Caregiver development of activity-supporting services for smart homes

Rafik Belloum, Amel Yaddaden, Maxime Lussier, Nathalie Bier, Charles Consel

Journal of Ambient Intelligence and Smart Environments 0 (0) 1
IOS Press

Caregiver Development of Activity-Supporting Services for Smart Homes

Rafik Belloum [a] Amel Yaddaden [b] Maxime Lussier [b] Nathalie Bier [b] Charles Consel [c,*],
[a] *Inria, Talence, France*
E-mail: charles-consel@bordeaux-inp.fr
[b] *Centre de Recherche de l'Institut en Gériatrie de Montréal,Université de Montréal, Montréal, Canada*
E-mail: {amel.yaddaden, maxime.lussier, nathalie.bier}@umontreal.ca
[c] *Department of Computer Science, Bordeaux INP, Bordeaux, France*
E-mail: charles-consel@bordeaux-inp.fr

Abstract. Older adults often need some level of assistance in performing daily living activities. Even though these activities are common to the vast majority of individuals (*e.g.,* eating, bathing, dressing), the way they are performed varies across individuals. Supporting older people in performing their everyday activities is a major avenue of research in smart homes. However, because of its early stage, this line of work has paid little attention on customizing assistive computing support with respect to the specific needs of each older adult towards improving its effectiveness and acceptability. We propose a tool-based approach to allowing caregivers to define services in the area of home daily living, leveraging their knowledge and expertise on the older adult they care for. This approach consists of two stages: 1) a wizard allows caregivers to define an assistive service, which supports aspects of a daily activity that are specific to an older adult; 2) the wizard-generated service is uploaded in an existing smart home platform and interpreted by a dedicated component, carrying out the caregiver-defined service. Our approach has been implemented. Our wizard has been successfully used to define existing manually-programmed, activity-supporting services. The resulting services have been deployed and executed by an existing assisted living platform deployed in the home of community-dwelling individuals. They have been shown to be equivalent to their manually-programmed counterparts. We also conducted an ergonomics study involving five occupational therapists, who tested our wizard with clinical vignettes describing fictitious patients. Participants were able to successfully define services while revealing an ease of use of our wizard.

Keywords: Smart home, Ambient assisted living, Assistive computing, End-user programming

1. Introduction

Smart homes are a promising approach to assisting individuals with a range of disabilities and supporting their independent living [1]. This approach has numerous potential benefits, including reducing the burden on caregivers [2] and the use of health and social services [3]. Research on applying smart homes to assisted living is a very active field [4]; advanced platforms have been used for real-world experiments (*e.g.,* CART [5], CASAS [6], and HomeAssist [7]) and have shown such benefits as preventing everyday functioning losses in older adults [8]. We conducted such an experiment using HomeAssist to address the needs of three populations – older adults, persons with intellectual disability, and persons with autism spectrum disorders – in performing their home activities independently. Our aim was to explore assistive services with practical case studies, covering all aspects from collecting needs for specific users, to deploying services tailored to each user in their home. To do so, we formed an interdisciplinary group with a range of

*Corresponding author. E-mail: charles-consel@bordeaux-inp.fr.

expertise, including psychology, occupational therapy, professional caregiving, and computer science. Early in the project, we found that, even though some services could apply to a range of users, those creating the most interest in users and caregivers often required specific interviews, analysis, and software development. Although specific, this work involved common stages: (1) analyzing needs with a user and/or their caregiver; (2) writing a specification of an assistive service with feedback from the user and/or their caregiver; (3) developing the assistive application for the smart home platform; (4) and, assessing the application with the user and/or their caregiver. These stages needed to be iterated, as in any development process. Thanks to our human-centered approach, we were able to adjust the services during development, preventing any gap between the behavior of the services and the needs expressed by the user and/or their caregiver.

This systematic approach allowed us to produce services highly tailored to users, not necessarily knowing a priori the specific topics we would be addressing. Such services showed a positive impact on the users and their caregivers because they felt their individual needs had been taken into account and they were able to concretely assess the outcome of their inputs in the resulting services. As an illustration of this exploration, we developed a service to manage outside appointments of a user. This service uses a calendar to manage events. If an event is triggered and corresponds to an outside appointment, the service informs the user of the upcoming appointment early enough to give them time to prepare. Then, a sensor is used to check whether the user left home. If not, when the appointment is important (*e.g.,* health related), the caregiver is notified, in addition to the user. Other examples covered in this exploration included such activity areas as household chores (*i.e.,* homemaking), vocational, leisure and health management. Even though satisfying for users, our approach showed practical limitations, as we tried to grow the number of users and assistive goals: it did not scale up because of the amount of time required to gather the user needs and develop the corresponding services.

To resolve our software development bottleneck, we set out to analyze the activity-supporting services we had developed. This analysis revealed that they had extensive common properties, which suggested that they formed a program family [9]. As reported in the literature, the variations and commonalities of a program family can be leveraged to factorize parts of the software development process. Factorization typically takes the form of domain-specific languages (*e.g.,* [10]) and gives rise to program generation tools (*e.g.,* [11]). This finding was a key insight toward solving our software development bottleneck problem.

Our approach

We propose a complete approach to developing activity-supporting services, ranging from the modeling of the target activities, to an end-user tool to define services, to a layer to run services in a smart home.

A taxonomy of activities To model the activities to be supported by our approach, we have developed a taxonomy, drawing from 1) the taxonomies of home activities reported in the literature, 2) discussions with caregivers, and 3) needs analysis of our participants.

A wizard for activity-supporting services To prevent any gap between the gathered user needs and the resulting activity-supporting service, we have developed a wizard, which allows a caregiver to express a service within our taxonomy of target activities. This wizard runs on a tablet and was designed and developed in close collaboration with three professionals in aging to ensure its usability. Specifically, at key development stages, we conducted interviews and usability tests.

Execution support for wizard-defined services Our wizard generates a representation of a caregiver-defined service that is fed to the smart home platform. A dedicated layer is in charge of interpreting this representation to realize the service, leveraging available connected objects (*e.g.,* sensor), services (*e.g.,* calendar), and interaction modalities (*e.g.,* user notifications).

To validate our approach, (1) we used our wizard to define existing activity-supporting services and observed their behaviour equivalence when deployed in the home of our participants; (2) additionally, we used our wizard to define a number of new services to test the coverage of the target taxonomy of activities – the wizard-defined services targeted older adults, users with intellectual disability, and users with autism; (3) finally, we conducted a study to measure the usability of the wizard with five occupational therapists (OTs) that used the wizard's features to respond to clinical fictitious situations; the results reveal a good usability of our wizard by OTs.

As can be noted, the goal of our work is not to introduce new techniques to develop wizards. Instead, we aim to examine whether a wizard can be an effective tool to allow caregivers to define realistic activity-supporting services which, in doing so, directly benefit from their knowledge and expertise.

Overview

The rest of this paper is organized as follows. Section 2 discusses the related work, covering the salient features of our approach. In Section 3, we analyze our target domain – activities of daily living in the home – and develop a taxonomy of such activities that can be supported by technology. This taxonomy drives the definition of a wizard, which allows end-users to define their own services. This wizard is presented in Section 4. The support required to execute wizard-defined services is described in Section 5. An evaluation of our approach is presented in Section 6, followed by concluding remarks and future work given in Section 7.

2. Related Work

In this section, we investigate smart homes that provide an infrastructure for services supporting activities of daily living. We then examine these activities, drawing from how they are modeled and classified in the literature. Next, we review computing approaches to supporting activities of daily living. Finally, to enable caregivers to develop their own assisted living services, we review some approaches for end-user development.

2.1. Smart Homes

A smart home is commonly viewed as a set of connected objects, allowing the user to control, via conventional or voice interface [12], the various home components (heating, shutters, entrance gate, electrical outlets, *etc.*), and providing technical solutions to meet comfort needs (energy management, optimization of lighting and heating), security (alarm) and communication (remote controls, visual or audible signals, *etc.*) [13]. Despite the many benefits of smart home, it does not address the specific needs of individuals with cognitive decline and/or disability. Their needs consist of environmental support to helping them perform their daily activities, as increasingly evidenced [14, 15]. As such, these needs go beyond existing forms of smart home but could leverage this infrastructure towards forming an environmental support.

2.2. Activities of Daily Living and Their Classification

There is an extensive literature on activities of daily living (ADLs), produced by such domains as occupational therapy *(e.g.,* [16]), human factors (*e.g.,* [17]), psychology *(e.g.,* [18]). ADLs are generally divided into two categories: basic activities (BADLs) that are necessary for fundamental functioning – eating, getting dressed, looking after the appearance, *etc.* – and instrumental ADLs (IADLs) that are necessary for independent living – cleaning and maintaining the house, preparing meals, shopping for groceries and necessities, leisure, taking medications, *etc.* [19]. The disciplines producing the classification of activities pursue various goals, ranging from evaluating the functional status of an individual, to devising an occupational rehabilitation program. Our goal is complementary in that we aim to develop a taxonomy of home activities, which serves as a framework for caregivers to define technology-based assistive services. The aim of this framework is to guide the caregivers in a step-by-step process in identifying and declaring the specificities of the user needs. Refining this process should contribute to develop a tool that supports service development.

2.3. Computing Support for Activities of Daily Living

The ability to perform ADLs is a determining factor for independent living. Given that performing ADLs at home often translates into interactions of a user with their environment, a smart home is a promising infrastructure for monitoring ADLs. In fact, this topic has been receiving much attention for more than a decade in research areas related to ubiquitous computing. An ambitious approach is *activity recognition*, where the system infers which activity a user is performing, how they are performing it, and its current stage [20]. Although promising, in the context of smart homes, this approach is still being studied in experimental settings. Furthermore, machine learning algorithms, often used in this context, face major challenges when applied to computing systems supporting individuals with cognitive decline and/or disability. Whether supervised or unsupervised, in a naturalistic setting, machine learning-based systems have to account for changes in sensors (*e.g.,* moved, broken, replaced) and changes in activities (*e.g.,* new activity patterns due to declining/acquired abilities). Putting these systems to practice still requires research.

Another approach proposed by Caroux *et al.* consists of verifying activities based on user declarations, instead of inferring them [21]. This pragmatic approach has been successfully used in single-occupant homes in real-life settings and applied to a realistic set of activities, namely, meal preparation, getting up from/going to bed, and taking a shower [21]. Caroux *et al.* do not address the software development needed to handle additional activities.

Because our primary goal is to allow caregivers to define activity-supporting services, we need to trade expressiveness for simplicity (*i.e.,* reducing the scope of the services that can be expressed). Consequently, we do not envision to support a general form of activity detection and the configuration space that would be required. Instead our approach should apply activity verification using a wizard to leverage the knowledge of the caregivers and focusing on single-occupant homes. Following the conclusions of the activity verification experiments, the sensing capabilities available in the wizard can be limited [21, 22]. This should simplify the service definition process, while retaining the ability to detect insightful interactions of the user with their environment when performing activities of interest.

2.4. Service Development

As observed by Greenhalgh *et al.*, successful assistive technology is often characterized by pragmatic customization, often performed by their caregivers [23]. This situation can be quite an impediment when developing an assistive service that requires programming skills. Beyond programming languages and domain-specific languages, end-user development (EUD) provides users with textual/visual forms of programming, which require little, if any, technical skills. However, even a successful end-user programming language, such as Scratch [24], has a long learning curve for less tech-savvy users; such languages require user practice and time, which represent barriers for novices [25].

In the context of smart homes, Brich *et al.* argue that involving end-users in the development of services requires interfaces that need to be easy to understand and use, especially for less tech-savvy users [26], as are caregivers. SPOK is an end-user programming language, dedicated to the smart home domain [27]. It is a rule-based, imperative language that offers the user a pseudo-natural syntax for ease of programming and constructs such as “while” and “if” for expressiveness. Another end-user approach to customizing smart homes is trigger-action programming, such as if-this-then-that, as popularized by the website IFTTT. However, as observed by Huang et al. specifying services in IFTT is difficult because the notion of event and state are frequently confused by users [28].

A study of visual languages for smart spaces is reported by Reisinger *et al.*, where form-filling and data-flow programming are compared [29]. Form-filling allows participants to complete programming tasks faster and higher overall completion rate, whereas significantly more items are remembered when participants are being presented with a data-flow visualization. The authors recommend to blend both approaches for end-user programming of untrained users. Leveraging this work, we are envisioning a wizard-based approach for end-user programming of services.

3. Taxonomy of Activities for Independent Living

First, we explore and organize activities of daily living and the needs they could address, according to users and their caregivers. Next, we present the assistive goals that result from activities of interest. Then, we examine the assistive applications that were (manually) developed based on these assistive goals and deployed in the smart home of our participants. Leveraging these applications, we identify and analyze their commonalities and variabilities towards forming a taxonomy of technology-supported activities. This taxonomy will serve as a framework to define activity-supporting services.

Exploring activities

To explore activities of daily living in the home, we leverage a taxonomy used by occupational therapists to assess the ability of individuals to live independently in their home [30]. An extract of this taxonomy is presented in Figure 1. As can be noticed, activities of daily living in the home are decomposed hierarchically: from general categories of activities at the root, to refined specific categories towards the bottom. Leaves define a set of concrete activities, such as taking out the garbage, vacuuming and sweeping. As such, this taxonomy allowed us to explore user needs in a systematic manner, down to specific activities, which can become assistive goals.

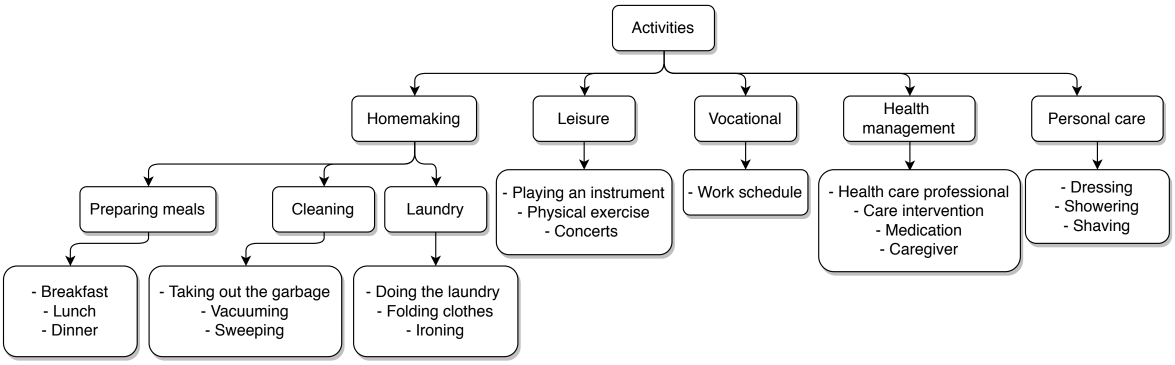

Fig. 1. An extract of a taxonomy of home activities

Activity	Assistive goal
Household chores – *Preparing meals (breakfast, lunch, dinner)*	Supervising and assisting meal preparation.
Sleep hygiene –*Bed times*	Supervising the user and suggesting bed times.
Vocational – *Going to work*	Supervising the user to ensure they leave home for work on time.
Household chores – *Vacuuming, sweeping, ironing, taking out the garbage, etc.*	Supervising and assisting household chores to ensure a well-managed home.
Leisure – *Going to the pool*	Supervising the user to ensure they leave home for the pool on time.
Leisure – *Practicing a musical instrument*	Supervising the user to ensure they practice their musical instrument.
Health management – *Healthcare visit*	Supervising the user to ensure they are ready for a visit of a healthcare professional.
Health management – *Medication*	Supervising the user to ensure they take their medication.

Table 1
Assistive goals

Assistive goals

Once an activity is targeted by a user and/or their caregiver as an assistive goal, we start specifying what assistance should be delivered and what technological support would be needed. Table 1 lists on the left column a few categories of activitities, extracted from the taxonomy, and illustrates them; the right column briefly outlines an assistive goal for each example of activity. Beyond the user and their caregiver, analyzing an assistive goal may also involve experts in human-related sciences to refine the user characteristics and needs by administering standardized assessments to determine the user's skill set and deficiency. This knowledge is then used to determine such dimensions as whether the assistance should be context aware and the type of assistive support that is required (*e.g.,* reminder, task prompting). These steps are inspired by the human-centered approach to developing assistive computing support proposed by Consel [31].

Assistive services

Assistive goals are carried out in practice by developing assistive services that will be deployed in the smart home of the target user. In Table 2, we describe a representative sample of assistive services that we developed; it lists an abbreviated name of the service used later for conciseness, its target activity, and a short description.

As we developed services for our participants, we realized that they consisted of recurring features. This situation is reflected by the analysis of the service descriptions, provided in Table 2. For example, examining meal preparation and vacuuming reveals that both activities are located at home; they must occur during a given time period and at recurring dates; they can be supervised via sensors; reminders can be sent to the user in case the activity is not performed. Let us systematize this analysis to identify the commonalities and variabilities of our assistive services.

Name	Activity	Service description
PM	Preparing meals	The service measures key user interactions with the environment (fridge, kitchen cabinet, *etc.*) via sensors to detect whether a meal is being prepared within a set time interval, supplied by the user at configuration time. The user and/or a caregiver is notified, when no meal preparation is detected via a tablet notification or a text/email message. The service can also assist the user in preparing a meal by launching a dedicated prompter.
BT	Bedtime routines	Driven by user-declared routines, the service checks whether they are realized by monitoring user interactions with their environment via sensors. When a mismatch is detected the user and/or the caregiver are alerted as in the previous service.
VA	Vacuuming	User is reminded of vaccuming, according to a user-supplied schedule. The vaccum cleaner is equipped with a sensor to check whether it is running, allowing reminders to be sent appropriately. Also, a dedicated task prompter can be launched to assist the user in performing the task.
IR	Ironing	Same as vacuuming. Sensor-equipped iron for context-aware reminders.
SW	sweeping	Same as vacuuming. A sensor is located at a strategic location to detect whether the activity is being performed (*e.g.,* the door of a cabinet containing cleaning items).
IN	Practicing a musical instrument	Same as vacuuming. The musical instrument is equipped with a sensor. Dedicated task prompter can be launched to assist the user in starting setting up the instrument.
SH	Showering	The service notifies the user and/or their caregiver, when no showering activity is detected (via a motion detector), according to the user-supplied schedule.
TR	Taking out the garbage	The service notifies the user and/or their caregiver when the garbage is not taken out, according to the user supplied-schedule. This activity relies on a dedicated sensor, placed at a strategic location.
WO	Going to work	The service sends a notification to the user before and at departure time, according to a user-declared schedule. User departure is checked via sensors. If the user is late, an alert is sent to them and/or their caregiver.
SP	Going to the pool	Same as previous service.
CP	Healthcare-related visit	The service sends a reminder to the user before the time of the appointment. Additionally, a dedicated prompter can be launched to assist the user in preparing the visit (personal care, household chores, *etc.*).
CG	Caregiver visit	Same as previous service with a dedicated task prompter.
ME	Medication taking	A dedicated sensor checks medication is accessed (*e.g.,* the door of a cabinet) at the user-supplied times. An alert is sent to the user, if the activity is not performed. A dedicated task prompter can be launched to guide the user, if needed.

Table 2
Description of services

Analyzing commonalities and variabilities

Because of the features they shared, we approach our assistive services as a program family and analyzed their commonalities and variabilities. This work first allowed to group services into three main categories: indoor, outdoor, home visit. Indoor consists of activities performed at home (*e.g.,* vacuuming, sweeping, showering, preparing meals) and may be supervised via sensors. Outdoor activities may require preparation time; it should eventually lead the user to leave home at a given time, which can be checked via sensors. Home visit occurs indoor and may also involve activities to prepare it. Variabilities are concerned with the time of an event, the time period, the sensor involved, the kind of user interaction, the communication modality with a caregiver, and the task prompter. Commonalities and variabilities are summarized in Table 3.

A taxonomy of technology-supported activities

We have organized the commonalities and variabilities identified previously into a taxonomy (displayed in Figure 2). As such, it can serve as a guide for caregivers to define an activity-supporting service and address the user's needs. At the root of this hierarchy, an activity needs to have a description. It may be recurring and may be supported by actions. The next level introduces a choice between outdoor, indoor, and home visit-related activities. Outdoor activities require a date and a time at which the user is notified to start preparing, as well as a date and a time at which the user is supposed to have departed from home. User departure can be checked via a detector. Indoor activities consist of a date, a time period, and a sensor, if supervision is needed. Finally, home visit-related activities require a date and a time. The leaves of our taxonomy consist of

	Indoor									Outdoor		Home visit	
	PM	BT	VA	IR	SW	SH	TR	IN	ME	WO	SP	CP	CG
Description	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Begin date	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×
End date	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	×
Recurrence	✓*	✓*	P	P	P	✓*	P	P	P	✓	✓	P	P
Reminder	×	×	×	×	×	×	×	×	×	P	P	✓	✓
Alert	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×
Preparation date	×	×	×	×	×	×	×	×	×	✓	✓	×	×
Exit date	×	×	×	×	×	×	×	×	×	✓	✓	×	×
Date of reminding	×	×	×	×	×	×	×	×	×	×	×	✓	✓
SMS	P	P	P	P	P	P	P	P	P	P	P	P	P
Email	P	P	P	P	P	P	P	P	P	P	P	P	P
Guiding (Prompter)	P	P	P	P	P	P	P	P	P	P	P	P	P
Supervised (sensor)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×
Departure detection	×	×	×	×	×	×	×	×	×	✓	✓	×	×

P: Possible (depends of the needs) ✓*: mandatory recurrence for such activities as preparing meals and showering.

Table 3
Family of assistive services

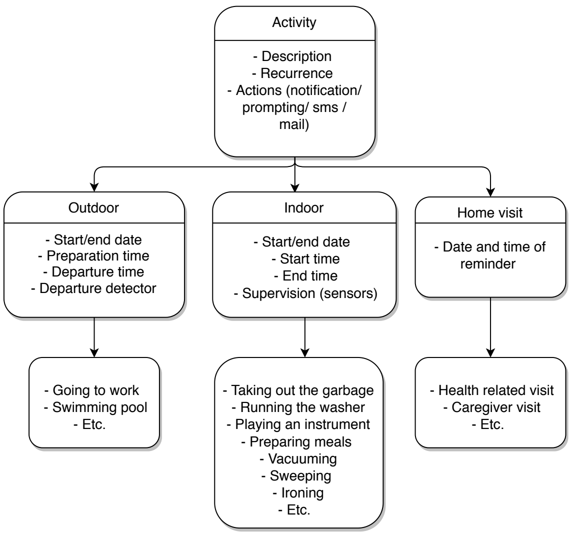

Fig. 2. A taxonomy for technology-supported activities

actual activities that inherits the characteristics of the parent levels.

Our taxonomy of technology-supported activities suggests a staged process to define services that could be tooled. This opportunity is explored in the next section.

4. A Wizard for Caregiver Development of Services

Our aim is to create a tool that 1) covers the taxonomy for technology-supported activities and 2) provides an accessible user interface such that caregivers and clinicians without programming skills can define services that address their care receiver's needs. As suggested by our taxonomy of technology-supported activities, defining assistive services should be a staged process, allowing the user to specify the characteristics of the target service in a stepwise manner. To match this requirement, our tool has been designed as a wizard, which makes explicit the decomposition of a service definition, reducing the risk of errors [32].

We first discuss the design of our wizard. Then, we illustrate the use of our wizard by creating an indoor activity-supporting service, showing screenshots of our tablet-based Android implementation.

4.1. Designing a Wizard

We examine the service characteristics that need to be supplied by the wizard user. Then, we present the task flow underlying our wizard. Finally, we outline a few elements used to design the user interface of our wizard.

User-supplied service characteristics

Our taxonomy (Figure 2) has already made explicit the activity characteristics that need to be supplied by the user of our wizard to define a service. As can be noticed, three categories of services emerge: indoor, outdoor, home visit. We thus revisit the activity characteristics by defining them for service category. Consequently, indoor activities consist of an activity description, a start date and time, an end date and time, a recurrence (optional), a sensor (optional), and an action. A sensor is selected for a service when its activation at a given time period suggests that the activity is being performed (*e.g.,* personal care activity can be assumed when motion is detected in the bathroom in the morning). Different actions can be included in a service; they are detailed in our example below.

Outdoor activities are composed of an activity description, a date and time to start preparing, a date and time to depart from home, a recurrence (optional), and an action to trigger if departure is not detected. Last, home visits consist of a description, the date and time of a reminder, a recurrence (optional), and an action if a preparation activity is not detected.

Task flow

Our taxonomy (Figure 2) suggests a flow of specific information to be supplied and decisions to be taken by the user to define a service. This task flow is shown in Figure 3 with each step represented as a rectangle. The first step is to choose a type of activity: indoor, outdoor, home visit. Then, the user is prompted with category-specific information. Every step requires the user-supplied information to be complete before going to the next step. Note that an indoor activity requires a time interval within which the activity must occur. An outdoor activity also requires a time interval to be defined: the start time is when preparation must begin, whereas the end time is when the user is supposed to depart from home. In contrast, home visit does not define an interval but a time at which the visit is reminded to the user.

User Interface

The general design of the user interface of our wizard follows the usual rules of such a tool: conforming to the users' mental model of the target process, enforcing a clear sequential order of the steps, showing a progress status with numbered steps, allowing navigation buttons to go back and forth in the process, *etc.* We iterated the design of our wizard with caregivers to ensure the activity characteristics were prompted in an order that matched their preference. We also ensured

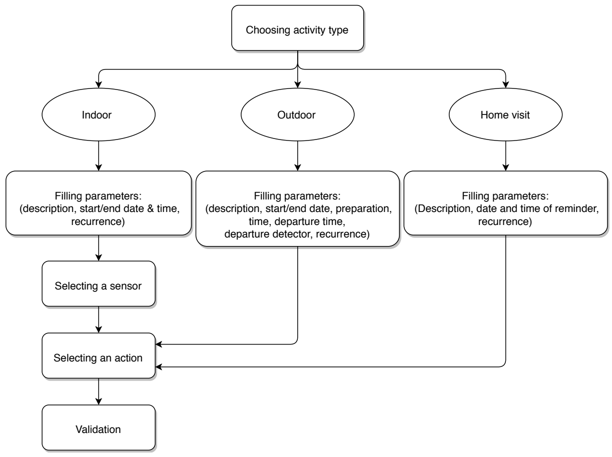

Fig. 3. The task flow of our wizard

that each wizard step consisted of a self-explanatory title and field names.

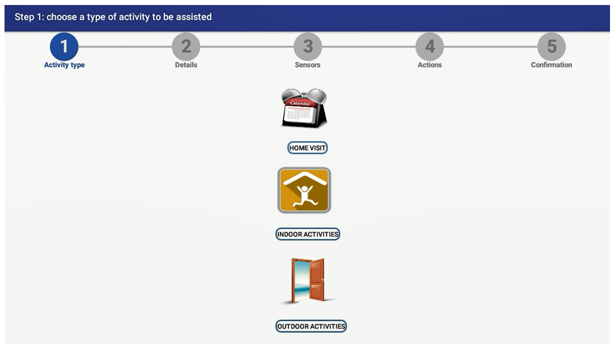

Fig. 4. Step 1: Choosing the kind of activity to assist

4.2. An Example

Let us explore the details of our wizard by creating an assistive service for doing laundry. The first step, shown in Figure 4, allows the user to choose the indoor activity category. Next, the user is prompted with the parameters of the target activity to be assisted, as shown in Figure 5: the activity description, the date and time, and the frequency. Start/end dates and times are selected via a calendar and a clock, respectively. Frequency is defined via a dedicated menu.

The third step, shown in Figure 6, involves deciding whether the activity needs to be monitored. To do so, a sensor category is first selected; there are three categories: 1) sensors attached to electric appliances (iron, coffee machine, washing machine, *etc.*) to detect whether they are running; 2) contact sensors to

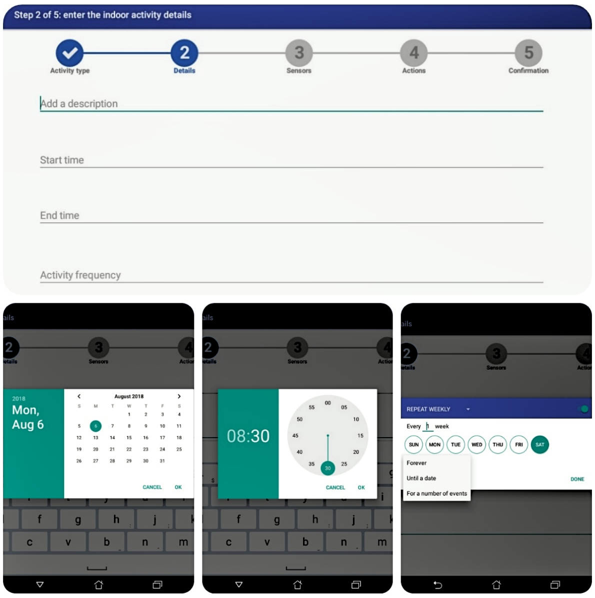

Fig. 5. Step 2: Indoor activity details step (description, periodicity, frequency)

detect the opening/closing of drawers, cabinet doors, and room/entrance doors; 3) motion sensors to detect a presence in a room or a specific location in a room (depending on the layout). In practice, we have added sensors as new assistive needs were revealed by discussions with participants and six caregivers over various durations of deployment, ranging from one month to a year.

In the fourth step, Figure 7 shows the actions that can be associated with an activity. The first action is a reminder to be sent to the user, whose meaning depends on the activity type. For a home visit, it corresponds to a time at which the user needs to get ready. For outdoor activities, one message is issued to inform the user that their preparation should start. An alert is then sent, if the user is still detected at home after the departure time. Indoor activities can trigger an unconditional alert when the time of the activity has arrived, or a conditional alert if the activity is monitored, as is the case in our laundry example. When an alert is issued, it prompts the user for one or more answers, which acknowledge that it has been taken into account.

Note that alerts can be defined as critical or non-critical, depending on the nature of the activity. Non-critical notifications can be ignored by the user, whereas critical ones will repeat the notification until the user responds. A notification is associated to an answer, allowing the service to check whether the user has responded to it. The second and third actions presented in Figure 7 are an email or text message that can be sent to a caregiver in case the activity has not been performed by the user.

Last, Figure 7 shows a menu allowing the wizard user to launch a task prompter to guide the user in performing an activity. In practice, this task prompter is launched on a tablet and takes as argument the name of the prompting scenario to invoke.

In the last step of the wizard, shown in Figure 8, the wizard user is presented with a summary of the activity to be assisted.

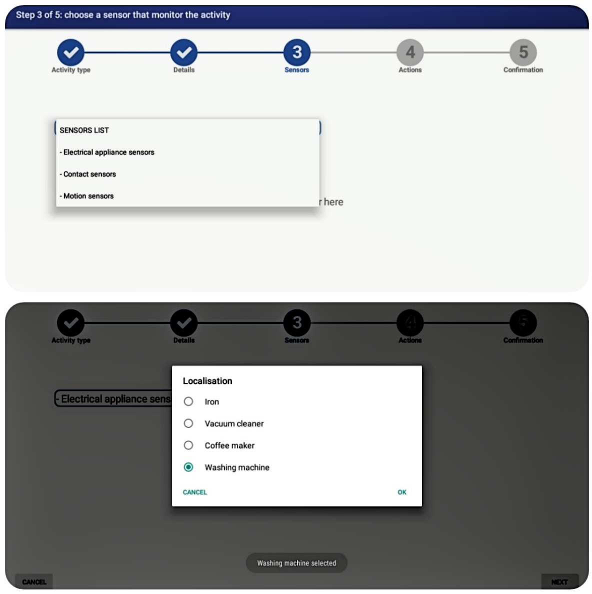

Fig. 6. Step 3: choosing a sensor

4.3. Implementing our Wizard

Our wizard runs on Android tablets and has been implemented in Java. Tablets allow intuitive touch-screen interface, facilitating the usability of the wizard by caregivers. We used Android's activity transition layout to navigate back and forth between the different wizard forms to be filled by the user. The Android SDK provides a range of UI controls and components to support the implementation of applications such as wizards.

5. Executing Wizard-Defined Services

We now present the different building blocks that allow wizard-defined services to be executed by a smart

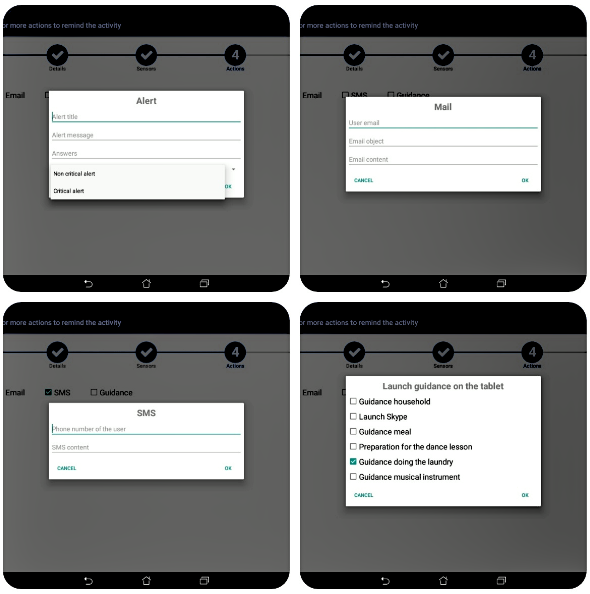

Fig. 7. Step 4: choosing one or more actions for the user and their caregiver

Fig. 8. Step 4: validation step

home. Our overall system following the wizard stage is displayed in Figure 9 taking the output of our wizard as the starting point. First, we examine what is required to implement our approach in a smart home. Then, we describe how we implemented it using the HomeAssist platform.

5.1. Smart Home Requirements

As suggested by the previous section, executing wizard-defined services revolves around a calendar to manage dates, times and recurrence. In fact, part of the output of our wizard consists of standard calendar event parameter information; this wizard output is denoted by the red arrow in Figure 9. Most calendar pro-

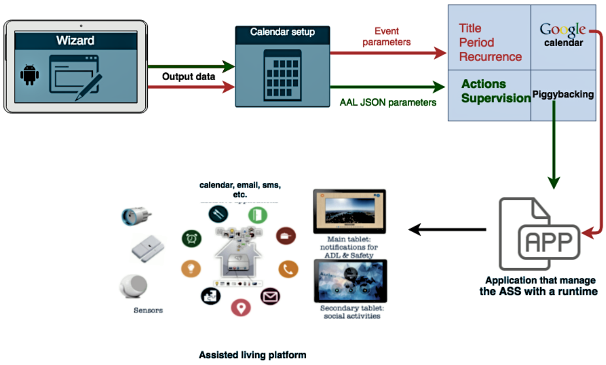

Fig. 9. The overall system

vides an API, allowing event to be created with respect to these parameters.

Executing a wizard-defined service still requires to invoke a runtime component to carry out the assistance of the activity, when its calendar event is triggered. The assistance-specific parameters are denoted by the green output arrow of the wizard (Figure 9) and include information mentioned earlier, such as sensor and notification. These parameters need to be associated with the calendar event and be passed to the runtime component, which is in charge of performing the required actions on the smart home, such as querying a sensor and issuing a notification.

5.2. HomeAssist Implementation

Figure 9 presents our implementation based on HomeAssist. As can be noticed, HomeAssist uses Google Calendar, whose API is used by our implementation to manage events. Furthermore, the activity-supporting service characteristics are piggybacked in a calendar event so that the runtime component can extract them when the event is triggered. Specifically, Figure 10 shows the ouput of the wizard (green arrow) in a JSON format for the example of doing laundry, in the context of our HomeAssist implementation. Property **MonitoredEvent** is true when the activity is supervised by a sensor, whose name is given by Property **Conditions**. If the activity is not performed by the user, actions to be triggered are listed in Property **Actions**. For example, Property **Android intent** contains the package name of the prompter application, which gets triggered to assist the user in accomplishing the target activity. The last property defines the notification to be issued to the user, including its title and message (Property **non-critical_notification**).

```
{
   "monitoredEvent":true,
   "conditions":{
      "Emeter_Laundry":true
   },
   "actions":{
      "android_intent":{
         "packageName":"com.apps.gk.firstthen"
      },
      "non_critical_notification":{
         "id":"IdNotifier",
         "title":"Turn on the washing machine",
         "text":"It is time to do the laundry.",
         "answer":[
            "Ok"
         ]
      }
   }
}
```

Fig. 10. The JSON output of the wizard

In HomeAssist, smart home applications can be developed and added to a catalog of applications available to users, in the spirit of mobile app platforms. Applications of this catalog support three main areas: ADLs (*e.g.,* monitoring meal preparation and self-care), user and home safety (*e.g.,* a light path to the bathroom at night and monitoring the stove), and social participation (*e.g.,* simplified email tool and games).

We leveraged this capability by developing an application, dedicated to carry out the assistance of all wizard-defined services. This application subscribes to wizard-related calendar events, extracts piggybacked information from an event field, and provides the assistive support accordingly. For example, in the case of doing laundry, the application checks whether the electric meter of the washing machine is on within the time interval set for this activity. If not, it issues a non-critical notification to the user and launches the prompter on a dedicated tablet.

6. Evaluation

6.1. *Activity coverage and execution equivalence*

To evaluate our approach, we used our wizard to define existing activity-supporting services that had been developed manually for older adults, adults with autism, and adults with intellectual disability. Note that these existing services were designed and developed using a user-centered approach, used daily in a range of ecological environments, and user experience was measured [7, 33].

By leveraging these existing services, we wanted to determine whether the wizard could be used to reproduce the development of realistic and practical services. This work was quite useful to refine the functionalities of the wizard and ensure that it offered the features needed to cover the existing applications, whose usefulness had already been validated by users and caregivers. Although this first phase allowed us to validate the coverage of the wizard in practice, it did not address the execution of the wizard-defined services. In particular, we still had to show that the execution of wizard-defined services was equivalent to their manually-programmed counterparts. To do so, we developed our special-purpose application in HomeAssist, which is dedicated to execute the wizard-defined services (as explained in Section 5). After testing it, we deployed it in the home of our participants to enable wizard-defined services to be executed in real environments. These updated platforms allowed us to validate that the behavior of wizard-defined services was equivalent to their manually-programmed counterparts.

6.2. *Usability study*

Usability tests were conducted with occupational therapists in an apartment laboratory. The goal was to document the perspectives of occupational therapists on the Wizard. Indeed, these clinicians are trained professionals 1) to assess the needs of people living with cognitive impairments and 2) to determine the types of interventions, which can ensure their safety and increase their independence with respect to specific activities [34]. They are also able to anticipate facilitators and obstacles to the facilitators and obstacles to the implementation of new technologies, such as assistive technologies for cognition [35].

6.2.1. *Methods*

Our usability testing approach was based on two methods: *Cognitive Walkthrough with Users*, and administration of standardized usability questionnaires. The Cognitive Walkthrough with Users is a method that consists of evaluating the usability of an interactive system by constructing different usage scenarios [36]. While they interact with a system, the users are asked to *think aloud*, allowing the experimenter to record their thoughts, feelings and opinions on different aspects of the system being studied. Users perform the tasks of interest after a brief presentation of the experiment. The user evaluation of the design features of a system is a key factor that determines technology acceptance and is of great importance to software designers [37]. Each occupational therapist was met during a 60-minute session. First, the participants spent 5 minutes introducing themselves to the technology by reading a document presenting the various features of the wizard. Then, they received two clinical vignettes with 2 fictitious patients for whom they had to find solutions using the Wizard application. During this period, subjective data was collected through recording of the participant's voice; objective data (*i.e.,* time spent for each task, number of errors) was collected through recording of the tablet screen.

Two usability questionnaires (System Usability Scale (SUS) and Attrakdiff) were also administered after the completion of the tasks by each participant. The SUS is a 10-item questionnaire with five response options for respondents; from Strongly agree to Strongly disagree. It is commonly used to assess a wide range of technologies from hardware to mobile applications [38, 39]. The AttrakDiff is a 28-item questionnaire, which assesses user experience through 3 dimensions: Pragmatic Quality (PQ), Hedonic Quality (HQ) and ATTractiveness (ATT) [40]. For both of these questionnaires, psychometric properties such as reliability and validity have been demonstrated.

	Gender	Age	Degree	Years of experience	Familiar type of software
P1	F	29	Master	3	Android
P2	F	44	PhD	17	iOS
P3	F	49	Bachelor	20	iOS
P4	F	25	Master	1	iOS
P5	F	27	Master	3	Android

Table 4
Participants

6.2.2. Results

A total of 5 occupational therapists from different clinical settings in psychogeriatrics agreed to participate in the study, as shown in Table 4. As reported in the literature, 5 participants can lead to the identification of approximately 80% of the usability problems [41].

Qualitative data Subjective data about participants' thoughts, feelings and opinions reveal good usability potential of our wizard, with some suggestions for improvement. One suggestion is related to the way the wizard is supplied information to schedule an activity. Specifically, all our participants found it difficult to program a recurring activity (*e.g.,* from Monday to Friday). One participant suggested: *"It would be more intuitive to specify that an activity is recurring while setting its date and time than to do it in two phases ."*

Another participant further suggested: *"It would be nice to have access to a small calendar that gives access to all configured reminders because it is easily forgotten".*

In relation to the way users can configure alerts, participants suggested that an option to make them repeat should be offered since some care receivers may need to receive an alert more than once to ensure appropriate actions are taken. Participants also were uncertain about how to fill the parameters of the alert menu (Figure 7). One participant said:

"It's not obvious to understand what message to put in the alert menu... In particular, It's not clear how to fill 'Answers'; it should show answers by default or be more explicit... ". In fact, this field was introduced at the end of our design process and its understanding was not properly tested with users prior to our study. Since then, it has been changed to take these comments into account.

Another issue noted by the 5 participants was about the sensor options, offered to monitor an activity (Step 3 of the Wizard – See Figure 6). Most participants found it too restrictive to use only one sensor for monitoring indoor activities. Indeed, the unique sensor may be activated, and yet, the activity may not be properly completed. For example, one participant suggested that a care receiver may open and close the washing machine door, without loading the laundry, putting the soap, or launching the washing machine. Yet, since the contact sensor of the door was activated, the activity could wronly be considered as completed. A participant suggested:

"It would be interesting to have the possibility to add several sensors to detect an activity. For example, a contact sensor for monitoring the washing machine door and an electric sensor for finding out whether it runs"

Participants also gave suggestions to improve the process of defining services. For example, one participant suggested to use speech recognition to improve efficiency, as most clinicians have time constraints. Another participant suggested to add a fourth type of activity, named “preparation/organizer”; a programmed alert and/or launch of the task prompter would assist the care receiver to organize and prepare their upcoming activities.

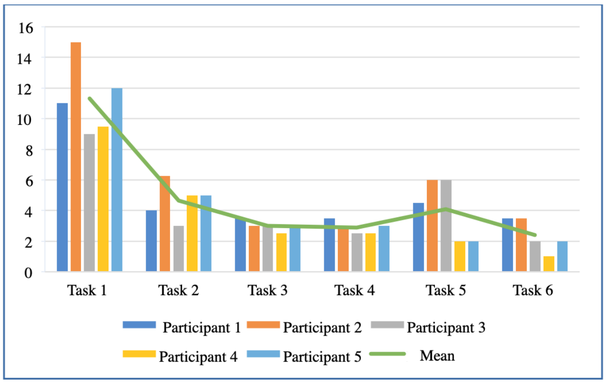

Fig. 11. Time (mins) to achieve tasks 1 to 6 for each participant (n = 5)

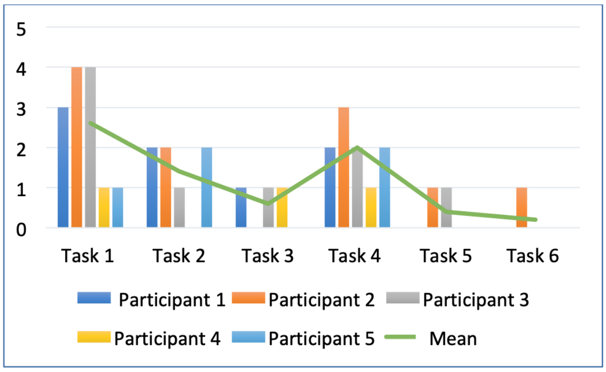

Fig. 12. Amount of errors per participant for tasks 1 to 6

Quantitative data They were collected while the participants completed their tasks using our wizard; their analysis reveals promising findings. Specifically, as shown in Figure 11, the average time to complete each task decreased as the participants became more familiar with the application. The number of errors per task also decreased, as shown in Figure 12. This trend does not apply to the fourth task, for which all the participants experienced difficulties to select the days of the week for which an activity needed to be scheduled, as discussed earlier. These results suggest that with time and practice, the application becomes easier to use.

Finally, the data collected from the usability questionnaires suggest good usability properties. In particular, Figure 13 shows that the average score of the participants’ answers to the Attrakdiff items are positive, except for 3 of them: creativity, practical aspect and human aspect. For the SUS, participants’ responses were generally similar for each question, as shown in Figure 14.[1] The only negatives scores matched the issues discussed during the recording of the participants, as mentioned above.

One direction to improve the practical and human aspects of the wizard is to provide caregivers with pre-selected options when they fill in the parameters of a new service; this strategy should facilitate the creation process. To enhance the creative aspect of the wizard, one direction is to follow a participant’s suggestion: adding a fourth type of activity, namely preparation, which enables an alert to be programmed and/or a task prompter to be launched. This type of services would assist the care receiver in organizing and preparing an upcoming activity, extending the scope of the wizard.

7. Conclusion and Future Work

We have characterized an area of home activities that is needed for independent living and can be supported by smart homes. To address this area, we have introduced a wizard-based approach toward empowering caregivers to develop activity-supporting services, leveraging smart home functionalities. As such, our approach allows the expertise of caregivers to be directly applied to defining assistive support for an individual they care for. We showed how the information gathered by the wizard can be interfaced with a smart home, to carry out the activity-supporting service. We evaluated wizard-defined services by comparing them to manually-programmed services and ensuring that they both had the same behavior. In particular, this evaluation was done by deploying wizard-defined services in the home of participants. We also conducted a usability study of our wizard with professionals. The study showed a good usability potential and an ease of use.

In the future, we plan to extend the kind of sensors that can be used in the wizard to detect richer activity contexts than those defined by a unique sensor. In particular, we would like to introduce a high-level notion of sensors that would allow caregivers to exploit

[1]The horizontal axis of Figure 14 displays the number of participants for each response. *E.g.,* for Question 1, one participant disagreed and four agreed.

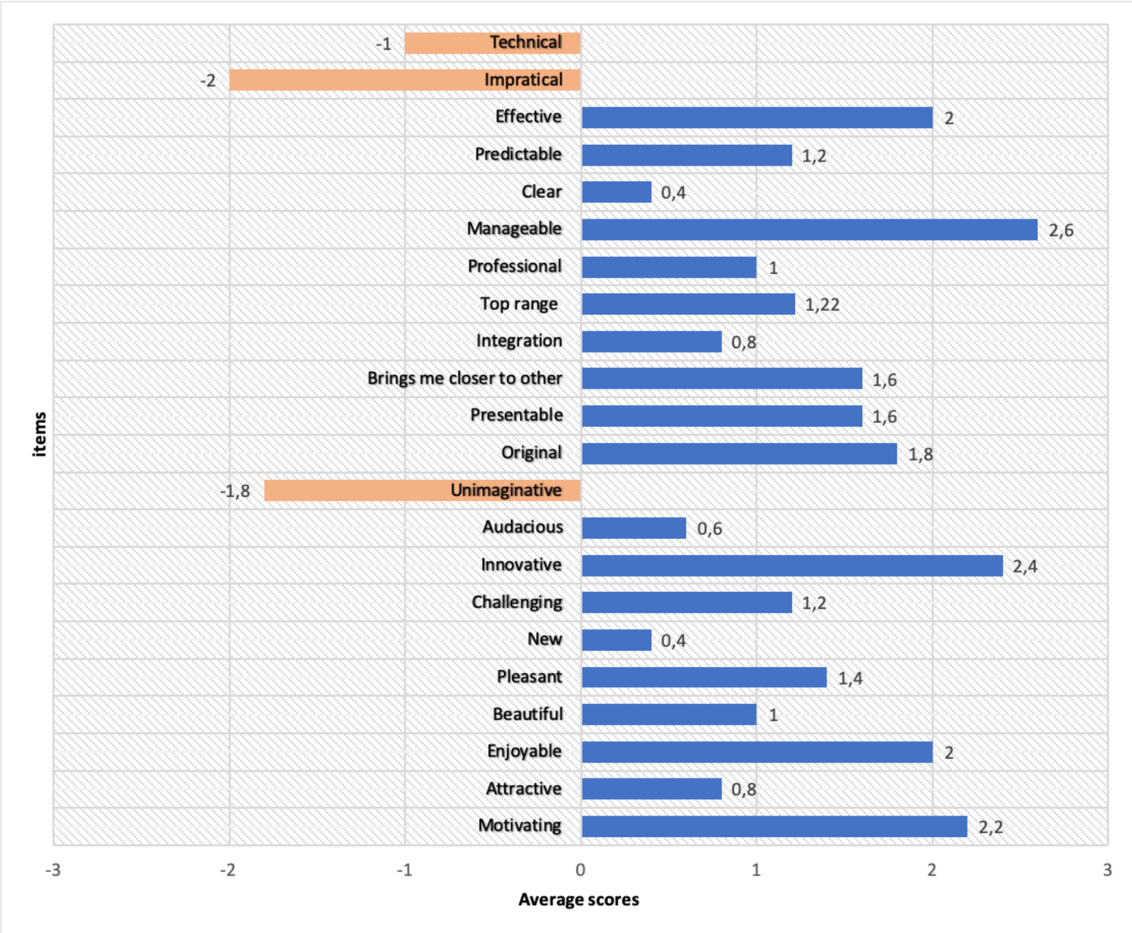

Fig. 13. Participant Outcomes (n = 5) to the ATTRAKDIFF Questionnaire

activities involving a set of sensor activations, activation durations, *etc.* In fact, we already introduced this kind of sensors with our departure detector. In practice, not only does this detector monitors the entrance door, but it also checks that there is no motion at home for a while before declaring that the user has departed. For another example, consider a routine for going to bed that may involve motion in the bathroom, followed by motion in the bedroom. Needs for such high-level sensors are naturally and promptly expressed by caregivers, as reported by our study, as they discover the potentials of technology to support independent living of individuals they care for. These high-level sensors, as well simple ones, should be made available in the wizard increasing the coverage of activity-supporting services.

Another direction for future work is to implement our approach on another smart home platform. This is important to assess the applicability of our approach to a range of smart homes.

References

[1] P. Visutsak and M. Daoudi, The smart home for the elderly: Perceptions, technologies and psychological accessibilities: The requirements analysis for the elderly in Thailand, in: *Information, Communication and Automation Technologies (ICAT), 2017 XXVI International Conference on*, IEEE, 2017, pp. 1–6.

[2] K. Madara Marasinghe, Assistive technologies in reducing caregiver burden among informal caregivers of older adults: a systematic review, *Disability and Rehabilitation: Assistive Technology* **11**(5) (2016), 353–360.

[3] C.A. Wingrave, M. Rowe and S. Greenstein, WIP: Designing Smart Systems to Support@ Work Caregiver Needs, in: *AAAI Fall Symposium: Artificial Intelligence for Gerontechnology*, 2012.

[4] P. Rashidi and A. Mihailidis, A survey on ambient-assisted living tools for older adults, *IEEE journal of biomedical and health informatics* **17**(3) (2013), 579–590.

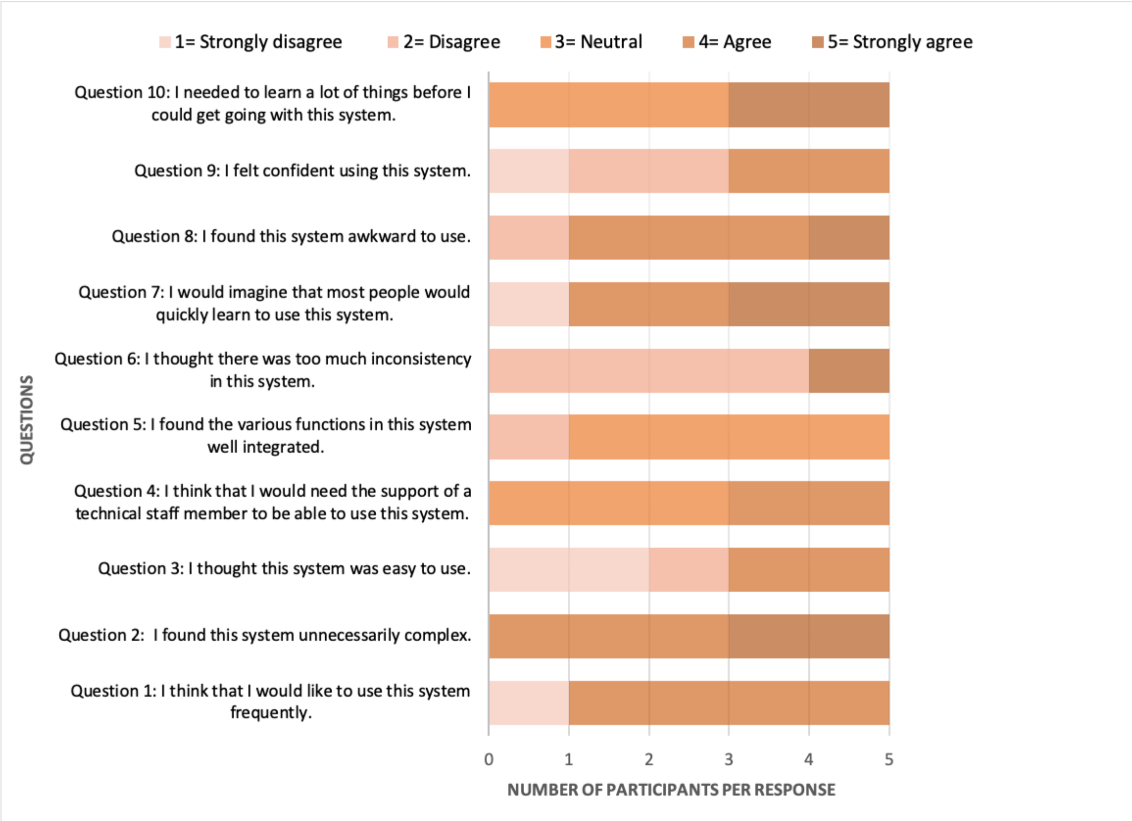

Fig. 14. Participant Responses (n = 5) to the System Usability Scale Questionnaire (SUS)

[5] J.A. Kaye, S.A. Maxwell, N. Mattek, T.L. Hayes, H. Dodge, M. Pavel, H.B. Jimison, K. Wild, L. Boise and T.A. Zitzelberger, Intelligent systems for assessing aging changes: home-based, unobtrusive, and continuous assessment of aging, *Journals of Gerontology Series B: Psychological Sciences and Social Sciences* **66**(suppl_1) (2011), i180–i190.

[6] D.J. Cook, A.S. Crandall, B.L. Thomas and N.C. Krishnan, CASAS: A smart home in a box, *Computer* **46**(7) (2013), 62–69.

[7] C. Consel, L. Dupuy and H. Sauzéon, HomeAssist: An assisted living platform for aging in place based on an interdisciplinary approach, in: *International Conference on Applied Human Factors and Ergonomics*, Springer, 2017, pp. 129–140.

[8] L. Dupuy, C. Froger, C. Consel and H. Sauzéon, Everyday Functioning Benefits from an Assisted Living Platform amongst Frail Older Adults and Their Caregivers, *Frontiers in aging neuroscience* **9** (2017), 302.

[9] D.L. Parnas, On the design and development of program families, *IEEE Transactions on software engineering* (1976), 1–9.

[10] M. Mernik, J. Heering and A.M. Sloane, When and how to develop domain-specific languages, *ACM computing surveys (CSUR)* **37**(4) (2005), 316–344.

[11] K. Czarnecki, U.W. Eisenecker and K. Czarnecki, *Generative programming: methods, tools, and applications*, Vol. 16, Addison Wesley Reading, 2000.

[12] F. Portet, M. Vacher, C. Golanski, C. Roux and B. Meillon, Design and evaluation of a smart home voice interface for the elderly: acceptability and objection aspects, *Personal and Ubiquitous Computing* **17**(1) (2013), 127–144.

[13] F.K. Aldrich, Smart homes: past, present and future, in: *Inside the smart home*, Springer, 2003, pp. 17–39.

[14] D.G. Morrow and W.A. Rogers, Environmental support: An integrative framework, *Human Factors* **50**(4) (2008), 589–613.

[15] J. Reijnders, C. van Heugten and M. van Boxtel, Cognitive interventions in healthy older adults and people with mild cognitive impairment: a systematic review, *Ageing research reviews* **12**(1) (2013), 263–275.

[16] E.A. Townsend and H.J. Polatajko, Advancing an occupational therapy vision for health, well-being, and justice through occupation, *Ottawa, ON: CAOT Publications ACE.* (2007).

[17] S.J. Czaja, R.A. Weber and S.N. Nair, A human factors analysis of ADL activities: A capability-demand approach, *Journal of Gerontology* **48**(Special_Issue) (1993), 44–48.

[18] J. Ormel, F.V. Rijsdijk, M. Sullivan, E. Van Sonderen and G.I. Kempen, Temporal and reciprocal relationship between IADL/ADL disability and depressive symptoms in late life, *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences* **57**(4) (2002), P338–P347.

[19] M.P. Lawton and E.M. Brody, Assessment of older people: self-maintaining and instrumental activities of daily living, *The gerontologist* **9**(3_Part_1) (1969), 179–186.

[20] M. Philipose, K.P. Fishkin, M. Perkowitz, D.J. Patterson, D. Fox, H. Kautz and D. Hahnel, Inferring activities from interactions with objects, *IEEE pervasive computing* **3**(4) (2004), 50–57.

[21] L. Caroux, C. Consel, L. Dupuy and H. Sauzeon, Towards context-aware assistive applications for aging in place via real-life-proof activity detection, *Journal of ambient intelligence and smart environments* **10**(6) (2018), 445–459.

[22] L. Caroux, C. Consel, L. Dupuy and H. Sauzéon, Verification of daily activities of older adults: a simple, non-intrusive, low-cost approach, in: *Proceedings of the 16th international ACM SIGACCESS conference on Computers & accessibility*, 2014, pp. 43–50.

[23] T. Greenhalgh, J. Wherton, P. Sugarhood, S. Hinder, R. Procter and R. Stones, What matters to older people with assisted living needs? A phenomenological analysis of the use and non-use of telehealth and telecare, *Social science & medicine* **93** (2013), 86–94.

[24] M. Resnick, J. Maloney, A. Monroy-Hernández, N. Rusk, E. Eastmond, K. Brennan, A. Millner, E. Rosenbaum, J. Silver, B. Silverman et al., Scratch: programming for all, *Communications of the ACM* **52**(11) (2009), 60–67.

[25] A. Sutcliffe, Evaluating the costs and benefits of end-user development, in: *ACM SIGSOFT Software Engineering Notes*, Vol. 30, ACM, 2005, pp. 1–4.

[26] J. Brich, M. Walch, M. Rietzler, M. Weber and F. Schaub, Exploring end user programming needs in home automation, *ACM Transactions on Computer-Human Interaction (TOCHI)* **24**(2) (2017), 11.

[27] J. Coutaz, A. Demeure, S. Caffiau and J.L. Crowley, Early lessons from the development of SPOK, an end-user development environment for smart homes, in: *Proceedings of the 2014 acm international joint conference on pervasive and ubiquitous computing: Adjunct publication*, 2014, pp. 895–902.

[28] J. Huang and M. Cakmak, Supporting mental model accuracy in trigger-action programming, in: *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, ACM, 2015, pp. 215–225.

[29] M.R. Reisinger, J. Schrammel and P. Fröhlich, Visual languages for smart spaces: End-user programming between data-flow and form-filling, in: *Visual Languages and Human-Centric Computing (VL/HCC), 2017 IEEE Symposium on*, IEEE, 2017, pp. 165–169.

[30] R.B. Dever, *Community living skills: A taxonomy.*, American association on mental retardation, 1988.

[31] C. Consel, Assistive computing: a human-centered approach to developing computing support for cognition, in: *2018 IEEE/ACM 40th International Conference on Software Engineering: Software Engineering in Society (ICSE-SEIS)*, IEEE, 2018, pp. 23–32.

[32] D. Kovalenko, 16 Tips that Will Improve Any Online Form, 2017. https://uxplanet.org/the-18-must-do-principles-in-the-form-design-fe89d0127c92.

[33] A. Landuran, Conception et validation d'assistants numériques de soutien à l'autodétermination pour les personnes présentant une déficience intellectuelle, PhD thesis, Bordeaux, 2018, (in French).

[34] W. Wittich, E.A. Barstow, J. Jarry and A. Thomas, Screening for sensory impairment in older adults: Training and practice of occupational therapists in Quebec: Formation et pratique des ergothérapeutes du Québec dans le dépistage des troubles sensoriels chez les personnes âgées, *Canadian Journal of Occupational Therapy* **82**(5) (2015), 283–293.

[35] S.S. Roley, C.J. Barrows, L. Susan Brownrigg OTR, D.I. Sava, L. Vibeke Talley OTR, B. Kristi Voelkerding, L. COTA, E.S. MOT, M. Pamela Toto, O. Sarah King MOT et al., Occupational therapy practice framework: domain & process 2nd edition, *The American journal of occupational therapy* **62**(6) (2008), 625.

[36] T. Mahatody, M. Sagar and C. Kolski, State of the art on the cognitive walkthrough method, its variants and evolutions, *Intl. Journal of Human–Computer Interaction* **26**(8) (2010), 741–785.

[37] T. Ben-Bassat, J. Meyer and N. Tractinsky, Economic and subjective measures of the perceived value of aesthetics and usability, *ACM Transactions on Computer-Human Interaction (TOCHI)* **13**(2) (2006), 210–234.

[38] M. Georgsson and N. Staggers, Quantifying usability: an evaluation of a diabetes mHealth system on effectiveness, efficiency, and satisfaction metrics with associated user characteristics, *Journal of the American Medical Informatics Association* **23**(1) (2015), 5–11.

[39] A. Bangor, P.T. Kortum and J.T. Miller, An empirical evaluation of the system usability scale, *Intl. Journal of Human–Computer Interaction* **24**(6) (2008), 574–594.

[40] C. Lallemand, V. Koenig, G. Gronier and R. Martin, Création et validation d'une version française du questionnaire AttrakDiff pour l'évaluation de l'expérience utilisateur des systèmes interactifs, *Revue Européenne de Psychologie Appliquée/European Review of Applied Psychology* **65**(5) (2015), 239–252.

[41] C.W. Turner, J.R. Lewis and J. Nielsen, Determining usability test sample size, *International encyclopedia of ergonomics and human factors* **3**(2) (2006), 3084–3088.