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ADL Monitoring of Elderly People in Smart Homes Based on Task Models

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Abstract. Monitoring activities of daily living (ADL) is a frequent practice to determine the independence of elderly people in their homes instrumented with a set of sensors. To do so, the representation of ADL is an issue that must be addressed. In this paper, ADL representation based on task models is presented. To this extent, we propose an approach for task modelling of ADL by means of HAMSTERS-XL, an extensible task notation and tool allowing the design, visualisation, and simulation of task models. The proposed approach consists of several steps aiming to determine parameters, such as time and location, of both activities and sensors, as well as the events that need to be identified. To demonstrate the suitability of our approach, we present the description of two ADL performed by a resident within a smart home environment by employing the AGGIR grid variables, a tool adopted by the French government for determining the autonomy of an elderly individual. The obtained results are analyzed with the purpose of indicating the advantages of using ADL representation by means of task modeling.

Keywords. Pervasive health systems and services, Ambient assisted living, Elderly behavior analysis, Model-based design, Task Modeling, AGGIR grid

1. Introduction

In 2019, it was calculated population of 703 million people aged 65 years or over in a global scale. This number is estimated to elevate to 1.5 billion in 2050, when it is contemplated that one in six people worldwide will be aged 65 years or over [1]. Because of such an augmentation in the population sector, improving quality of care service as well as decreasing medical costs have become in recent years a requirement for new care delivery structures and mechanisms. Moreover, the number of people suffering from loss of autonomy and depending on others for performing activities of daily living (ADL) is increasing [2]. Technologies for assisting and surveilling the health of residents at home are relevant concerning this topic, leading to the articulation of assisting and monitoring tools for people at home in a more efficient manner and contributing to healthcare solutions that may evolve into ambient and pervasive [3]. These technologies demand reliable representation and modeling of ADL to support their automatic identification from data collected in smart home environments. However, human activity modeling is a difficult aspect regarding smart environments, since factors such as location, physical object, and time, must be considered [4]. Furthermore, the person-fit environment theory presented in [5] establishes that compatibility between individuals and their environment must be reached in order to cover the requirements of its residents adequately.

In this regard, the representation of ADL within smart home environments can be supported by task analysis including three major aspects [6]: (i) collection of data; (ii)

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data analysis; and (iii) modeling of the tasks. Collection and analysis of data can be supported on IoT and Big Data techniques; however, there is still a gap on the standardization of task modeling and representation. There exist studies focused on modeling basic ADL, such as AGGIR (Autonomie Gérontologique et Groupe Iso Ressources – Autonomy Gerontology Iso-Resources Groups) grid [7] and SMAF (Functional Autonomy Measurement System) [8], but there is still a need of proposals for ADL representation by means of both task and measurement models in the domain of health and dependency evaluations. Previous works considering **task-models-like** approaches for modeling ADL are introduced in [2,9,10], where behaviour trees (used in the area of planning as well as to define and implement the behaviour of non-player individuals in the video game field) are employed [2]. Real-time behavior analysis in the elderly concerning their context has been addressed in [9]. The work presented in [10] analyzes ADL by comparing data recovered from sensors within a smart home to prior task models in order to determine when modifications regarding the ADL performance are required. These works are focused on identify correctly activities that require monitoring. However, there is still a lack of ADL to be modeled, whereas others consider a subset of specific activities; but most importantly, they are not based on a specific tool, such as the AGGIR grid, to guide the model of ADL in smart homes to evaluate elderly independence.

To contribute in this context, we propose an approach for task modeling of ADL by means of HAMTERS-XL [11], an extensible task notation and tool allowing the design, visualisation, and simulation of tasks models, as well as adapting the notation to tasks specific to a device, a context, or a domain. The proposed approach consists of four steps: (i) specification of time and location criteria of each ADL; (ii) identification of type and location of sensors, according to the required events that need to be detected; (iii) orchestration of daily scenario routines to measure the execution of ADL performed by the household resident; and (iv) modeling the scenarios based on HAMSTERS-XL.

In order to evaluate our approach, ADL based on the AGGIR are studied in a simulation environment. For simulation, two of the AGGIR variables are selected (i.e., Elimination and Dressing) with the aim to represent the performance of activities of the elderly inhabitant. The obtained results in several scenarios requiring physical, virtual, and both physical and virtual interaction of elderly with their environment, are analyzed with the purpose of indicating the advantages of using ADL representation by means of task modeling and demonstrate the suitability of our approach.

2. Modeling of ADL via HAMSTERS-XL

Task models consist of an abstract description of user activities structured in terms of goals, sub-goals, and actions [11]. Task models enable ensuring the effectiveness of an interactive system, i.e., to guarantee that users can perform their work and can reach their goals. Many instances of task analysis and modeling techniques exist to provide support for the design, development, and evaluation of interactive systems and of user performance while interacting with a system [11].

ADL in the context of taking care of aged people, patients' tasks strongly rely on motor, cognitive, and perceptive abilities and actions, as well as on the abilities for coordinating these actions. This type of ADL are strongly evaluated according to the patients' capacity of manipulating physical objects, as well as their capacity of processing information. Thus, a task-modeling notation that supports the description of ADL requires embedding elements to represent motor, cognitive, and perceptive actions, as well as elements to represent the temporal ordering of actions and elements to represent manipulated objects and information. The HAMSTER-XL notation fulfills these requirements.

HAMSTERS-XL provides a tool-supported task modeling notation for representing tasks users perform when interacting with systems. It enables to produce precise and unambiguous descriptions of user tasks. HAMSTERS-XL allows representing human activities in a hierarchical temporally ordered way, with the intention of supporting modeling large sets of user tasks [12], as well as supporting consistency, coherence, and conformity between user tasks and interactive systems [13]. A task model looks like a tree diagram with nodes being either a task or a temporal ordering operator (e.g., >> stands for sequence, [> stands for deactivation). HAMSTERS-XL provides support to represent refined types of user tasks [14]: motor, perceptive, and cognitive (depicted in Fig. 1). Cognitive tasks can also be refined into cognitive analysis tasks or cognitive decision tasks (on the right in Fig. 1), to indicate the information that must be managed by the user; they are not necessary detected with sensors.

HAMSTERS-XL provides support to represent data such as devices, information, knowledge, and objects manipulated by users (which can be physical objects or software objects), and are depicted by using labels preceded by the abbreviation of the type of data [15]. Fig. 2 shows examples of such representation, where arcs between data and tasks represent how the data is used. In Fig. 2, from the left, the arc between the physical object *Phy. O: Soap* and the motor task *Take soap* means that the task requires the physical object labelled *Soap*. The arc between the information labelled *Inf: soap amount on skin* and the perceptive task *Perceive soap on hands* means that the task produces the information *soap amount on skin* when performed. The arc between the cognitive analysis task *Decide no soap is left on hands* and the information labelled *Inf: Soap amount on skin* means that the cognitive task requires the information *soap amount on skin*, which should be perceived by the user.

With the purpose of generating the representation of ADL by task modeling, we propose the following steps. **Step 1**: Specification of the criteria concerning time and location of each ADL, which in turn demands the specification of the events that describe each ADL; **Step 2**: Identification of type, as well as location of sensors, according to the required events that need to be detected; **Step 3**: Orchestrate daily scenario routines concerning the performance of ADL by the household resident, which includes physical and virtual interaction with the environment; and **Step 4**: modeling the scenarios based on HAMSTERS-X.

3. Use case description

The AGGIR grid is an assessment tool used in France to measure the autonomy level of elderly people; consisting of a six-level dependence scale (GIR1 to GIR6), that can be defined based on seventeen three-state variables, which can have one of these values: **A**, for complete dependency; **B**, for partial dependency; and **C**, for complete independency. The variables are classified into two groups: discriminatory and illustrative variables, as shown in Table 1.

In order to evaluate the proposed approach, a set of simulations is presented, where two of the AGGIR variables are concerned: Elimination and Dressing. The dressing variable assesses the ability to wear clothing, upper and lower body parts of the subject. The elimination variable monitors the ability to maintain personal hygiene concerning urinary and fecal elimination. The difficulty in determining the values of these variables lays on the fact that some can be measured directly, such as opening or closing a door, whereas some others, such as elimination, have a complex context to be determined based on the values of a number of sensors within a time range. For each ADL, three scenarios are evaluated, requiring: (i) physical interaction; (ii) virtual interaction; and (iii) both physical and virtual interaction.

Figure 1.: Types of user tasks in HAMSTERS-XL notation

Table 1.: AGGIR variables

Discriminatory	**Illustrative**
Coherence, Location	Management
Toileting, **Dressing**	Cooking
Self-feeding/Alimentation	Housekeeping
Elimination, Transfer	Transportation
Indoor movement	Purchases
Outdoor movement	Medical treatment
Distant communication	Leisure activities

3.1. User tasks for the AGGIR elimination variable

Step 1. The timeline for the AGGIR elimination variable is conformed by: (i) accessing the toilet; (ii) use of WC; (iii) wash hands; (iv) leaving the toilet.
Step 2. Different sensors are considered to detect the events identified in the previous step (see Table 2).
Step 3. The orchestration of the identified events and the sensors needed according to the three scenarios (i.e., physical, virtual, and physical+virtual interaction) is determined, as shown on Table 2.

Table 2. Orchestration of ADL for the elimination variable

Physical		**Virtual**		**Physical+Virtual**	
Activity	**Sensor**	**Activity**	**Sensor**	**Activity**	**Sensor**
Open bathroom door	Bathroom door	Presence in bathroom	Presence	Open bathroom door	Bathroom door
Turn light on	Light switch	Use of WC	WC proximity	Turn light on	Light switch
Use of toilet flush	Toilet flush		Automatic toilet flush	Presence in bathroom	Presence
Wash hands	Washbasin proximity	Wash hands	Washbasin proximity	Use of WC	WC proximity
Turn light off	Light switch			Use of toilet flush	Toilet flush
Close bathroom door	Bathroom door			Wash hands	Washbasin proximity
				Turn light off	Light switch
				Close bathroom door	Bathroom door

Step 4.1. Modeling of the AGGIR elimination variable requiring physical interaction from the user. With the purpose to exemplify a scenario where physical interaction with the smart home environment is necessary, tasks must be performed by the user as described in both Table 3 and Fig. 2.
Step 4.2. Modeling of the AGGIR elimination variable requiring virtual interaction from the user. In order to assure the virtual interaction with the environment, in this scenario, both the door and the light switch are replaced by a presence sensor. Moreover, a sink proximity sensor is added in this scenario. Both Table 4 and Fig. 3 illustrate the task model related to the aforementioned description.
Step 4.3. Modeling of the AGGIR elimination variable requiring both physical and virtual interaction from the user. Aiming to analyze as well as making a comparison with the two scenarios previously proposed regarding the AGGIR elimination variable, a task model concerning both physical and virtual interaction is introduced. Table 5 and Fig. 4 portray the task model requiring both physical and virtual interaction.

3.2. User tasks for the AGGIR dressing variable

Step 1. The timeline for the achievement of the dressing variable is described by: (i) approach wardrobe area; (ii) get dressed; (iii) Move away from wardrobe area.

Table 3. Necessary tasks for the AGGIR elimination variable requiring physical interaction

1. Access bathroom (*abstract task*), refined in a sequence of two tasks:
   - Open door (*interactive input task* conformed by an *user motor task*, and an *input task*).
   - Turn light on (light switch device, consisting on an *interactive input task* conformed by an *user motor task*, and an *input task*).
2. Use of WC (*abstract task*), refined into a sequence of five tasks:
   - Approach WC (*motor task*).
   - Sit on WC (*motor task*).
   - Get up from WC (*motor task*).
   - Pull toilet flush (toilet flush sensor *interactive input task* conformed by a sequence concerning an *user motor task*, and an *input task*).
3. Wash hands (*abstract task*), composed of a sequence of six tasks:
   - Get close to faucet/sink (*motor task*).
   - Open faucet (*motor task*).
   - Get hands wet (*motor task*).
   - Use of soap (*motor task*).
   - Rub hands (*motor task*).
   - Get hands wet/remove soap (*abstract user task*), refined with *Rinse hands* (*iterative abstract user task*) disabled by *Decide no soap is left on hands* (*cognitive task*). Rinse hands is refined in a sequence of two tasks:
     - ∗ Rub hands to remove soap (*motor task*).
     - ∗ Perceive soap on hands (*perceptive task*).
   - Dry hands (*motor task*).
4. Leave toilet (*abstract task*), consisting on a sequence of:
   - Turn light off (light switch device, consisting on an *interactive input task* conformed by an *user motor task*, and an *input task*).
   - Close door (*interactive input task* conformed by a *user motor task*, and an *input task*).

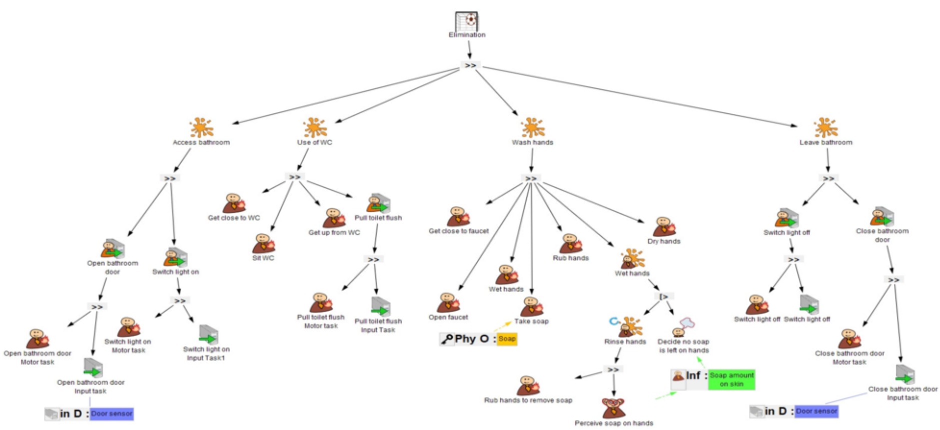

Figure 2. Description of the user tasks to *elimination requiring physical interaction* with HAMSTERS-XL notation

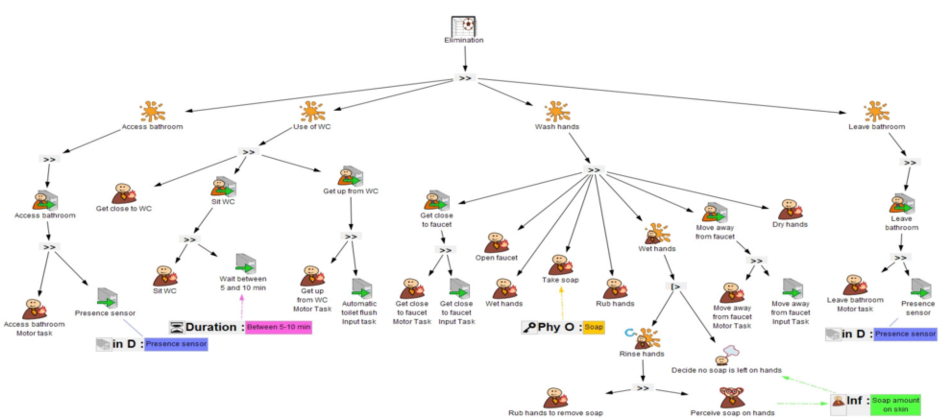

Figure 3. Description of the user tasks to *elimination requiring virtual* with HAMSTERS-XL notation

Table 4. Necessary tasks for the AGGIR elimination variable requiring virtual interaction

1. Access bathroom (an *interactive input task* conformed by an *user motor task*, and an *input task*).
2. Use of WC.
   - Approach WC (*motor task*).
   - Sit on WC (*interactive input task*); refine with the sequence:
     - Sit on WC (*motor task*)
     - Wait between 5 to 10 minutes (*input task* relying on a WC proximity sensor).
   - Get up from WC (*user input task*), refined with the sequence containing a *motor task*, and an *input task* relying on an automatic flush sensor.
3. Wash hands(*abstract task*), conformed by a sequence of eight tasks:
   - Get close to faucet/sink (washbasin proximity sensor, consisting on an *interactive input task* conformed by an *user motor task*, and an *input task*).
   - Open faucet (*motor task*).
   - Get hands wet (*motor task*).
   - Use of soap (*motor task*).
   - Rub hands (*motor task*).
   - Get hands wet/remove soap (*abstract user task*), refined with *Rinse hands* (*iterative abstract user task*) disabled by *Decide no soap is left on hands* (*cognitive task*). Rinse hands is refined in a sequence of two tasks:
     - Rub hands to remove soap (*motor task*).
     - Perceive soap on hands (*perceptive task*).
   - Move away from faucet/sink (washbasin proximity sensor, consisting on an *interactive input task* conformed by a *user motor task* and an *input task*).
   - Dry hands (*motor task*).
4. Leave bathroom *interactive input task* conformed by a *user motor task* and an *input task*).

Table 5. Necessary tasks for the AGGIR elimination variable requiring both physical and virtual interaction

1. Access bathroom (*abstract task*), refined in a sequence of three tasks:
   - Open door (*input task* relying on door sensor).
   - Detecting the presence of the subject (*input task* relying on presence sensor).
   - Turn light on (light switch device, consisting on an *interactive input task* conformed by an *user motor task*, and an *input task*).
2. Use of WC refined with a sequence of five ADL:
   - Approach WC (*motor task*).
   - Sit on WC (*motor task*).
   - Wait between 5 to 10 minutes (*input task* relying on a WC proximity sensor).
   - Get up from WC (*motor task*).
   - Pull toilet flush (toilet flush sensor "interactive input task" conformed by a sequence concerning an "user motor task", and an *input task*).
3. Wash hands(*abstract task*), a sequence of eight tasks (as presented on the task model requiring virtual interaction).
4. Leaving bathroom (*abstract task*), refined in a sequence of three tasks:
   - Turn light off (light switch device, consisting on an *interactive input task* conformed by an *user motor task*, and an *input task*).
   - Detecting the absence of the individual (*input task* relying on presence sensor).
   - Close door (*input task* relying on door sensor).

Step 2. Different sensors are considered to detect the events previously identified (see Table 6).

Step 3. The orchestration of the identified events and the sensors needed according to the three scenarios (i.e., physical, virtual, and physical+virtual interaction) is determined, as shown on Table 6.

Table 6. Orchestration of ADL for the dressing variable

Physical		Virtual		Physical+Virtual	
Activity	**Sensor**	**Activity**	**Sensor**	**Activity**	**Sensor**
Turn light on	Light switch	Presence in wardrobe area	Presence	Turn light on	Light switch
Open wardrobe door	Wardrobe door	Spent time changing clothes	Wardrobe proximity	Presence in wardrobe area	Presence
Spent time changing clothes	Pressure floor sensor mat			Open wardrobe door	Wardrobe door
Close wardrobe door	Wardrobe door			Spent time changing clothes	Pressure floor sensor mat
Turn light off	Light switch			Close wardrobe door	Wardrobe proximity
				Turn light off	Light switch

Step 4.1. Modeling of the AGGIR dressing variable requiring physical interaction from the user. Aiming to present a scenario where the physical interaction with the environment is necessary, a wardrobe door sensor as well as a light switch are placed in the smart home. In Table 7, the aforementioned task model is presented.

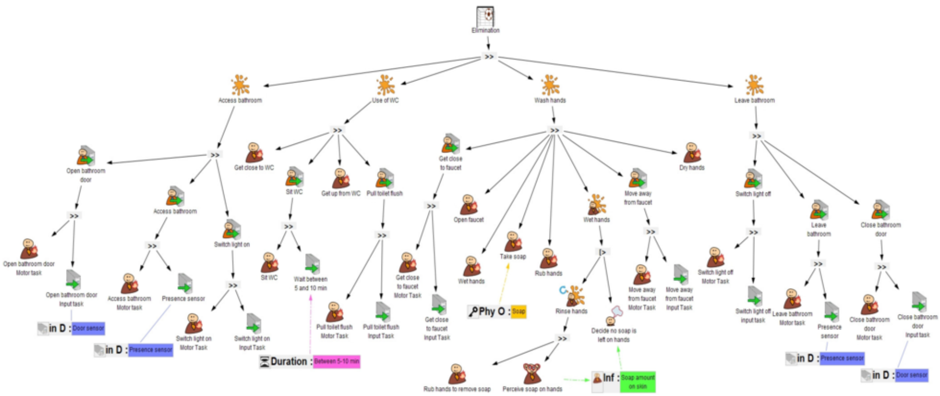

Figure 4. Description of the user tasks to "elimination requiring physical and virtual interaction" with HAMSTERS-XL notation

Table 7. Necessary tasks for the AGGIR dressing variable requiring physical interaction

1. Approach wardrobe area (*abstract task*) area, which comprises two tasks in a sequence:
   - ◦ Turn light on (light switch device, consisting on an "interactive input task" conformed by an *user motor task*, and an *input task*).
   - ◦ Open wardrobe door (door sensor device, sequence of an *interactive input task* conformed by an *motor task*, and an *input task*).
2. Get dressed (abstract task), conformed by a sequence of seven tasks:
   - ◦ Step on pressure floor sensor mat (*user input task*), a sequence with a *motor task* and an *input task*.
   - ◦ Wear underwear (*abstract user task*), consisting on a sequence of two tasks:
     - ∗ Grab underwear (*arm left stretch* task for reaching clothes). The arc between the *arm left stretch* task *Grab underwear* and the information labelled *DK: Recognise front part of underwear* means that the *arm left stretch* task requires the knowledge *Recognise front part of underwear*.
     - ∗ Put underwear on (*cognitive task*).
   - ◦ Wear t-shirt (*abstract user task*), consisting on a sequence of two tasks:
     - ∗ Grab t-shirt (*arm left stretch* task for reaching clothes).
     - ∗ Put t-shirt on (*cognitive task*).
   - ◦ Wear pants (*abstract user task*), consisting on a sequence of two tasks:
     - ∗ Grab pants (*arm left stretch* task for reaching clothes).
     - ∗ Put pants on (*cognitive task*).
   - ◦ Wear shirt (*abstract user task*), consisting on a sequence of two tasks:
     - ∗ Grab shirt (*arm left stretch* task for reaching clothes).
     - ∗ Put shirt on (*cognitive task*).
   - ◦ Wear socks (*abstract user task*), consisting on a sequence of two tasks:
     - ∗ Grab socks (*arm left stretch* task for reaching clothes).
     - ∗ Put socks on (*cognitive task*).
   - ◦ Wear shoes (*abstract user task*), consisting on a sequence of two tasks:
     - ∗ Grab shoes (*arm left stretch* task for reaching clothes).
     - ∗ Put shoes on (*cognitive task*).
3. Move away from wardrobe area (*abstract task*) area, a sequence of two tasks:
   - ◦ Close wardrobe door (door sensor device, sequence of an *interactive input task* conformed by an *motor task*, and an *input task*).
   - ◦ Turn light off (light switch device, consisting on an *interactive input task* conformed by an *user motor task*, and an *input task*).

Step 4.2. Modeling of the AGGIR dressing variable requiring virtual interaction from the user. With the purpose to introduce a scenario where the virtual interaction with the environment is needed, the wardrobe door sensor as well as the light switch are replaced by a presence sensor. The task model regarding the dressing variable with virtual interaction is depicted on Table 8.

Step 4.3. Modeling of the AGGIR dressing variable requiring both physical and virtual interaction from the user. With the aim to study a scenario involving the aforementioned characteristics; a task model concerning both physical and virtual interaction

Table 8. Necessary tasks for the AGGIR dressing variable requiring virtual interaction

1. Approach wardrobe area (*interactive user task*), by means of a *motor task* and an *input task* relying on a presence sensor.
2. Get dressed, *abstract task* refined with a sequence of seven tasks.
   - Spending time changing clothes (*interactive input task*): detecting proximity of the user between five and ten minutes (wardrobe proximity sensor, consisting on a *motor task* and an *input task*).
   - The rest of ADL are the same last six *abstract user tasks* of the dressing task model with physical interaction.
3. Move away from wardrobe area (*interactive input task*), by means of a *motor task* and an *input task* relying on a presence sensor.

is provided. The above-mentioned task model is portrayed in Fig. 5.

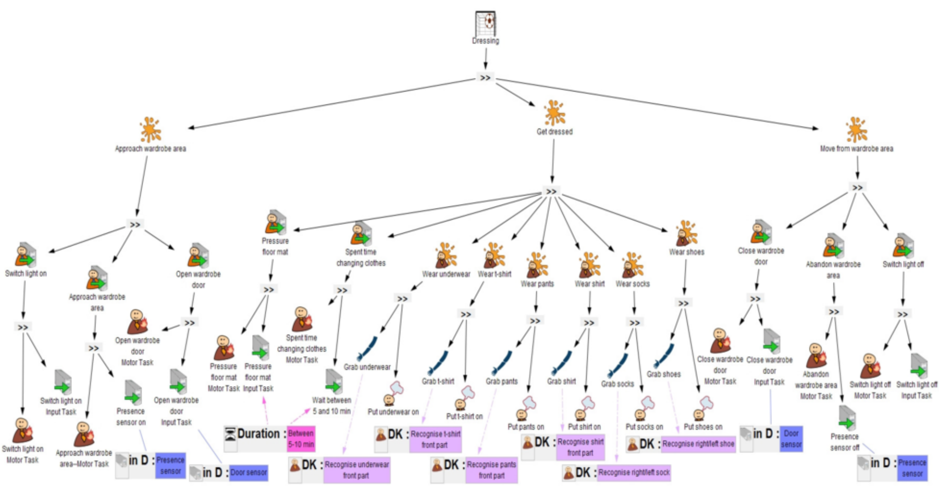

Figure 5. Description of the user tasks to "dressing requiring physical and virtual interaction" with HAMSTERS-XL notation

4. Task models analysis and discussion

The proposed tasks models are analyzed in order to introduce the differences of the specific task models related to a specific AGGIR variable. To do so, the HAMSTERS-XL environment provides the ability to instantiate the three task models – i.e., physical interaction; virtual interaction, both physical and virtual interaction task models. The purpose of such instantiations is the representation of the performance of each user action on a specific task model.

Fig. 6(a), Fig. 6(b), and Fig. 6(c) show the scenarios deployed for each of the proposed elimination task models. Colors depict each event performed for achieving a specific ADL: (i) red for *accessing bathroom*; (ii) blue for *using the WC*; (iii) green for *washing hands*; and (iv) pink for *leaving the bathroom*. It can be remarked that more events are required for the detection of the inhabitant *accessing the bathroom* in the physical and virtual interaction scenario; whereas the scenarios requiring either physical or virtual interaction, the number of events are four and two, respectively. Additionally, the first two scenarios (Fig. 6(a) and Fig. 6(b)) present five events for *the use of WC*; and six for the third scenario (Fig. 6(c)). Also, the physical scenario requires less events concerning the ADL of *washing hands*. Moreover, the number of events for recognising the subject *leaving the room* are the same as *accessing the bathroom*. In these scenarios, it is highlighted that the number and the type of sensors employed influences the number of events

(a) (b) (c) (d) (e) (f)

Figure 6. (a) Elimination (physical) (b) Elimination (virtual) (c) Elimination (physical/virtual) (d) Dressing (physical) (e) Dressing (virtual) (f) Dressing (physical/virtual)

for each ADL. For this matter, the scenario for elimination with virtual interaction can be considered the most suitable for the recognition of the AGGIR elimination variable. A similar situation occurs with the dressing AGGIR variable task models (shown in Fig. 6(d), Fig. 6(e), and Fig. 6(f)); where the most favourable results after simulation for the analyzed ADL is the scenario concerning virtual interaction.

ADL carried out by elderly people in an assistive system need to be properly monitored and human action must be detected with the purpose to provide accurate guidance [16]. In this regard, tasks models represent a useful way to better model ADL, by establishing an ordering of activities, as well as the type of tasks that the inhabitant need to perform, taking into consideration both the manipulated objects and the relevant information prior to ADL performance by the resident. Additionally, setting a daily routine for seniors, concerning the particular needs and interests of the elderly subject could be beneficial [17]. To this aim, task models can be proposed as a guideline for a daily routine or specific activities inside the household environment in order to help the inhabitant to accomplish their daily ADL in a coherent manner, which can be achieved by means of a checklist throughout the day.

With the purpose to recognise which sensors are appropriate, it is necessary to identify the amount of information that can be extracted from each sensor [18]. To this extent, task models serve as a tool for choosing in advance both the adequate quantity and type of sensors for detecting the ADL within a smart home; helping to improve the orchestration of ADL by means of sensors, as well as the optimization of ADL monitoring. In this regard, several orchestration of ADL can be assessed in order to analyse if multiple sensors related to the identification of one activity can be replaced in case of malfunction (e.g., light switch and presence sensor for detecting the inhabitant accessing the room).

The most notable limitation of our four-step proposal is the binding with the AGGIR model. To use another model to assess independence of elderly, such as SMAF, Step 3 and Step 4 must be restated; for example, by providing an interactive user interface.

5. Conclusions

We present an approach to represent ADL based HAMSTERS-XL, a task model, intended to describe activities performed by a resident within a household environment relying on the AGGIR variables, a tool for determining the autonomy of an inhabitant adopted by the French government. Our approach consists of a set of steps aiming to establish parameters, such as time and location, of both activities and sensors, as well as the events that need to be detected. The AGGIR dressing and elimination variables are assessed in three simulated scenarios concerning physical, virtual, and both physical and virtual environments. Results are analyzed in order to point out the advantages and disadvantages of representing ADL via task modeling.

We plan to study other AGGIR variables and develop other study cases to adjust the approach and validate it further. We will improve our approach by generalizing the use of different dependency evaluation models and make it more flexible and extensible.

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