consolidate; other ones, should be improved and more widely investigated, implementing, for example, machine learning algorithms for daily activity recognition. At this development stage, the research is focused on testing the PoC, evaluating usability of user interfaces and checking false positive or missed alarms by reasoning algorithms already implemented. The testing phase exploits both simulations and real users. Such users do not fit the target user, since they are typically young volunteers, but their contribution could be very useful to improve algorithms and interfaces, and to obtain a feedback on the system reliability and effectiveness. Based on this PoC, more refined reasoning algorithms will be implemented. Further improvements foresee the addition of other sensors, to recognize more precisely the behavioural activities performed by the user.

2 OUTLINE OF OBJECTIVES

The project presented in this paper aims to introduce an integrated platform for telecare and Ambient Assisted Living (ADL) aimed at prolonging independent living of the elderly at home. The working hypothesis is to consider a person who normally lives alone. In this scenario the project presented in this doctoral contribution refers to the design and development of a touch screen interface tailored to the needs of the elderly person, in order to control the home automation system, monitor the status of some sensors and help the user in the management of drug therapy. For this purpose, the criteria of usability and acceptability of technologies, and more specifically of touch screen technologies, by elderly subjects have been widely investigated.
Another aspect on which the paper is focused is represented by the extraction and processing of the data acquired from environmental heterogeneous sensors to implement server side services necessary for the proper functioning of the user interface. From these data it is also possible to obtain quite detailed information on the user behaviour. Such information allows us to recognize his daily activities and monitor the state of health in the long term, noting for example the vitality level, the sleep duration and the frequency of eating. For this purpose, some simple algorithms for presence/absence and wakefulness/sleep recognition have been implemented.

3 RESEARCH PROBLEM

Numerous studies have shown that in developed countries the number of elderly people has greatly increased in recent years: elderly people (aged over 65 years) are estimated to rise by 2050 to 19.3% worldwide (Gavrilov and Heuveline, 2003) . Causes can be traced in many different factors and, particularly, great relevance has the medical and scientific progress, and the development of public health, which allows to extend the people's lives, even when suffering from injuries or diseases. As a result of the increase in life expectancy, however, the need to create a protected and safe environment that allows the elderly people to best use their residual motor and cognitive skills is becoming gradually more obvious. In fact, in (Organisation mondiale de la santé et al., 2004) the authors show that the problem of falls is a critical issue in the lives of elderly people. Typically, as a result of a fall, physical activity is reduced for both the need of healing from injuries, and for the fear of falling again, leading to muscle atrophy, less social interactions and, in general, to a reduced quality of life. Nevertheless, the elderly should be encouraged to leverage their residual capabilities, to take care of themselves as much as possible and to preserve their own autonomy. The day-to-day monitoring of daily activities can be extremely useful for identifying problems, worsening or improvements in their health state, abnormal behavior or dangerous situation. This kind of monitoring, however, is often performed with wearable devices, quite intrusive and affecting the daily habits of the user. These solutions do not represent a real answer to the problem, as they require an action by the user that should remember to wear the sensor every morning. For this reason, it is necessary to use devices that do not interfere with the user's normal activities and are "transparent" for him. Intelligent environmental technology, which uses sensors and actuators to dynamically control the environment of the domestic life, has strongly grown in recent years: intelligent systems are appearing in nursing homes and assisted living environments to help caregivers to offer the elderly more comfort and safety. However, although many older people see the benefits of environmental technology, they have never used a computer and have trouble in learning new technologies; furthermore, many of them do not like that someone can monitor or control their home environment. The challenge is therefore to develop systems, devices and interfaces that older people can use easily, intuitively and independently in their home environment, without having to face the difficulties of learning the smart home systems and without feeling constantly observed.

4 STATE OF THE ART

The expression "Smart Home" is used to indicate dwellings equipped with devices and technologies promoting the safety, independence and improving the user's quality of life. These technologies allow to obtain a variety of information about the behaviour and health of its inhabitants. Most smart homes use such knowledge to automate the environment and to provide more comfort, but such technologies can also be exploited to promote and facilitate the independent living of vulnerable and elderly subjects. As well described by (Rashidi and Mihailidis, 2013), there are many projects in the literature aimed at creating "assisted" home environment. However, as written by W. Kearns and L. Normie in Gerontechnology vol.6, no.3, "The reluctance of older adults and policy makers to adopt technological change may be described by the ancient proverb: Better a known devil than an unknown god". Therefore, there are two main challenges to consider during the implementation and design phase of a smart home for AAL: the choice of appropriate interfaces and the use of less intrusive as possible technologies.

4.1 User Interface Design for Elderly

When designing technological solutions addressed to elderly or disabled people, as it happens in Ambient Assisted Living (AAL) frameworks, it is very important to select human-system interfaces that can match the user's abilities, and make the user feel secure and at ease (Wood et al., 2005). In the design phase of the user interface, taking into account the usability related aspects is crucial: if these aspects have been considered, there are more chances the interface is accepted positively by users. Consequently, the primary goal is the ease of use.

Jakob Nielsen (Nielsen, 1995) has provided a list of 10 "heuristic" principles for the interaction design. Such a list does not refer to a specific type of interface, but is quite general and establishes guidelines that must be followed in the design phase in order to provide a tool that is as much easy to use as possible, and has a good impact on the user from the beginning. Referring more specifically to older users, it is important to note that different age-related disabilities affect the way elderly people can interact with technological devices. Chaparro et al. (Chaparro et al., 1999) and Wood et al. (Wood et al., 2005) have shown that the use of computer equipped with keyboard and mouse can cause problems with older people. The touch interaction is commonly seen as an easier approach to enable older people to interact with a machine, because it is a more direct interaction that does not require an advanced mental model. The most obvious advantage of using the touch screen is, according to Greenstein and Arnaud (Helander, 2014), that the input device is the output device too. Furthermore, touch interaction does not require special motor skills (Wood et al., 2005), however, the interface design needs a particular attention, especially when dealing with the elderly. Among the factors that may influence the effectiveness and quality of touch interaction it is worth mentioning the hand used (if the "preferred" or the other one), if the device is used in static conditions or moving (eg. sitting or walking), and the position of the target area (ie the area which, when clicked or interacted, determines a command activation) with respect to each hand. The size of the target area, typically a button, has a great influence on the accuracy of the interaction, no matter which hand is used. Park et al. (Park et al., 2008) have shown that the size of the graphic button have a significant influence on the number of errors, success rate and the optimal pressure; that is, applying a normal pressure, the larger the size, the lower the error rate and the higher the rate of success. The results of a study by Pari et al. (Parhi et al., 2006) have shown the buttons should be approximately 9.2 mm wide for a mobile device: with these dimensions, the target areas are as small as possible, without decreasing performance. Moreover, as Yang (Yang,) states, complex control techniques should be avoided - older people may find it difficult to perform sliding and revolving gestures on touch screen. While evaluating the use of web-based interfaces by the elderly, Kurniawan and Zaphiris (Kurniawan and Zaphiris, 2005) found that they prefer the presence of graphics if it is logically associated with the content, and not only for decorative purposes. Animated elements tend to confuse older users and therefore should be avoided in general, while animated avatars are considered useful. The icons should be simple and meaningful, and large enough to be identified by people with impaired vision (Maguire, 1999). All these studies help us to create an overall picture about the general rules for designing usable touch screen interfaces, which require a minimal effort in understanding by older users.

4.2 Behavioural Analysis Through Environmental Sensors

In the literature there are a multitude of AAL systems aimed at monitoring the daily activities to support independent living, evaluating in a natural and continuous way the health and cognitive state, providing automated assistance, and reducing the pressure on relatives or caregivers. In this context, one of the most important applications is represented by the fall detection. As previously mentioned, in fact, falls are one of the main threats to independent life of the elderly subjects. Several systems have been developed for this purpose, especially based on computer vision, such as (Gasparrini et al., 2014), or wearable sensors (Huynh et al., 2014; Pierleoni et al., 2014). Other solutions focus, instead, on the individual activity detection, such as moving (walking, standing, etc.), as shown in (De Santis et al., 2014). In (Zhang et al., 2013) a platform, called ENLIVEN,using environmental non-intrusive sensors, has been presented: the system is able to understand activities and vital signs, and, using such data, to make decisions. Algorithms based on fuzzy logic have been used in (Medjahed et al., 2009) for the recognition of different activities, such as Sleeping, Getting up, Toileting, etc. In this case, the monitoring system uses three main subsystems: two microphones to monitor the sound, a wearable device that measures physiological data, a set of infrared sensors for detection of the presence and posture of the subject. Even in (Fleury et al., 2010), the monitoring system consists of presence sensors (IR), microphones for the sound and speech recognition and a wearable sensor; contacts on doors and refrigerator, temperature sensors and humidity are also added. The technique used for the activity classification exploits the Support Vector Machines (SVMs). The method presented in (Nam et al., 2011), based on (Kim et al., 2009), allows to obtain, instead, data such as time of occurrence, probability of occurrence, daily time intervals and the relations between the various activity sets, shown according to a specific graphical model. Algorithms that can distinguish patterns of activity occurring frequently, through the analysis of the temporal relations in a multi-user environment, have been described in (Jakkula et al., 2007). These algorithms have been used in the context of the CASAS project (Rashidi and Cook, 2009), a smart environment providing a non-invasive assistive tool for dementia patients at home.

5 METHODOLOGY

The following section describes the platform adopted, the design choices and the methodologies used in the development phase. A brief overview on the AAL platform underlying the project is presented first, then the user interface based on touch screen technology is explained in detail, paying close attention to the design choices. Finally, algorithms for the presence and activity recognition are exposed.

5.1 Context: A Smart Home in AAL

Before discussing the design methodologies used, a quick overview of the underlying AAL framework will be provided. Such a framework covers several aspects of the home living, such as independent living, home security, health monitoring and environmental control. From a general point of view, in the system architecture the information is generated by a multiplicity of subsystems. They implement specific functionalities and, through well defined policies and rules, send the data to a local server (some specific information are delivered remotely), which correlates all the received data, collects information on the status of the system and on the user's habits and behaviour (see Fig 1).
The system is able to:

- analyse behavioural data in a unobtrusive way on the long term in order to make a preliminary diagnosis compared to the observed changes in habits;
- allow the user to interact with the home environment, facilitating certain tasks, such as opening or closing windows and blinds, and turning on or off

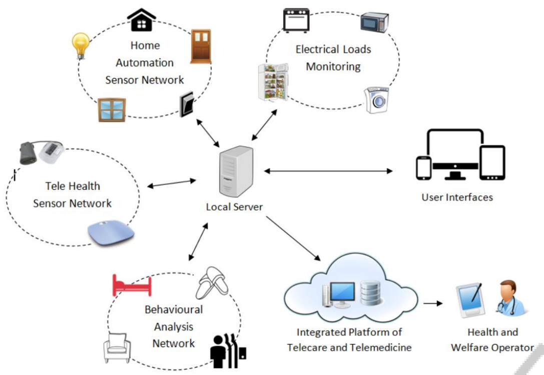

Figure 1: Different subsystems in the platform architecture.

lights, through the home automation sensor network;

- monitor the power consumption of the household appliances in order to optimally manage the spending for the electrical energy;
- collect medical data, such as weight or blood pressure, acquired through electrical devices and transmit the data to a health professional or a doctor for diagnosis.

Each subsystem uses different devices, transmission media (CAN bus, ETHERNET, WI-FI and wireless sub GHz) and communication protocols. All the acquired data are sent via proper network interfaces to a central server, to store and process information. The server also listens for requests from the user interface to provide adequate information and services.

5.2 User Interface Design and Prototyping

The user interface relies on three different types of touch screen devices: tablets, smartphones and fixed touch screens. Each device has features and offers different advantages, for this reason it is important to choose the right device according to which user is interfacing the system. Smart phones are characterized by a great portability, but due to the small size of the screen, they do not fit with users affected by visual impairments or poor motor skills. Conversely, fixed touch screens allow to display contents even to visual impaired subjects, but cannot be moved from a room to another easily. In this sense, the tablet is a good compromise, ensuring mobility and acceptable screen size. According with the general rules of interface design, previously mentioned, some specific guidelines for the touch screen interaction have been arranged. In particular, they relate to four key aspects:

- The target elements design: buttons at least 9.2 mm wide for smartphones, and larger for tablets and fixed screens will be used. Once the target is captured, in order to communicate to the user the success of the operation, a visual or audible feedback is performed.
- The graphic elements design: among the elements that influence the effectiveness and the quality of interaction, particularly important are the graphics. To facilitate the understanding of the content, each button has an icon and a text label that specifies its meaning. The used graphics is simple and intuitive, there are no animations.
- Navigation: while browsing it is important that the user is always able to know where he or she is; For this reason, each page is characterized by a title that defines its content. Moreover an extra help provides aid during the navigation. One aspect to consider is the navigation hierarchy: it is not recommended to use deep navigation hierarchies that may cause confusion and disorientation to the user.
- The design of the contents layout: having small screens, the use of the text has been limited to the minimum, preferring to use keywords instead of long sentences. The information and graphics are concentrated in the central area of the touch screen; the background and the contents are colored appropriately.

In addition to these criteria, an initial check on the network connection and popup windows notifying the results of the performed procedures have been implemented. Moreover, the application final appearance differs automatically according to the screen size, i.e. the interface is optimized for the used device.
The prototype application uses the Android operating system, from version 3.0 Honeycomb. It allows to check the status of the lights and turn them on or off , activate scenarios and open or close blinds and windows. Through a specific service, the user can obtain the values of the measurements obtained from electromedical devices and visualize them on the screen. Monitoring functionalities are also available for checking the status of the environmental sensors, of the power consumption and of the activities carried out by the user; an example of graph that summarize the user's daily or weekly behaviours are visible in Fig. 2 Finally, additional functionalities allow to display notifications to remind to the elder to take medicines at the prescribed time. All these services are requested from the local server, according to the classic client-server model, which answers to each request using a string formatted in JSON standard.

Figure 2: An example of daily activity graph: a time line representation of sleeping activity displayed by the user interface.

5.3 Behavioural Analysis

As already widely discussed, the smart home for AAL allows to monitor and assist the daily activities of the elder living alone at home, in order to obtain information on his or her behaviour. From the analysis of these information, it is possible to deduce any progressive worsening in the state of health, potential risks and emergency situations. One of the strengths of the project described in the previous subsection is the ability to collect a large number of behavioural data without the need for any user action. As already mentioned, this is an essential aspect in the design of systems intended for older users. In order to make the system non-intrusive, environmental sensors have been used, such as:

- PIR;
- magnetic sensors for fridge, doors and windows;
- pressure sensors for beds and chairs;
- power meters for electrical consumption;
- flow meters for water and gas.

The fusion of the data obtained from these sensors allows us to determine the activities carried out by the user. The behavioural data that can be identified are mainly of three types: energy consumption, presence and activities. While the first concerns only the energy consumption and thus may be derived directly from the observation of the data acquired from the power meter, without using more challenging algorithms , the last two types exploit more complex methods of data analysis.

5.3.1 Presence Recognition

The presence recognition at home is a very important point that allows to identify any abnormal situations or alert. For example the elderly could turn on the stove and, forgetting it on, leave the home. This represents a potentially dangerous situation that should be avoided. To this aim a presence recognition algorithm has been implemented. For the assessment of the state of presence, only some sensors have been considered: PIR, magnetic and pressure sensors. The flow meter and power meter have not been considered at present. The position of some sensors is essential for the proper functioning of the algorithm. In particular it is necessary to monitor the front door (the working hypothesis is that there is only an entry). For this purpose two PIRs, one inside and one outside the door, and also a magnetic sensor which can detect its opening/closing, have been positioned. The basic concept of the algorithm is that, depending on the user's location, the probability that he exited may be higher or lower; consequently the time needed to determine if he is absent varies according to this consideration. In order to determine where is the user, eight states have been identified:

- Absent;
- User out, door closed: the house is empty and the user is outside; the door is closed;
- User out, door open: the house is empty and the user is outside; the door is open;
- User in, door open: the user is in the house, and the door is open;
- User in, door closed: the user is in the house, and the door is closed;
- Sleeping/resting: the user is in the house, and he is sleeping (night time) or resting (during the day);
- Present (generic): the user is in the house, indoor or outdoor, but we have no more information on what he is doing or where he is;
- Multiple users: the user is in the house, with someone else.

The algorithm consists of a state machine in which events allowing to move from a state to another are those detected by the sensors (such as opening a door or activating a PIR sensor).
When a sensor detects an event, the presence reliability is increased by certain percentage value. As time passes, without the occurrence of other events, this value progressively decreases. When reliability reaches zero, the status changes to Absent. The value of decrease depends on the current state. For example, if the user is outdoor and the door is closed, just a few minutes without the occurrence of another event are sufficient to assert that the user is absent; while, when the user is in the house and the door is closed, much more time is necessary before the system can notify the absence. When multiple events occur at the same time in different rooms it is possible to state that there are multiple users. Also in this case

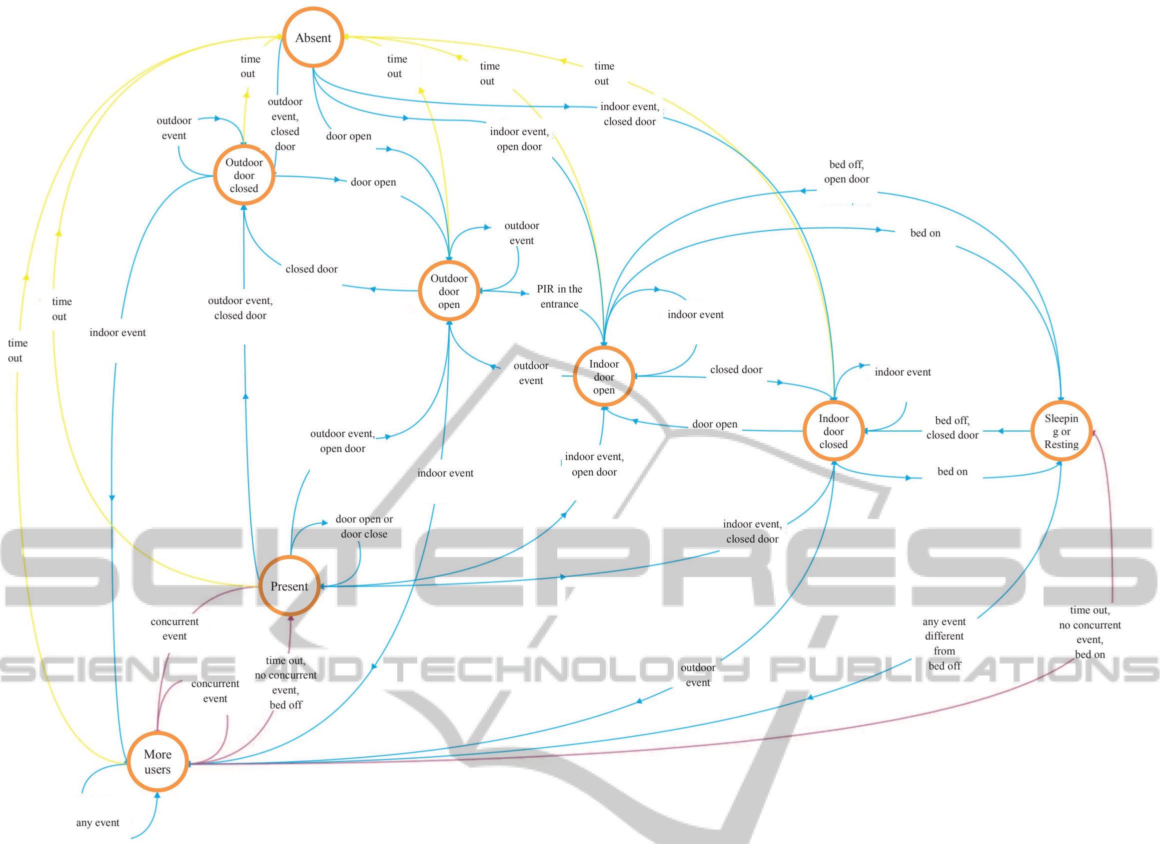

Figure 3: The state diagram of presence recognition algorithm.

when the timer expires, if no further concurrent event occurs, the system assumes there is only one user. The state diagram of the algorithm for the presence recognition is shown in Fig. 3. As obvious, the more refined is the algorithm, the bigger the state diagram becomes.

5.3.2 Activity Recognition

Through environmental sensors, it is possible to recognize the activities carried out by the user. In this regard, first elementary algorithms have been implemented to understand if the user is cooking, sitting or sleeping. Such information can be obtained using respectively, a fluxometer on the cooker to detect the gas flow, a pressure sensor under the mattress of the bed and a pressure sensor under the cushion of the sofa. Currently, combining the sensor activations and deactivations, it is possible to recognize the individual activity. However, more complex algorithms based on the sensor fusion, are foreseen to detect activities more carefully. About that, for example, the activity of cooking could be recognized by analysing the data from other sensors, such as those indicating the use of microwaves, by means of the power meters or those indicating the opening of the refrigerator, using magnetic sensors. One of the ideas currently under study to understand if the user is sitting or is sleeping consists in implementing truth tables considering the status of multiple sensors, such as PIR and magnetic sensors.

6 EXPECTED OUTCOME

As previously explained in section 1, the platform is already available as a PoC. The system is able to acquire data from sensors and send such information to the local server in real time.

A first prototype of the user interface is already available. Some screenshots of the application are shown in Figs. 4 and 5. Respecting the criteria mentioned above, graphics chosen are very simple and easily understandable, there are no animations and the buttons are large sufficiently. Moreover different layouts have been chosen to best fit the size of the screen as you can see in Figs. 6 and 7. Once the development phase has been concluded, a verification of functions, us-

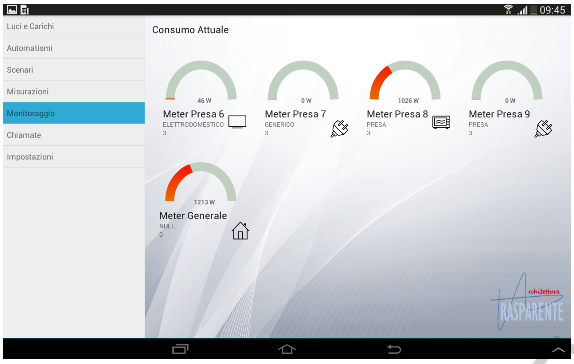

Figure 4: Screenshot of the user interface that monitors the current power consumption of different loads (from left to right: tv, generic load, microwave, generic load and in the bottom the general meter).

Figure 5: Screenshots of the user interface that controls the opening/closing of windows and shutters.

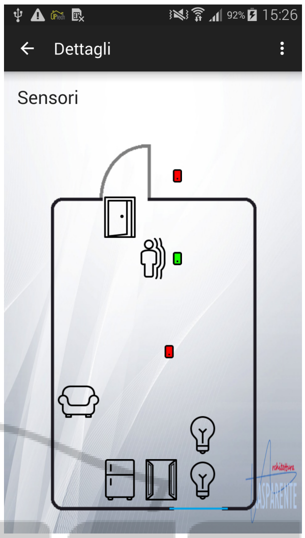

Figure 6: Screenshot of the user interface that monitors the state of some sensors: the application can automatically understand the size of the screen and choose the right layout (layout for smartphones).

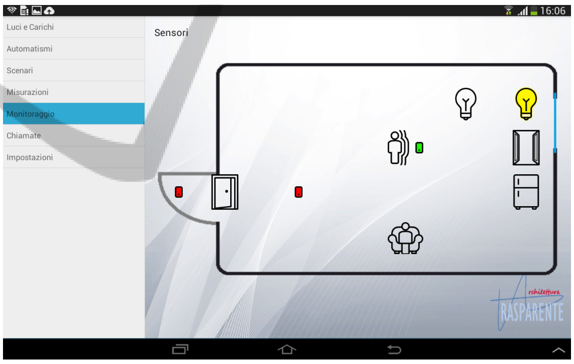

Figure 7: Screenshot of the user interface that monitors the state of some sensors: the application can automatically understand the size of the screen and choose the right layout (layout for tablets and fixed screens).

ability, reliability and effectiveness of the interface prototype for user-system interaction has been realized. The system works correctly in all the different conditions of use. Moreover, in order to obtain an opinion on usability, some volunteers have tested the application and filled out an evaluation form, providing an overall judgement on the interface. It has been also request a personal opinion on the level of usability of the application when used by elderly people. The group of volunteers is composed of 13 subjects, whose average age is 27 years; in Tables 1 and 2 the evaluations expressed by them are shown.

Although the tests were not carried out by individuals with characteristics similar to those of the target users, they still provide an initial positive response from people external to the project, considering the first impressions and getting tips for the improvements. Among the various features provided by the touchscreen application, several concern the visualization of daily or weekly charts of the activities performed by the user. Although more complex or refined algorithms have not been implemented yet, such graphics allow us to determine the actions with a certain degree of reliability. The presence recognition algorithm is currently in the testing phase. From tests carried out so far, it is able to correctly recognize the user's status. Some of the hypothesis made in the design phase have been changed as a result of tests done in the laboratory environment, to better adapt to the real functioning of the system and make it more efficient. The results of the algorithms for the presence and activity recognition are stored in a database and

Table 1: Different aspects evaluated by volunteer users voting in a range from 1 to 10 (1: very bad, 10: very well.)

Evaluated aspect	Rate on the prototype
Visual Appearance: clarity, visual impact, coherence between the different sections	8.7
Intuitive use: easy to learn how to interact with the application	8.4
Immediate detection of functionalities, ease of navigation	8.8
Efficiency: level of user control, reachability of the objectives	8.7
Feedback, notifications, error handling	7.6

Table 2: Findings on the use within the AAL evaluated by volunteer users, voting in a range from 1 to 10 (1: very bad, 10: very well).

Evaluated aspect	Rate on the prototype
Usability by disabled or elderly users	7.2
Acceptability and impact on users	7.5

periodically sent to a remote telecare platform which deals with charts. In Figs. 8 and 9 you can see some graphs of the data collected in the testing phase.

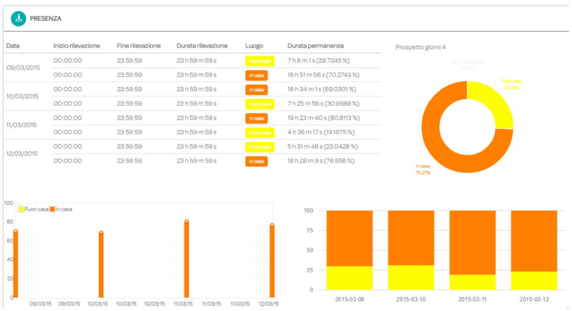

Figure 8: Screenshot of the remote platform interface showing presence graphs: yellow and orange portions represent respectively the absence and presence percentage time.

Further improvements foresee the implementation of more refined algorithm for the activity recognition and machine learning algorithms in order to predict the elder's behaviour, relying on observations of behavioural data in the long period.

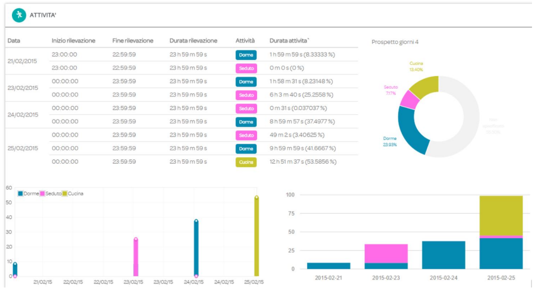

Figure 9: Screenshot of the remote platform interface showing presence graphs: each color represents the average time spent for the respective activity (blue for sleeping, green for cooking, magenta for sitting, grey for undefined).

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