Joining semantic and augmented reality to design smart homes for assistance

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Abstract
Introduction: Smart homes for assistance help compensate cognitive deficits, thus favoring aging in place. However, to be effective, the assistance must be adapted to the abilities, deficits, and habits of the person. Beside the elder, caregivers are the ones who know the person's needs best. This article presents a Do-it-Yourself approach for helping caregivers designing a smart home for assistance.

Methods: A co-construction process between a caregiver and a virtual adviser was designed. The knowledge of the virtual adviser about smart homes, activities of daily living and assistance is organized in an ontology. The caregiver interacts with the virtual adviser in augmented reality to describe the home and the resident's habits inside it. The process is illustrated with an ordinary activity: ‘Drink water’.

Results: The proposed process highlights two main steps: describing the environment and determining the resident's habits and the assistance required to improve activity performance. Visual guidance and feedback are provided to ease the process.

Conclusion: Designing a co-construction process with a virtual adviser allows interactive knowledge sharing with the caregivers who are experts of the person's needs. Future work should focus on evaluating the prototype presented and providing deeper advice such as highlighting incomplete or incorrect scenarios, or navigation aid.

Keywords
smart home, augmented reality, design, caregivers, DiY, health care, habits

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Introduction
With the world population aging, the number of people carrying cognitive impairments tends to grow. Such cognitive deficits, especially memory, planning and attention deficits, can lead to a loss of autonomy. The activity theory of aging proposes that older adults age optimally when they stay active and maintain social interactions. However, it is necessary to compensate cognitive deficits to favor aging in place. With Ambient Assisted Living (AAL) approaches, it is possible to define smart environments considering the requirements of people with disabilities and thus counter this loss of autonomy, especially for improving performance in Activities of Daily Living (ADLs).

An AAL system detects behaviors and provides visual or oral cues in real-time to help compensate the disabilities. For example, the activation of a light path indicates where to go to people suffering from night wandering. Thanks to a pressure sensor under the mattress, the system detects the person leaving the bed, identifies the nighttime wandering scenario involved, and provides the adequate assistance in this case, powering the light path to prevent spatial disorientation, anxiety and falls.

As people are more likely to follow routines with age, assisting habits, by determining pre-programmed scenarios, proves to be an effective solution for elders. Therefore, AAL systems must get an internal representation of the home and the actions performed to ensure people behave adequately.
The choice of this internal representation is constrained by the desire to allow any caregiver to design the AAL system for assistance. As caregivers and, even more, residents are experts of their daily living, a Do-it-Yourself (DiY) approach seems the more appropriate, as suggested by De Roeck et al.\textsuperscript{12}: “In order for the IoT to really take off, end-users need to participate in the creation process on a larger scale. They need to have the power and control over the creation and use of applications for smart environments.”

Since the 1990s, DiY communities are invited by human computer interface communities to explore user-friendly interactions.\textsuperscript{13,14} Indeed, to design a smart home suiting the resident’s habits, the caregivers need to easily interact with an expert-system which abstracts the technical complexity underlying.

Regarding smart homes, several approaches tackles the assistance. Artificial Intelligence (AI)-driven approaches such as neural networks extract habits from patterns in the daily activities of the resident.\textsuperscript{15,16} However, such approaches do not describe the decisions explicitly, making it hard to customize the assistance. We adopt a symbolic approach,\textsuperscript{17} by mapping real-world entities to digital structures in a language that stays readable by humans.

Such symbolic scenario-based approaches are proven to be beneficial\textsuperscript{18,19} by providing a unified interface for the resident and the various stakeholders that are involved in the design process (occupational therapists, caregivers, etc.).\textsuperscript{18}

Regarding user-friendly interactions, Augmented Reality (AR) tends nowadays to be used in various domains, such as entertainment,\textsuperscript{20} medical training\textsuperscript{21} or assistance.\textsuperscript{22} It shows great usability properties as it superimposes additional information to the real world. For instance, during the broadcast of a football match, AR is used to superimpose, in real-time and on the field, the attacking team distance to gain, or the trajectory of individual players during a replay. Furthermore, through headsets such as the Microsoft Hololens or Magic Leap One, or through smartphones, mobile AR is becoming more and more accessible, offering users the freedom of movement.

We propose a Virtual Adviser (VA) that allow the caregivers to digitalize (i.e. convert information in the real world into computer-readable information) by themselves, the habits of the resident inside her environment, and specify the scenarios of assistance that will augment this environment. AR supports the merging of both the real environment of the resident and the virtual world of the smart home data. The digital scenarios created with the VA could then feed an AAL system, offering an assistance tailored to the resident’s needs and habits.

This paper presents the design of a smart home for assistance when accompanied by a VA. The VA helps caregivers virtually map the habits of the resident to her environment; specifying the ideal scenario; and determine how sensors will detect the concerned ADL when processing the assistance inside the smart environment.

The next section presents several Related Works to help situate our work within the existing literature. We then discuss how Assistance Inside a Smart Home for Assistance works before describing our Do-it-Yourself Approach and the resulting Design Process for such assistance. The specific Implementation of our VA is later discussed before presenting how it applies to a Use-Case Example. Finally, we discuss the Limitations of the current work before presenting our future visions in the Conclusion.

**Related works**

Few works tackle the use of AR to support people with cognitive difficulties, especially in a smart home environment or taking into account the caregiver. In Hayhurst’s 2018 review of virtual reality and AR works to support person living with Dementia,\textsuperscript{23} only five such works are presented whereas D’Cunha’s 2019 non-systematic minireview\textsuperscript{24} only cites one article when considering participants with impairment or dementia.

Among them, Scavo et al.’s\textsuperscript{25} GhostHands allow mentors to remotely control virtual hands to provide instructions to distant workers. GhostHands authors discuss that “users generally perceived the experience as greatly stimulating and with a strong sense of connectedness and playfulness, hence improving engagement”. Similarly, caregivers could accompany the residents during their daily tasks by showing the right movements or by pointing items to improve their engagement. However, such solution would imply that a caregiver is reachable at any time and that the resident wears an AR display, making it invasive on both ends and unrealistic considering our goal. We suggest that building a representation of the tasks and the instructions, in the form of the assistance, can help the resident without needing the intervention of a caregiver in real-time.

On the other hand, MemHolo\textsuperscript{26} proposes to alleviate the deficits through cognitive training exercises such as finding pairs of identical objects, with a Microsoft Hololens. The exploratory studies pursued in MemHolo show positive acceptance of AR technology for persons with mild Alzheimer’s Disease. Despite not being focused on assistance in smart homes, the article provides useful design hints and uses the same AR devices as our VA.
Closer to our work, Memory Palace\textsuperscript{27} encourages caregivers to attach media cues, called ‘memories’, to items of significance in the home environment. When the resident passes nearby with a phone and app, those memories are played back. Morel et al.’s conclusion focuses mainly on the resident’s application and less on the caregiver side. Nonetheless, the authors highlight that despite having some difficulty to interact with the application, the elderly people liked the personalized aspect and are open to learn new things. We follow the same idea of augmenting the home environment and personalizing the experience. Yet, where Memory Palace relies solely on interviews to build unstructured cues, we pursue a semantic approach to provide context to the cue and automation through the smart home, removing the need to carry a phone.

Finally, cARe\textsuperscript{28} is a framework designed to be easily adapted by caregivers to various use-cases without programming knowledge. A desktop application allows caregivers to create instructions with associated media files, later placed within the resident’s environment using a Microsoft Hololens headset and a Unity3D application. A Unity3D patient application for the Hololens headset provides guidance to the next instruction and displays its details while playing the media attached. Once more, Wolf et al. findings are focused on the tests performed with patients and less about the caregiver experience. Individualized assistance is once again highlighted as well as the possible discomfort of wearing a headset. The caregiver applications from cARe and Memory Palace are quite similar as they provide the same possibility to place instructions or cues inside the environment. Thus, the same comparison applies and we provide more contextual information through a semantic approach. As for the discomfort, we suggest that AR headsets evolution could alleviate it. Moreover, this finding emphasizes the need of user testing, one of the limitations of our study. As sensors provide low-level signals such as binary or numeric values, data have to be interpreted, sometimes combined, to determine higher-level actions, for instance through pattern recognition\textsuperscript{15,16} or semantic rules.\textsuperscript{5} The change in value of a contact sensor can be translated into the action of opening or closing a closet while the value of a pressure sensor can be compared to a threshold to determine if someone is lying on a bed.

Actions are then sent to a reasoner, the AI core of the SHA, that will compute the assistance. This reasoner holds a state of the environment, for example the date and time, sensor values, or previous actions.

As we follow a scenario-based approach\textsuperscript{17} to determine the adequate assistance, our reasoner also holds a set of scenarios of assistance composed of a known course of action and the adequate assistance actions for each step.

The goal of this work is to provide a tool allowing a caregiver to build such scenarios.

By comparing the state of the environment with the scenarios of assistance, the SHA can determine which scenario(s) is(are) actually followed by the resident and its(their) advancement. For instance, if the last action of the resident was to ‘lie down on the bed’ of her bedroom, scenarios involving ‘using the oven’ in the kitchen can be discarded. On the opposite, scenarios such as ‘afternoon nap’ or ‘night sleep’ might be valid. Finally, considering that this example takes place at 4PM, the reasoner excludes the ‘night sleep’ scenario in favor of the ‘afternoon nap’ scenario.

Once the current scenario and its advancement is known, the assistance associated to the current action can be provided to the resident. To do so, high-level assistance action are translated back to low-level signals and sent to the actuators. For instance, as the assistance action ‘turning off the light’ is associated to the action ‘lie down on the bed’ from the

Before diving into how we approach the Design Process of the assistance, we describe how the Assistance Inside a Smart Home for Assistance works in the next section.

### Assistance inside a smart home for assistance

In order to provide assistance in the daily living, a Smart Home for Assistance (SHA) relies on a network of sensors, to detect the activity of the resident, and actuators, to provide real-time feedback through visual or oral cues or by modifying the environment. For instance, a warning cue can be played when the stove is left open, or a closet can open automatically when the resident needs to take a glass inside it.

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‘afternoon nap’ scenario, the reasoner sends an off signal to the lights of the bedroom.

Do-it-yourself approach

As explained previously, SHAs provide a way to help a resident stuck in an ADL completion. Indeed, as diseases and aging impact abilities to stay autonomous at home, it might become difficult to complete ADLs, either forgetting items, processing inappropriately some steps or organizing badly the overall activity.

SHAs answer this problem by displaying cues to help the resident follow the usual course of actions of her ADL. But, the design of such a smart home rises challenges as every house is different, every resident is specific and behaves in her own way. Adapting the assistance to the home, the resident and her habits is then mandatory, hence justifying a DiY approach.

Actors

According to a DiY approach, family members or caregivers are privileged actors to design the assistance in a smart home, as they know well the habits of the resident. However, it is necessary to help them designing the assistance the resident needs. Therefore, appears a new actor, the VA, which helps the caregiver designing the smart home for the resident (Figure 1).

We define the roles of the various actors involved in the assistance as resident, designer, VA, static home and smart home:

The resident is a person who experiences difficulties to complete some ADL at home. Issues are caused by cognitive or perceptual deficits, either due to neurological diseases or normal aging. Instead of performing the right scenario, the resident fails in selecting the appropriate object, in using it properly, in orientating in her home or in carrying out the activity adequately at the right time and in the right place.

The designer aims to define the assistance that will alleviate the autonomy of the resident. She could be any caregiver, member of the family, of the neighborhood or even of the medical staff. She is characterized by her knowledge of the resident’s needs but may have low knowledge of the smart home technology. To determine the appropriate assistance for a given ADL, the designer describes how this ADL is carried out by the resident in her home.

The Virtual Advisor (VA) is a technological help that assists the designer. It is characterized by its knowledge of the smart home technology but has no prior knowledge of the resident nor her living environment. The VA can understand the spatial geometry and can be interacted with. It also has expertise on successful execution of activities.

The static home is the usual home of the resident, considering no smart features are already installed.

The Smart Home for Assistance (SHA) is a smart home able to track the resident’s activity with sensors; and provide some environmental cues with actuators.

Scenarization of the daily living

As the backbone of the assistance, a Scenario of Activity of Daily Living (SADL) is defined as a sequence of steps that must be performed in a specific order, at the right place during an adequate time and involving adequate objects.

We then distinguish the resident performance, the ideal scenario and the operationalized scenario:

The resident performance describes how the resident is performing the SADL.

The ideal scenario is the SADL that best fits the ADL that the resident is performing. The ideal scenario may include alternatives.

The operationalized scenario is the application of the ideal scenario at the resident’s home according to her habits. It includes the sensors to detect the right and wrong actions of the resident; and the actuators to provide assistance.

Following those definitions, the SHA detects the resident performance in order to help her achieving the ideal scenario. Based on the theory of instrumented activity, the operationalized scenario empowers the resident by offering appropriate cues when she fails during the activity realization.
The purpose of introducing a DiY approach to design the SHA is to offer any designer, whatever her technical knowledge, ways to describe the resident’s needs and the operationalized scenario to foster the resident’s autonomy. Any designer is supported during the design process with knowledge available in a user-friendly form, thanks to a VA. Designing the assistance becomes a co-construction between the designer, who is expert in the resident’s habits, and the VA, who is expert in ADL scenarios and assistance needed to achieve them.

The next sections covers the co-construction design between the designer and the VA, regarding the knowledge they share. First, we present how the physical environment of the resident is described and second how the ADL scenarios are introduced in the resident’s virtual environment.

**Design process**

**Semantic representation of the environment**

ADLs are situated by definition: they involve specific elements at specific places and times. During her ADLs, a resident performs actions with furniture or appliances which are placed inside specific rooms of the home. Those objects and rooms are crucial for recognizing the resident’s performance and assist her, if necessary. The physical environment is therefore composed of the rooms, furniture and objects that will be involved in the SADL. For instance, in case of hygiene assistance, the environmental description may include bathroom, taps, toilet as well as toothbrush.

Thus, the first step for defining the operationalized scenario is to describe the environment where it will take place.

The physical environment description emerges from both the designer and the VA. Indeed, the VA can understand the geometry of the surroundings, but only the designer knows the semantic underlying the environment.

For example, when the designer looks around with an AR headset, the VA can determine the floor and the walls as physical obstacles. However, the designer is the one to explain the usage of the rooms, such as the kitchen or the corridor, and the physical objects, such as the oven or the table.

The result of this step is a digitalized description of the resident’s home where each room and each relevant furniture and objects are stored in a computerized plan. This plan comprises geometrical information linked to semantical information, in order to explicit the operationalized scenario according to spatial information and meaning.

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**Shared Representation of the Physical Environment**

This co-construction process leads to the ensuing model being used by the VA:

- **A corner** is defined as a tridimensional point \((x,y,z)\) in the space;
- **A wall** holds, at least, two corners and a depth;
- **A room** is made of multiple walls as well as a type (kitchen, living room, etc.);
- **A furniture or an appliance** has, among other attributes, three dimensions \((\text{width}, \text{height}, \text{depth})\) as well as a type (table, light, fan, etc.).

Eventually, implicit walls are added. Implicit walls allow rooms to be separated according to their usage even if there is no physical separation between them. For instance, an open kitchen is separated from a dining room or a living room based on its usage but no concrete wall is present to do the separation. Thus, this separation is only present in the resident’s semantic of the space, what could not have been detected by the VA.

In our model, implicit walls are walls with the attribute ‘implicit’ set to `true` and ‘depth’ to 0. An implicit wall is identified by the two corners its extremities. As the wall have no collision part between the ground and the ceiling, those corners are placed either on the ground or the ceiling.

In the end, each physical element is linked to a virtual element in the knowledge base resulting in a fully digitalized apartment (Figure 2) that allows the VA to superimpose some additional information when needed.

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**Figure 2.** Overview of the DOMUS lab apartment fully mapped. Furniture and appliances are displayed in blue. Virtual walls are displayed in green.
**Digitalization Process** To digitalize the resident’s home in AR, the designer follows the steps below:

1. Digitalize the walls corner by corner. Once a space is enclosed by walls, the designer specifies the type of the room delimited.
2. Identify the objects (appliances, furniture, lights, etc.) by placing a bounding container (box, sphere, etc.) around them.
3. Specify the type of the element from a contextual list depending on the actual room type.

With the VA, building a wall is as simple as selecting its extremities. A wall is then filled from the floor to the ceiling using the environment geometry (Figure 3(a)).

Each time a wall is digitalized, the VA performs a check to find if it closes an area. If so, the semantic of the delimited room is asked through a list of room types, from which the designer chooses one option (Figure 3(b)).

By adding the semantic of rooms to the virtual environment, the VA detects the missing furniture or appliances that commonly appear in this given room. Creating a room thus triggers a search inside the VA knowledge of the more common items inside it. For instance, if no sink is specified inside a kitchen, the VA will suggest digitalizing it as it is a common furniture.

Furniture or appliances are identified by creating bounding containers around them, then by selecting their type (Figure 4(a)). Moreover, such elements hold a reference of the supports they stay on (floor, ceiling, wall, furniture or appliance), themselves linked to the room where they belong.

In addition of the functionalities presented previously, the designer may, at any time, ask, using natural language, where some furniture is. The VA then searches for the corresponding furniture and shows the path to follow. This provides easier navigation (Figure 4(b)) for people who are not familiar with the environment as well as a way to verify the elements mapped previously.

**Semantic representation of the habits**

Once the environment is digitalized, the designer must digitalize the resident’s habits.

The habits knowledge comes both from the designer and from the VA. Indeed, as a caregiver, the designer is an expert of the resident’s habits. On the other side, the VA is the expert in SHA and IoT network. It is, thus, the best actor to translate habits into sensors and actuators that enable the SHA to detect and assist the resident.

**Shared Representation of the Habits:** For both actors to be able to understand each other, a common model has to be specified at a level of abstraction suitable for the designer.

Most often, people express ADLs according to a hierarchical view, where activities are subdivided into subtasks and atomic tasks (i.e. tasks that cannot be decomposed) called actions.\(^\text{19}\)
A natural level of abstraction is to talk about ADLs in terms of a tree of tasks produced by the resident to answer a specific goal. This transfers the burden of handling complex low-level concepts such as devices and signals to the VA.

In such tree, tasks can be optional or can even repeat. For instance, when drinking water, one resident could drink three glasses of water while another one could drink only one, meaning the task of serving water could repeat as much as needed.

Formally, SADLs are defined as trees with “a goal (root), several tasks (internal nodes) and actions (leaves)” such as:

- The goal is reached once all its mandatory subtasks are accomplished;
- Tasks and subtasks represent the steps involved in reaching the goal. Subtasks can have preconditions that should be met for the task to happen, post-conditions that are set once the task completes, and operators defining their order, repetition or importance (i.e. optional vs mandatory);
- Actions are atomic tasks that can be translated into sensor and effector signals. They are either sensed property of the environment or cues targeted at the resident, and are associated to an element of the environment, e.g. the whole house, a room, or a furniture.

A generic SADL is depicted in Figure 5.

In order to be able to associate actions to elements of the environment, each furniture is linked to several actions that have been specified beforehand into the VA knowledge base. For example, the action ‘Lie Down’ is associated to the ‘Bed’ type so it can be performed only on elements defined as beds. The VA knowledge also includes which sensors can detect this action or which actuator can produce it.

The ideal scenario is thus digitalized in an operationalized scenario, making explicit the order of actions and the assistance specified by the designer.

**Digitalization Process:** By gazing at an element of the environment, the designer sees, juxtaposed to it, all the actions that can be performed with it or the scenarios that involve it (Figure 6). She then selects an action or a previously defined scenario to append to the SADL. Actions are grouped by categories if there are too many of them to display at the same time.

While the scenario is built, the VA displays an overview of the steps (Figure 7). Editing the scenario is then possible by expanding the timeline to its full view and selecting a step to edit, erase, or append. The designer can also specify task operators such as ‘Optional’ or ‘Repeat’. This workflow allows easy iteration, as scenarios can be opened and edited whenever needed.

Besides the timeline, the VA builds a spatial map of the designer’s movements. Instead of displaying the back and forth between rooms, the VA computes the ideal path, trimming irrelevant path during trials.

Having the VA compute this path avoids having to specify explicitly the moves. The movement steps are added in the timeline between other steps automatically (Figure 7).

To promote the co-design between the designer and the VA, all computed information is displayed in real-time. For instance, the path recorded by the system is
displayed as footprints on the ground (Figure 8). Moreover, computing the timeline and paths ensure the consistency of the SADL.

Implementation

The VA is composed of two applications: the AR application the designer interacts with and the ontology that provides the knowledge needed to build the assistance.

AR application

The AR application is installed on a Microsoft Hololens or Hololens 2 AR headset (see https://www.microsoft.com/en-us/hololens) that allows to superimpose virtual knowledge on the environment seen by the designer. The headset uses a see-through display composed of two lenses on which is projected the virtual image.

No other headset or AR devices are currently supported but efforts are being made to allow the AR application to run on devices such as the Magic Leap One headset or even smartphones. We use multi-platforms libraries and implement abstraction layers and chains of responsibilities in that respect.

Interacting in AR: The interaction in AR is mainly composed of two actions: gazing and selecting. The designer watches her environment through the headset that builds a mesh on every physical objects (Figure 9). The headset follows the gaze of the designer to determine the commands that the designer can use depending on the context. To send commands, the designer must select choices proposed by the VA in AR. For instance, when a room is digitalized, the AR application proposes to choose the type of the room amongst a list. To select an option, the designer may speak aloud or pick an option by pinching its label.

Technical details.

- The AR application is being developed in C# 4.7 using the Unity 2019.2 engine.
- The user interface uses the Microsoft Reality Toolkit (MRTK) 2.1.0 framework to provide the base interactions and a consistent design for the Hololens as well as standard UnityAR devices such as smartphones.
- Asynchronous communication with the ontology is ensured using async REST calls to the ontology API thanks to the AsyncAwaitSupport assets. All data exchanged with the ontology is parse from JSON to C# model classes and vice versa using the Newtonsoft.JSON 12.0.2 API.

Architecture: The AR application is based on the concept of scenes, managers and controllers which define what elements are visible at a given time, how they are retrieved or persisted and how the designer can interact with them.

For instance, the MainMenu scene relies on the MainMenuController to switch between the available scenes while the Plan scene relies simultaneously on multiple controllers such as the WallsController or the RoomsController to allow the designer to respectively build walls and identify rooms. Finally, the Scenario scene enables the ElementsController to identify furnitures or appliances, the ActionsController to display the available actions for the elements in the field of view and the ScenariosController to organize the actions in SADLs.

For the interactions, WallsController listens to clicks on the Hololens mesh to create new corners and to clicks on corners to build the walls that separate

Figure 8. Footprints on the ground indicate the path recorded by the virtual adviser after back and forth moves have been trimmed.

Figure 9. Mesh built by a Microsoft Hololens of a living room with a sofa and a low table.
them. On the other hand, RoomsController waits until walls are created to search for newly closed rooms that should be identified.

Ontology

The VA is connected to an OWL (see https://www.w3.org/TR/owl-features/) ontology through an API endpoint. When the designer interacts with the AR application, the AR application updates its internal representation of the environment and the resident’s habits by taking concepts from this domain ontology and applying them to the current situation. The OWL-DL ontology is the outcome of several years of work of a multi-disciplinary team of researchers, students and occupational therapists at the DOMUS Laboratory8,9,32 and is still being extended at the time of writing. This knowledge base is being built using Protégé 4 and the dul (http://www.ontologydesignpatterns.org/ont/dul/DUL.owl) ontology as a baseline. It integrates multiple aspects such as homes, tasks, assistance, devices, persons and activities as depicted in Figure 11.

Home concepts such as corners, walls, rooms and elements are primarily used by the AR assistant to digitize the resident’s environment.

Task concepts such as tasks, scenarios (scenarios are actually tasks), actions, conditions or operators are used by the AR assistant to digitize the resident’s habits.

Use-case example

Dehydration is a well-known symptom experienced by people with dementia or elderly people.32 Encouraging elderly people to drink more often is then important. On the other hand, people with Alzheimer may present nighttime wandering that could be assisted by a SHA to ensure they go back to bed.9 During night, the resident may desire to drink water and the SHA should assist her to go to the kitchen and satisfy her need.

Figure 10. Software architecture of the AR application. Scenes contains controllers that determine which interaction and display is active. Controllers use managers to retrieve and persist entities into the ontology through the REST client.

Figure 11. Overview of the DOMUS ontology31 Relation names have been omitted for readability reasons.
Both the previous situation of dehydration and nighttime wandering share a common scenario: ‘Drink water’. The inclusion of this scenario in a nighttime wandering context is illustrated in Figure 12.

In this scenario, the goal is to ‘Drink water’. Several tasks should happen, starting with the resident leaving the bed, then performing some tasks in the kitchen and ending by going back to bed. Tasks such as ‘Leave the bed’ or ‘Get back to bed’ are actions (atomic tasks) that can be gathered by sensors, for example by a pressure sensor under the mattress.

To implement the scenario, the designer first digitalizes the bedroom, the bathroom and the kitchen. She determines the relevant objects, such as bed, taps, cabinet and glasses. On its side, the VA prepares the next step by gathering the actions associated to those objects, such as ‘Get up’ and ‘Lie down’ associated to the bed or ‘Open’ associated to the cabinet.

After the physical environment is digitalized, the designer goes through the home to specify the ‘Drink water’ scenario. She first goes to the bedroom to indicate that the scenario begins when the resident rises from her bed. She gazes at the bed and selects the action ‘Get up’ proposed by the VA, then moves to the kitchen.

At this time, the designer recognizes that complex scenarios like ‘Drink water’ can be decomposed into smaller ones, such as the ‘Take a glass’ and ‘Fill the glass’ scenarios. She tells the VA that she wants to create a new (sub-)scenario: ‘Take a glass from the cabinet’. To digitalize this scenario, she follows the steps listed below:

1. Gaze at a cabinet
2. Select the action ‘Open the cabinet’
3. Select the assistance ‘Turn the cabinet light on’
4. Select the action ‘Take a glass’
5. Select the assistance ‘Turn the cabinet light off’
6. Select the action ‘Close the cabinet’

Once this scenario is complete, the designer tells the VA to resume the creation of the ‘Drink water’ scenario. The ‘Take a glass from the cabinet’ scenario is associated to the cabinet object and added to the scenario. It will be available later if the designer wants to embed this specific scenario into another one.

Considering that the designer has already created the ‘Fill the glass’ scenario as well, the whole process of digitalizing the ‘Drink water’ scenario would be:

1. Go to the bedroom and gaze at the bed
2. Select the action ‘Get up’
3. Go to the kitchen and gazing at a cabinet
4. Select the category ‘Glass actions’
5. Select the scenario ‘Take glass’ (containing the actions: ‘Open the cabinet’, ‘Turn the cabinet light on’, etc.)
6. Gaze at the faucet
7. Select the category ‘Glass actions’
8. Select the scenario ‘Fill glass’ (containing the actions:
   9. ‘Put glass’, ‘Open faucet’, ‘Close faucet’)
10. Go to the bedroom and gaze at the bed
11. Select the action ‘Lie down’

This ‘Drink water’ scenario could later be included into a more global ‘Nighttime wandering’ scenario. Embedding scenarios supports the natural hierarchical way of thinking activities. It also allows easier design by avoiding repetition for the designer.

**Limitations**

The results presented in this paper must be interpreted with caution as this study presents some limitations. First and foremost, evaluation has yet to be performed either with researchers not involved with the project or with caregivers and residents. Future evaluation will lead to an in-depth discussion about the real-world usage of the VA highlighting its strength and pitfalls through test-user surveys and interviews. Several concerns may then be resolved such as technology acceptance and accessibility. However, as AR is
becoming more popular and accessible and as the VA is only used occasionally by the designer, ease-of-use and implementation choices may have most of the impact on the acceptance.

On the other hand, as accessibility can be linked to cost and since actual AR headsets can be expensive, we suggest that the headset could be leased, especially considering the sporadic use of such headset. Nonetheless, we also work on porting our VA to more affordable and widespread hardware such as smartphones as stated in the Implementation section.

Finally, we acknowledge that building ADLs scenarios, thus decomposing tasks, can be challenging, especially since the designer is not necessarily the resident herself. We suggest that the VA could answer this difficulty by stimulating the Engagement-Reflection cycle. Indeed, literature suggest that creative tasks are performed first by producing content (engagement) and then by reflecting over the produced material (reflection). By allowing the designer to go back and edit previous scenarios, the VA will help reflecting on the material while the real-time advices could help during the engagement. We are already developing the AI of the VA in this direction and this work will be the subject of future papers.

Conclusion

In this paper, we described a DiY approach to design smart homes for assistance. Without having knowledge in IoT, any designer, notably any caregiver, may determine the assistance the resident needs in her home to complete ADLs. This assistance is operationalized in a scenario of ADL that describes the tasks and actions necessary to achieve it. The designer is accompanied during the design process by a VA. The interaction with the VA allows the designer to describe the home and how the resident carries out ADLs.

Thanks to an ontology and AR, the home is digitalized according to both spatial and semantic points of view. The designer may then easily describe how the resident behaves in her home by going through the actions realized to complete a specific activity.

The scenario ‘Drink water’ illustrates how to use the VA, but also shows how scenarios may embed other scenarios. This hierarchical description of activities helps designing more complex scenarios. We show how it is easy to integrate scenarios, which have been previously defined.

Finally, we pursue the DiY approach that, in addition to offering an easy way for designing smart homes, aims to create a community. Our objective is to build a library of scenarios. As more people will be involved in designing smart homes, they will be part of the smart home designing community and may share the scenarios they have built.

The next step of this research is to evaluate the current implementation of our VA.

We also want to make the VA evolve into a guide rather than a tool. To do so, we plan to integrate an interactive agent that guides the designer, by highlighting forgotten basic furniture, incomplete or incorrect scenarios, or by providing navigation aid.

Mainstream AR is at its beginning. However, the trend is to diversify the applications and to make it more accessible. This offers a great opportunity to help caregivers designing by themselves smart home for helping older people to stay autonomous at home. This provides a good opportunity to facilitate aging at home, despite the scarcity of health services and medical staff shortage.

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CH.

Contributorship

CH, HP, SG researched the literature and designed the DiY approach. CH wrote the first draft and revisions. All authors reviewed and edited the manuscript and approved the final version and revisions of the manuscript.

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