A Virtual Caregiver for Assisted Daily Living of Pre-Frail Users*.

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Abstract. As Europe sees its population aging dramatically, Assisted Daily Living for the elderly becomes a more and more important and relevant research topic. The Movecare Project focuses on this topic by integrating a robotic platform, an IoT system, and an activity center to provide assistance, suggestions of activities and transparent monitoring to users at home. In this paper, we describe the Virtual Caregiver, a software component of the Movecare platform, that is responsible for analyzing the data from the various modules and generating suggestions tailored to the user's state and needs. A preliminary study has been carried on over 2 months with 15 users. This study suggests that the presence of the Virtual Caregiver encourages people to use the Movecare platform more consistently, which in turn could result in better monitoring and prevention of cognitive and physical decline.

Keywords: Virtual Caregiver · Assisted Daily Living · Ambient Intelligence.

1 Introduction

As the overall population in Europe is aging remarkably [5], developing solutions allowing users to stay cognitively and physically healthier becomes critical. A

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lack of cognitive and physical stimuli has been shown to encourage the appearance of Mild Cognitive Impairement (MCI), a condition that may later develop in dementia [12]. The development of the Internet of Things, robotic platforms, and communication technologies in general offers new possibilities for innovative solutions to provide such stimuli while monitoring the user's cognitive and physical state and evolution. This is the goal pursued by the MoveCare project. However, such systems need to be proactive and encourage the users to interact with the different tools provided so that they can be monitored efficiently while being prevented with relevant stimulus.

In this paper, we describe the Virtual Caregiver, a software component of the MoveCare platform, whose role is to analyze data collected by a monitoring system and generate interventions to assist and encourage the user to use the digital tools part of the MoveCare ecosystem. The remainder of this paper is organized as follows. Section 2 presents the overall MoveCare project and platform, explaining the interaction between the Virtual Caregiver and the rest of the platform. Section 3 presents the architecture of the Virtual Caregiver and Section 4 presents a pilot study performed in the context of MoveCare, which allowed us to test the feasibility and efficiency of the Virtual Caregiver. Finally, Section 5 present studies and systems related to ours, and Section 6 concludes this paper with a discussion of the limitations and opportunities created by our system.

2 The MoveCare project

The MoveCare project is an H2020 European project aiming at creating a complete solution to provide transparent monitoring, assistance and tailored recommendations to elders at home. The MoveCare platform, presented on Figure 1, integrates an activity center, along with a virtual community, an assistive robot (the Giraff platform[6]), and environmental sensors and smart objects

In MoveCare, data is collected from three different types of sources: environmental sensors, smart objects and a Community Based Activity Center (CBAC).

The set of environmental sensors include motion sensors in each room of the user's house, accelerometers under couches and beds, door sensors, and a smart scale. Two objects have been "smartified": a pen, which allows to measure handwriting-related parameters, and a ball, which is associated to an exergame on the CBAC to measure the user's grip force.

The CBAC is an interactive application that can be used from a Tablet or a TV and allows the user to play to a certain number of games, both cognitive (cards games, pictionnary) and physical (exergames) and record their score. Games can be single or multi-player. In case of multi-player games, a video chat system allows the players to interact with each other while playing. This video chat system is also available as an application of its own.

The Virtual Caregiver (VC) gathers data from all the monitoring components, analyzes it and provides feedback, assistance, and recommendations.

[6] http://www.giraff.org/

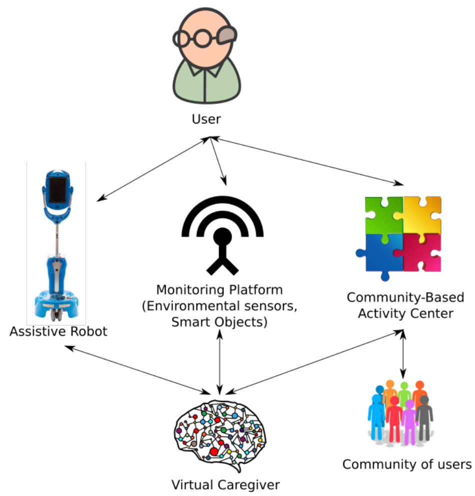


Fig. 1: The Movecare Platform

rThe assistive robot is the main face of the system. It will deliver interventions generated by the VC to the user and interact with them through voice interaction.

In the remainder of this paper, we will describe the architecture of the Virtual Caregiver as well as the different algorithms that it encompasses.

3 The Virtual Caregiver

3.1 Overview

The goal of the Virtual Caregiver is to gather all information provided from the different components in the system and create *interventions* for the user. An *intervention* is defined as a proactive action of the system which aims at helping the user in their everyday life. Each intervention triggers an action from the robot and/or a display on the CBAC for the user to read. Interventions are tailored to the user's needs and past behaviors and engineered to maintain their physical, cognitive and social health. Interventions are characterized by the following elements: (a) an intervention code, describing the type of intervention. (b) a priority, manually defined for each intervention type. Priorities range from 0 (lowest priority) to 7 (highest priority). (c) other data specific to this intervention. The structure of the Virtual Caregiver, presented in Figure 2, has been designed around scenarios characterized by their clinical value and interest for the user.

The movecare modules are separated in two categories: (a) the *scenarios* modules, which implement functionalities specific to each scenario, and (b) the *utility* modules which implement functionalities used across the different scenarios.

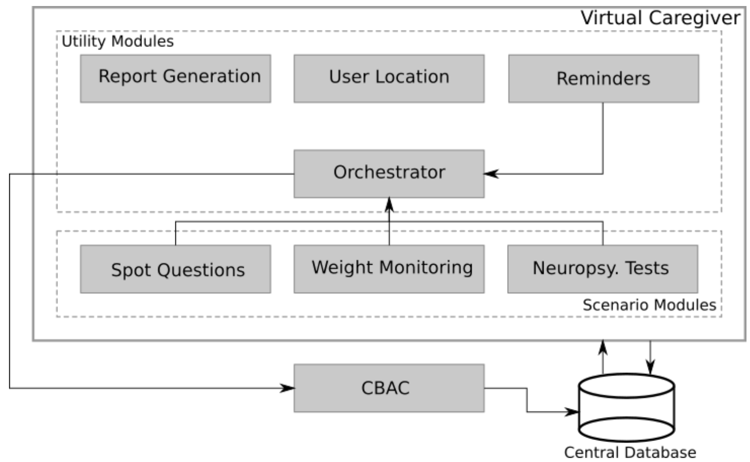


Fig. 2: The overall architecture of the Virtual Caregiver

The modules in the VC follow two types of workflows, which differ only by the way data is received. Workflows are not mutually exclusive and one module can implement both for different functions. In one case, which we call the *Reactive Workflow*, the module receives data from other components (monitoring system, robot, CBAC) in real-time, analyzes it, and generates an intervention. This is for instance the case for the analysis of weight in the Weight Monitoring or the User Location module. In the second case, which is the *Periodic Workflow*, the module "wakes up" after a pre-determined amount of time (usually daily or weekly), collects data from the database, analyzes it, and generates an intervention. This is for instance the case for the function that reminds the user to measure their weight in the Weight Monitoring module, or for the whole Reminder module. All modules send the intervention they generate immediately to the Orchestrator, who is in charge of timing the actual delivery to the user according context and pre-defined constraints.

To communicate within the VC and with the other components of the system, a set of MQTT [7] channels have been implemented. These channels are of a publish/subscribe type, and allow the VC to receive data from sensors and send interventions to the rest of the system. Within the VC, one channel has been implemented to send interventions from the different module to the orchestrator.

In the remainder of this section, we will describe in more details all the VC modules. We will first focus on the scenarios modules (Section 3.2) and then describe the set of Utility Modules (Section 3.3).

3.2 The Scenarios Modules

The scenarios modules implement the functionalities needed by the different scenarios. Scenarios have been designed focusing on their interest for the clinical

[7] http://mqtt.org/

aspect of the MoveCare project, their interest for the end-user, and their technical feasibility. Three separate scenarios have been implemented, described in the following.

Spot Questions In this scenario, the user is expected to answer several questions related to their previous activities, the current context (current day, current month) or an event in the past. This scenario has a high clinical value as it allows to monitor the user's cognitive state and to detect changes in the long-term. The types of spot questions, their purpose, and examples of such questions are presented in Table 1. The role of the Virtual Caregiver in this scenario is to select a question to ask according to a predefined frequency decided by the clinical partners of the projects and presented on Figure 2. The delivery of the selected spot questions is made by the robot, through voice interaction. The robot also records the user's answer, transcript to text thanks to a speech-to-text module and send it to the global database.

Type of question	**Aim**	**Examples of questions**
Episodic memory	Recovery related to different activities previously performed by the user	"To be able to offer you more varied exercises, can you tell me if you played cards in the last 3 days?" "Do you remember how much you weighed yesterday?"
Apathy	User's self-evaluation of their physical and cognitive states	"Are you more tired than usual today?" "Are you more irritable than usual?"
Temporal Orientation	Recovery related to current time	"What weekday is it today?" "Which month is the current one?"
Confabulation	Trigger recovery of long-term memory	"Do you remember how you spent the day of your 25th birthday?" Do you remember what you were doing a month ago at the same time?"

Table 1: Type of Spot Questions

Week 1	1 question per day for 4 consecutive days
Week 2	2 questions days 1 and 3, 1 question day 5
Week 3	4 questions during one randomly selected day
Week 4	1 question per day for 5 consecutive days

Table 2: Frequency at which spot questions must be asked

The Spot Question module follows the periodic workflow. Algorithm 1 presents the general algorithm used by the VC. For space reasons, we did not detail all of the functions used but only summarized them.

```
Data: fqcy: representation of Table 2
listAvailableQuestions: the list of available questions allSpotQuestions: the list
of all possible questions
Result: dailySpotQuestions: a list of interventions SQ, corresponding to the
        spot questions for the day with the corresponding correct answer (if
        any) and the time they should be asked
if listAvailableQuestions.length ¡= 3 then
    listAvailableQuestions = allSpotQuestions ;
end
nbQuestions = getNumberOfQuestionForCurrentDay();
delta = calculateDeltaBetweenQuestions() ;
for 0 ≤ i < nbQuestions do
    question = selectQuestion(listAvailableQuestions) ;
    answer = retrieveAnswerFromQuestion(question) ;
    listAvailableQuestions.remove(question) ;
    dailySpotQuestions.add(question, answer, currentTime + i*delta) ;
end
return dailySpotQuestions
```

Algorithm 1: Spot Questions main algorithm. The function getNumberOfQuestionForCurrentDay calculates how many spot questions are supposed to be asked on the current day according to the frequency given in Table 2. The function calculateDeltaBetweenQuestions distributes the questions evenly during the day and returns the minimum amount of time between two questions. The function retrieveAnswerFromQuestion retrieves the expected answer for each spot question and its implementation is tightly linked to the type of question selected by selectQuestion.

Weight Monitoring Sudden change of weight is an important indicator of frailty. For this reason, monitoring the user's weight variations has a high clinical value. The role of the VC in this scenario is twofold: it reminds the user to measure their weight and analyzes the measurement. In case an important change is detected (i.e., a gain or loss of at least 2% of the previous weight), then an alert is sent to the clinicians through the Report Generation module (see Section 3.3).

The Weight Monitoring module implements both the reactive and the periodic workflows. The reactive workflow is used when a new measure is received from the smart scale to analyze it. The periodic workflow is used to remind the user to measure their weight if they haven't done so in a week.

Neuropsychological Tests The user is expected to perform regularly two neuropsychological tests commonly used to detect early signs of cognitive impairment [9]. The role of the VC in this scenario is to detect when the tests need to be performed and present them for the user to perform. The Neuropsychological Tests module implements exclusively the periodic workflow. Algorithm 2 describes the main loop of the module.

```
Data: deltaTests: the number of days between two sets of tests
Result: Intervention CT to perform neuropsychological tests
Module wakes up every day at 01:00am ;
latestTests = getDateLatestTestsFromBD() ;
if no latestTests or latestTests are more than deltaTests days ago then
  | sendIntervention(CT) ;
end
sleepUntilNextDay() ;
```

Algorithm 2: The main loop for the neuropsychological tests.

3.3 The Utility Modules

The utility modules of the Virtual Caregiver implement functionalities that are not tied to any specific scenario but are of use for various situations and components. Five separate utility modules were developed, described in the following sub-sections.

Reminders The monitoring of the users is done through three components: environmental sensors, smart objects and activities played in the CBAC. If the monitoring through environmental sensors is completely transparent for the user, they still need to remember to use the Smart Objects and the CBAC. The VC can detect if they are doing so and remind them if needed through the Reminders module. The Reminders module uses exclusively the periodic workflow and creates interventions according to a set of rules and priorities summarized in Table 3. To avoid overwhelming the users, it has been decided that only one reminder should be sent per day (if needed). If several reminders were necessary for the current day, then the reminder with highest priority is sent.

In addition to reminding the user of several elements, this module also provides "positive feedback": every three days, a message is sent through the CBAC with an encouraging message of what the user has been using a lot during this period of time (e.g., "You have been using your smart pen a lot lately. It's important for me to be able to monitor your handwriting. Keep doing it!").

Report Generation The report generation component generates reports to send weekly to the clinician responsible for the study. These reports contain the

Reminder Name	Context	Rule	Priority
Grip Force game	The Grip Force game is an activity developed during the MoveCare project that aims at monitoring the user's grip force, a loss of grip force being a common sign of frailty.	There is not grip force data in the DB for the past 7 days	5
Smart Pen	The Smart Pen allows to monitor changes in handwriting, which can be signs of frailty.	There is no smart pen data in the DB for the past 7 days	1
Cognitive Games	Cognitive games in the CBAC allow to monitor changes in the user's cognitive state	There is no report of cognitive games played in the DB for the past 7 days	2
Physical activity	Maintaining a good level of physical activity is important for pre-frail users. Physical activity includes exergames from the CBAC and going outdoor.	There is no report of exergames in the DB and the user has not been outdoor for the past 3 days	3
Social games	Multi-player games in the CBAC allow the users to socialize with peers while playing.	There is no report of multi-player games in the DB for more than 3 days	4

Table 3: Rules and priority for each type of reminders. Priority ranges from 1 (lowest) to 5 (highest)

user's answers to the confabulation questions as well as alerts that might have been detected during the week. In the pilot study described in Section 4, we only generated upon abnormal weight measurement.

User Location Being able to locate the user inside the home is a central functionality for a system such as the MoveCare platform. This information is used by the robot to navigate to the user and by the Virtual Caregiver itself to infer some user's activity and context. In the MoveCare platform, the Virtual Caregiver infers the topological position of the user (i.e. the room in which they currently are) based on motion sensors only. The User Location module implements the reactive workflow and Algorithm 3 is called each time an event is received from one of the motion sensors. An event corresponds to the sensor turning on or the sensor turning off. The sensors map, i.e., the map between sensor IDs and the room they are located in, is supposed to be known. We also assume that one sensor monitors entrances of the user's apartment. In the case of the MoveCare platform, this sensor is a contact sensor installed on the main entrance door. Algorithm 3 can be summarized as follows: each new activation of a motion sensor in a room where the robot is not moving is added to a list of past locations and the user is located to the most recent location. When a sensor turns off, then all the occurrences of locations corresponding to this sensor are removed from the list. If the user cannot be located in the home (all the sensors are off), they are either considered outside (if the entrance sensor has been activated recently) or their position is unknown. This last case can happen when the user is in a room which is not monitored (for instance the bathroom) or too still for the sensors to be activated (for instance sitting on a chair)

```
Data: sensorEvent: event from one sensor, containing the sensor ID and the
      value (OFF or ON)
robotPosition: the room in which the robot currently is
robotState: the state of the robot (IDLE, NAVIGATING)
pastLocations: the list of past known locations
latestDoorActivation: timestamp of the latest time the entrance sensor was
activated
Result: userLocation: the room in which the user is present
eventLocation = getLocationFromSensorMap(sensorEvent.id) ;
if event.value is OFF then
    pastLocations.removeAll(eventLocation) ;
else
    if robotState is IDLE or robotPosition is not eventLocation then
        pastLocations.headInsert(eventLocation) ;
    end
end
if pastLocations is not empty then
    return pastLocations.firstElement() ;
else
    if latestDoorActivation ¡ currentTime - 5min then
        return OUTDOOR ;
    else
        return UNKNOWN ;
    end
end
```

Algorithm 3: The main user location algorithm.

The Orchestrator At the center of the Virtual Caregiver, the Orchestrator receives all intervention requests from the different modules and send them to the other components of the MoveCare system when appropriate. To do so, the Orchestrator uses a policy, based on rules and temporal constraints, presented in Table 4, to detect the appropriate time to send interventions. Rules are either context-based or ad-hoc.

The orchestrator implements both a reactive and a periodic workflow: Algorithm 4 is called in three cases: (1) when the orchestrator receives an intervention request from another VC module, (2) when the user's location is updated from OUTDOOR to another location in the home, (3) every hour between 08:00 and 21:00.

When the orchestrator receives a new intervention, it queues it in a list of pending interventions. It then selects the intervention with highest priority, and

Number	Name	Type	Description
1	Resting	Context-based	No intervention is sent if the user is detected in the bedroom.
2	Night time	Ad-Hoc	No intervention between 21:00 and 08:00. This rule has been implemented to ensure that the user won't be disturbed by the robot while sleeping, should the context from rule 1 not be detected properly
3	User at home	Context-based	No intervention is sent if the user is OUTDOOR
4	In bathroom	Context-based	No intervention is sent if the user is in the bathroom
5	Max. number of interventions	Ad-hoc	There should be a maximum of 5 interventions per day
6	Min. time between interventions	Ad-hoc	There should be at least 1 hour between 2 interventions

Table 4: Rules and Constraints implemented in the Orchestrator

checks that all the rules from Table 4 apply before actually sending the intervention through MQTT. At the end of the day, the list of pending interventions is cleared. Since all periodic modules wake up at regular intervals, interventions that have not been sent will be regenerated the next day.

4 Pilot Study

The developed system has been tested during a pilot study involving 15 users for 2 months. Users were situated in Italy (7 users) and Spain (8 users) and were recruited following interviews from clinicians, which allowed to categorize them in the pre-frail state. Among these users, 8 of them (4 in Italy and 4 in Spain) have been provided with the full MoveCare platform (environmental sensors, smart objects, CBAC, and robot) and 7 (3 in Italy and 4 in Spain) have been equipped with the platform without the robot. This separation allowed us to test whether the presence of the robot (the "face" of the Virtual Caregiver) had a positive impact on the use of the monitoring platform (smart objects and CBAC). Figure 3a shows the number of measurement corresponding to the use of the CBAC (code ARU), the use of the smart scale (code BWT), the use of the smart ball (code EXG) and the use of the smart pen (code PEN).

We can see that the presence of a robot systematically increases the use of the Smart Objects and the CBAC. However, when analyzing the number of interventions delivered to users with robots compared to number of actual measurements from the same users(Figure 3b) we can see that the users are interacting with the monitoring system much more than they are reminded to. This suggest that either the physical presence of the robot, or the few times

```
Data: requestedIntervention: the intervention requested by one of the VC
        modules (when real time),
pendingInterventionList: the list of all pending interventions,
Result: Publishes an intervention on the corresponding MQTT topic if
        constraints are met.
if intervention not null then
    pendingInterventionList.add(intervention) ;
    pendingInterventionList.sortBy(priority) ;
end
if Rules 1 to 6 are OK then
    intervention = getFirst() ;
    publish(intervention) ;
    pendingInterventionList.remove(intervention) ;
end
if currentTime > 21:00 then
    pendingInterventionList.clear() ;
end
```

Algorithm 4: The Orchestrator's main loop.

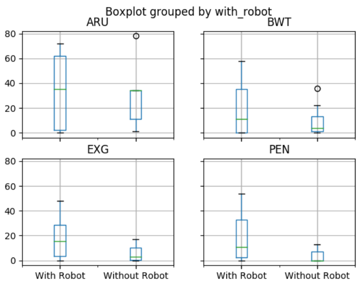
the robot actually reminded them to use the object were sufficient to encourage users to use the monitoring system. This could also result from the fact that users that have been equipped with a robot are more engaged with the study, and therefore more likely to use the system.

5 Related Work

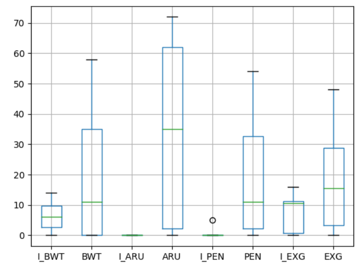
The development of Virtual Caregivers to assist elders at home has been a hot topic of research for several years now. Early work focused on the development of robotic platforms capable of assisting the user [11,13] and providing social interaction [14,10]. Other studies focused on creating platforms for rehabilitation, in which robots can help the patient train specific tasks [8,6]. These systems are focused on user's assistance and do not consider user monitoring.

With the recent booming of the Internet of Things and Ambient Sensing, many systems have been developed to monitor elders in Smart Homes and assess their cognitive and physical states, promoting independent living. Work as early as the one presented in [15] acknowledge the added value of monitoring users to provide better care and allow them to stay at home. Since, many studies relied on IoT and ambient intelligent systems to recognize user's patterns [1], activities [4] and habits [2].

When combining the monitoring and assistive aspects of elderly care at home, some systems preferred the use of "ambient actions" (actions to devices connected to the system) [16] or favored the use of Smart TVs [7,3].



(a) Number of measurements recorded during the study for groups of users with and without a robot. ARU corresponds to the activities in the CBAC (all types of activities), BWT is the weight measurement, EXG is the use of the smart ball and PEN is the use of the smart pen.



(b) Number of interventions reminding the users to use a certain component and number of actual use of this component. ARU corresponds to the activities in the CBAC (all types of activities), BWT is the weight measurement, EXG is the use of the smart ball and PEN is the use of the smart pen. I_X correspond to the intervention reminding the user to use X.

Fig. 3: Results of the Pilot Study

6 Conclusion

In this paper, we presented the Virtual Caregiver, a software component that analyzes data gathered from a monitoring system and generates interventions, with the goal of monitoring and assisting the user of the system. The VC uses context elements and constraints to decide when to send an intervention, thus providing assistance in an non-intrusive way. The system has been implemented and tested during a pilot study involving 15 users over 2 months, and results suggest that such a proactive component is beneficial for the system as a whole. Indeed, users equipped with the robot (which acted as the face of the Virtual Caregiver and delivered interventions) were more engaged with the platform as a whole. The main limitation of this study is in its size. The number of users and the duration of the study does not allow us to strongly conclude whether the presence of the system was beneficial overall to the users. Longer and bigger studies would be required. However, the results are encouraging and open a lot of possibilities for future improvement. The main line of future work concerns long-term analysis of the user's cognitive and physical state. In the current implementation of the Virtual Caregiver, only short term analysis was used to detect interventions. Some trend and pattern detection have been performed during the project after the end of the pilot, but were not considered during the pilot. Identifying trends and patterns in the user's state as the system runs would allow for more tailored recommendations.

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