A Proposal to Improve Voice-based Interfaces for Elders using Daily-living Activity Identification

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Keywords: Cognitive Decline, Telehealth, Smart Homes, Smart Speakers, Activities of Daily-living, Voice-based Games, Elder.

Abstract: It is a matter of common knowledge that the aging process entails a cognitive decline in certain processes such as attention, episodic memory, working memory, processing speed and executive functions. In recent years, efforts have been made to study the potential of Information and Communication Technologies to improve cognitive functioning and quality of life in elderly adults with and without cognitive impairments. In this paper, we introduce CODA (COgnitive Decline Alert kit), a system intended to keep record of the activities of daily living that also implements straightforward games heavily based on voice assistants that get leverage of such records with two main aims: the first one is to achieve a engaging gaming experience, by means of the introduction of questions related with activities of daily living that have been carried out recently by the elder. The second one is to have a means to evaluate the memory processes of the elder by analyzing their answers to the game questions; these are expected to be a useful source of information about the cognitive decline of the person.

1 INTRODUCTION

The impact of cognitive decline on everyday function is a major issue for the elderly and those who care for them. Impairments in real-world functioning are associated with a reduced quality of life for patients, increased economic burden, and can ultimately result in the loss of the ability to live independently. In addition, cognitive and functional deficits are essential markers for the early diagnosis of neurodegenerative diseases such as dementia. In brief, our proposal is based on monitoring relevant cognitive domains in everyday function in elderly individuals by means of smart environments and related technologies. More specifically, the implementation of smart homes in order to detect and identify anomalies in the execution of daily tasks that could be sign of cognitive decline, particularly in the cognitive domain of memory, an essential area in the diagnosis of mild cognitive impairment and dementia. In the long term our aim is to develop a neuropsychological or clinical "alert system" ecologically integrated at home that can operate semi-autonomously.

Monitoring a senior at home can be done through the design and implementation of a smart environment. To this end, one of our major efforts will be the definition of a COgnitive Decline Alert kit (CODA kit) as affordable and easy to install at home as possible. However, we are convinced that the execution of many tasks cannot be evaluated solely through the information obtained from traditional sensors, and for this reason, a novelty of our proposal is the inclusion in CODA of conversational Artificial Intelligence agents (e.g., smart speakers) as a way to introduce some degree of interaction between the elder and the system over the course of execution of the tasks. The informal conversations led by these agents must be carefully designed with the aim of inferring useful information about the elder cognitive state. As a second way to make inferences about changes in cognitive functioning of the elderly, a set of very straightforward games will be implemented by means of the smart speaker. These games will use the records of CODA about the user profile and activities of daily living (ADL) so that the games include questions about everyday tasks such as what TV programs they were watching last night or their personal information (e.g. name of their grandchildren that start with a vocal). As a result of these customized dialogues, we expect to obtain both more motivating

Martínez-Santiago, F., García-Viedma, R., Rueda-Ruíz, A., Ureña-Cámara, M., García-Fernández, Á. and Ureña-López, L.
A Proposal to Improve Voice-based Interfaces for Elders using Daily-living Activity Identification.
DOI: 10.5220/0009817703010307
In *Proceedings of the 6th International Conference on Information and Communication Technologies for Ageing Well and e-Health (ICT4AWE 2020)*, pages 301-307
ISBN: 978-989-758-420-6

games and information about cognitive functions such as working and declarative memory.

2 COGNITIVE DECLINE IN DAILY TASKS. OUR PROPOSAL

A possible case of study is the following: Brian is a 70-year-old man with mild cognitive impairment that lives alone. He wants to watch TV in the evening after the dinner as usual. To do that, he walks into the living room, sits on the couch, picks up the remote and turns on the TV. After some time the TV show finishes and Brian leaves the room but he does not turn off the TV. Later, maybe the next day at night, Brian decides to play by means of the smart speaker that is installed at home. The smart speaker proposes a quite naive game with special interest in working memory assessments. For example, remembering the names of his grandchildren sorted by gender (first the names of the girls and then the name of the boys). Then, when the game is finished, or when a given game level is finished, the smart speaker starts a small talk by saying something like “Did you watch a TV show last night?”. Brian answer is: “Yes, I was watching a TV show”.

The key point in these everyday scenes is the recognition of anomalies such as wrong or inappropriate answers to naive questions when playing or forgetfulness such as keeping the TV on when leaving the room and going to bed. When these anomalies are frequent enough and/or occur in conjunction with other similar faults, they may not be read as minor forgetfulness but as indicators of a possible cognitive decline.

From the point of view of the present work, the formalization, management and analysis of the scenario described above requires the following tasks: firstly, the neuropsychologist describes the steps that define the ADL (go to the living room, sit down, get the TV remote and so on) and the relationship between these steps, the cognitive domain and possible anomalies (e.g., getting a wrong object to turn the TV on would give us a clue about a possible gnosis), and supervises the design of the games with the aim to help to make assessments about memory. Secondly, the monitoring system installed at home is revised and modified if required to support ADLs identification, and the software in the server side is accordingly expanded (see Section 5). Finally, some degree of interaction is introduced by means of a smart speaker, intended as human-computer interfaces with an intelligent conversational agent that implements straightforward small talks and voice-based games designed in collaboration with the neuropsychologist with the aim to obtain additional clues about the cognitive domain of interest, more concisely the working memory. This process will be iteratively applied up to obtaining a minimal smart environment that could be implemented at seniors’ homes to monitor as many ADLs as possible. However, we have to remark that this paper describes a very preliminary stage of CODA, and our aim is to design, implement and test a functional proof of concept rather than a complete system; therefore the number of supported scenarios, ADLs, games and cognitive domains to study is very limited at this moment.

A contribution of the present paper is the description of the ontology OSLE. In order to describe ADLs, we propose the Ontology SmartLab Elder (OSLE). This ontology is related with Telehealth Smart Homes and enables us to describe the whole system: from sensor’s readings, how these readings should be interpreted as isolated events and how the sum of these events are matched as ADLs performed by the elderly. At the moment of writing this paper, we have created a formal model of a first ADL using OSLE: watching TV. This ADL is integrated in the course of five quite naive voice-based games: remembering names of cities whose first letter is a specific one, names of relatives of a given type (grandchildren, sons, daughters and so on) and repeating sequences of words in inverse order as said.

The rest of this paper is organized as follows. The next section introduces Telehealth systems, then section 4 enumerates the three types of ADLs that concerns to the present proposal. Section 5 describes the architecture of our proposal, CODA. Next, we introduce OSLE, the ontology that is part of CODA. Section 7 describes very briefly the games based on voice interaction that are implemented at this moment. Finally, conclusions and future works are introduced.

3 TELEHEALTH IN THE DOMAIN OF THE ELDERLY COGNITIVE DECLINE

Telehealth Smart Home is defined as an adequate model of a smart home designed to care for someone with loss of ognitive functioning (Rialle et al., 2002). Focusing on the specific field of smart environments applied to cognitive decline in aging, (Latfi et al., 2007) and (Dawadi et al., 2013) described the application of machine-learning algorithms to perform automated assessment of task quality based on smart home sensor data that are collected during task performance. Unlike our proposal, the tasks are neither spontaneous nor in real homes but they are fully predefined and must be executed in a laboratory, a smart home apartment. Later they proposed a more ecological approach at home so that the system ”predicts” the user cognitive state (Dawadi et al., 2015). For this purpose, a Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) test is applied every three months so that (i) it is possible to measure the accuracy of the predictions and (ii) the system learns by correlating RBANS results and the sensor lectures. As a result, this model is not suited as a diagnose tool since it is based on supervised machine learning and requires to be trained with the data obtained from tests carried out periodically. Finally, (Riboni et al., 2016) proposed the SmartFABER system, which focused on the detection of anomalies when ADLs are executed. To this end, they define a detailed ontology in order to model the ADLs and possible anomalies. Then, these anomalies are analyzed and interpreted by therapists and caregivers in a screenboard. In contrast to RBANS and our proposal, the aim of SmartFABER is monitoring the functional abilities of the seniors at risk and reporting the behavioral anomalies to the clinicians, rather than diagnose/predict cognitive decline and/or provide rehabilitation. Finally, it is important to note that neither RBANS nor SmartFABER introduce any kind of interaction with the elder by means of conversational agents or any other tool; this is an important forgotten part of the elder life in other projects. They propose pervasive systems in order to keep record and interpret at certain degree spontaneous, non-addressed ADLs when these happen. Finally, research on cognitive decline and impact of gamin on older adults health is adressed in (Loos and Kaufman, 2018) and (Zhou and Salvendy, 2016).

4 CLASSIFICATION OF ACTIVITIES OF DAILY LIVING

The first objective of this work is the identification and formalization of different types of activities of daily living (ADLs). We distinguish three types of ADLs depending on the degree that other actors different from the elder take part of the activity:

- *Passive*. The initiative and development of the activity is fully accomplished by the elder. These are the most natural and ecological activities, and the most difficult to be recorded and interpreted in psychological terms.
- *Interactive*. The initiative of the activity comes from the elder, but once the activity starts and is perceived by one or more smart home elements (sensors, smart speakers, etc) then a predefined action (a kind of sub-activity, an activity into the activity) is triggered and executed. The accomplishment of this sort of sub-activities require the interaction between the elder and an artificial actor such as a smart speaker. Sub-activities are carefully defined with the aim of measuring one or more cognitive domains of interest.
- *Proactive*. The activity starts by means of a request from a dialog-based assistant such as Alexa or Google Assitant. Then, the development of the activity continues in the same way that interactive activities. The main difference between proactive and interactive activities is that the latter are spontaneous, while the former are addressed from the beginning to the end by means of a dialog-based assistant.

Note that passive activities represent the most ecological approach, but these are the most difficult to manage. On the other hand, proactive activities can be seen as laboratory tests carried out at home. As a consequence, it is easier to deduce cognitive implications according to the elder's behaviour. Finally, games are implemented as interactive and/or proactive activities. The difference between both of then is that, in the first case, the elderly starts with the game whereas in the case of proactive activities, it is the smart speaker who proposes a game.

The role of neuropsychology is central in the definition of the ADLs that are relevant for the cognitive domain of memory, and also in the evaluation of the elder's performance in the most natural and ecological way.

5 CODA ARCHITECTURE

CODA follows a multi-tier architecture (see Figure 1) in which every level defines an abstraction layer:

- *CODA-Sensor*. Monitoring the ADLs requires a smart home whose design starts with a comprehensive study of the physical environment where it is going to be implemented, in order to determine the number and position of the sensors and compare different setups. These include sensors based on contactless technologies (e.g.: NFC, RFID, bluetooth beacons), thermal or depth cameras, like Intel RealSense. We discarded optical cameras and wearables since they can compromise the privacy of users. To this end, three sensor abstraction layers are defined:

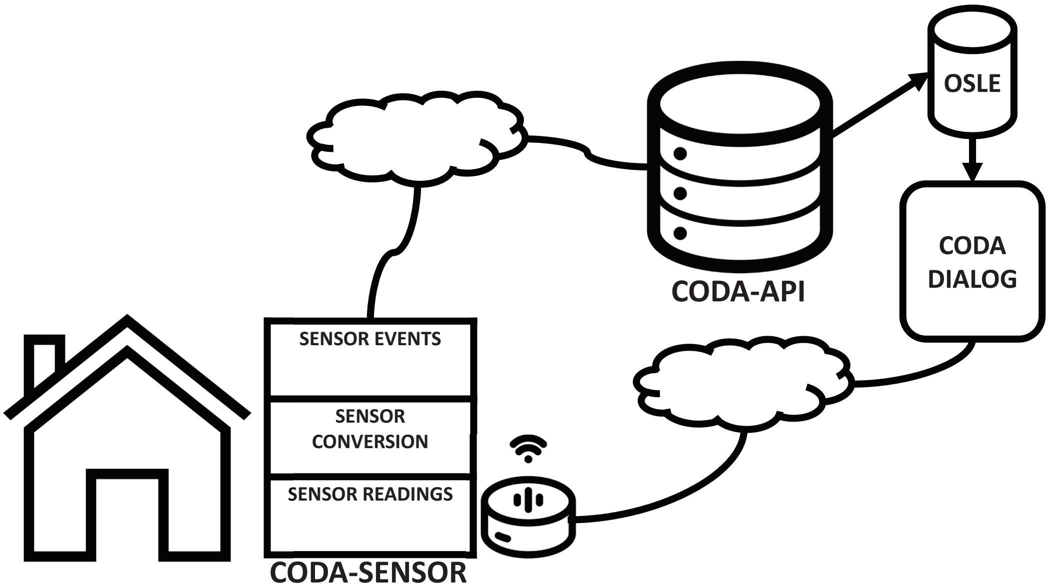

Figure 1: CODA architecture.

  – *Reading Layer*: Conversion of the signal data received by the sensor to physical units or Boolean values.
  – *Analog/Digital Data Conversion Layer*: For example, this level defines the activation/deactivation threshold for every sensor.
  – *Event Layer*: converts the different information of the sensors already catalogued into an event. For example, the activation of the TV energy consumption sensor together with the activation of the remote control fires a TV event such as turning TV off or channel selection.

- *CODA-API*: is a RESTFul Web Service implemented using the Spring framework(Dewailly, 2015). This API receives sensor events which are used to instance elements of the ontology (OSLE, depicted in section 6). The purpose of this ontology is to make inferences about ADLs that the elderly perform at home. HermiT reasoner(Shearer et al., 2008) is used for this end.
- *CODA-Dialog*: is the module where small-talks and voice-based games are implemented. The dialog manager integrates both user profile information and those ADLs identified by means of OSLE. CODA-Dialog is implemented as a set of Alexa skills, Amazon's cloud-based voice service which enables us to make fast-prototyping of such dialogues.

6 ONTOLOGY SmartLab ELDER (OSLE)

OSLE is our proposal to model activities of daily living (ADL). OSLE explicitly represents both activities defined as a sequence of predefined steps and activities without a specific structure, just a series of actions that happens in a given time window. The key difference between both types of activities is that, for the first case, the system "knows" what is the objective and structure of the activity. For example, doing the laundry. This is a knowledge-based approach, and OSLE follows the work reported in (Hong et al., 2009) that was briefly introduced previously. In this way, OSLE consists of sensors, contexts that are the interpretation of sensor readings, and activities that are defined as a group of contexts and/or other activities. For the second type of activities, the task that is accomplished by the user is not modeled as part of the ontology; the activities are not described, but the sensor data and the order in which every sensor activation happens are registered, even though such activities are not necesarily part of a predefined process hard coded in the ontology. It is a data-driven approach such as is proposed in (Salguero and Espinilla, 2017).

6.1 Implementation of OSLE

OSLE is implemented as a specialization of the Ontology for Biomedical Investigations, OBI(Bandrowski et al., 2016). OBI is part of the OBO Foundry which include NBO, GO and PATO.

OSLE as an Extension of OBI. Distinguishes between the specification of a plan (*obi: plan specification*) and the *realization* of that plan (*obi: planned process*) once this plan is *concretized*. As a specialization of these concepts, OSLE defines *osle:ADL specification* whose realization is achieved by means of ADL processes. At this point, OSLE defines a plan specification as a sequence of *osle:ADL specification step*s. In order to declare each step, an *osle:context* is required which is attached to a given *osle:sensor*, and may have a position in the sequence of steps. Finally, an *osle:daily living action* is the register of a context that is triggered as a consequence of the activation of a sensor at a given time-stamp. Eventually, an *osle:daily living action* is attached to an *osle:ADL specification step*. An overview of OSLE is depicted in Figure 2.

6.1.1 Creating Activities in OSLE

In favour of greater clarity, we include the sequence of steps to be followed to both create a new daily living activity specification and register occurrences of such activity or just sequences of sensor readings (contexts) over the course of the day:

Defining a New Type of Activity.

1. Create a new activity (*osle:ADL specification*). For example, *clean dirty clothes using the washing machine*
2. Create contexts as needed (*osle:context*). For example, *washing machine door*
3. Declare sensors as needed (*osle:sensor*) and attach them to the corresponding context (*obi:part of* property). For example, sensor *D09* is attached to *washing machine door*.
4. Define the sequence of activity steps (*osle:ADL step specification*). Every step is the activation of a given context with a specific value related to an activity. Optionally, it is possible to include the expected order of the step. For example. step *a_cdc step 2* is the second step of activity *clean dirty clothes using the washing machine* and it defines that the value of this context must be *open* (the person opened the door of the washing machine).

Recording the Occurrence of an Activity.

1. Declare the activity performer if it is not previously defined (mp:human being instances)
2. Makes concrete the activity to be performed (*bfo:specifically dependent continuant obi:concretizes osle:ADL specification*)
3. Declare a new *osle:ADL process* as the realization of the concretion of an activity
4. Record every daily living action performed by a *mp:human being* into a sequence of actions over the course of a period of time.

7 VOICE-BASED GAMES IMPLEMENTED

In this section we briefly describe five quite naive games whose interface is based exclusively in voice. For this end we have used several smart speakers compatible with Amazon Alexa. More concisely, we tested three different models: Amazon, Echo, Amazon Echo Dot, and Amazon Echo Show. The main difference among them is that the last one is a device with display. We believe that in spite of none of the current games provide any interaction by means of the display, such devices could be more user-friendly since the elderly receives visual stimulus, besides the Alexa voice. Anyway, at this moment, this intuition should be validated in real homes.

Our interest in this games is twofold: firstly, we want to check whether it is possible to measure memory decline at home by means of this games and, secondly, we want to check the impact of the introduction of small talks over the course of the games: is the game more engaging? are memory assessments more precise? Anyway, at this moment, the games and the dialog models are implemented, but the protocol to measure the variables of interest is not yet tested. The minigames are depicted below, and all of them are adaptations of WAIS-III (Wechsler-Bellevue Intelligence Test) in regard with working memory (Kaufman and Lichtenberger, 1999). The instructions that are provided for each game are the following ones:

Game 1. I'm going to say some numbers. Listen carefully and when I'm done, repeat them immediately.

Game 2. I'm going to say some numbers. Listen carefully and when I'm done, repeat them immediately in reverse order.

Game 3. I'm going to tell you a series of numbers and letters. You will have to repeat first the numbers in ascending order, and then the letters in alphabetical order.

Game 4. I'm going to tell you a letter of the alphabet and I want you to tell me as quickly as you can

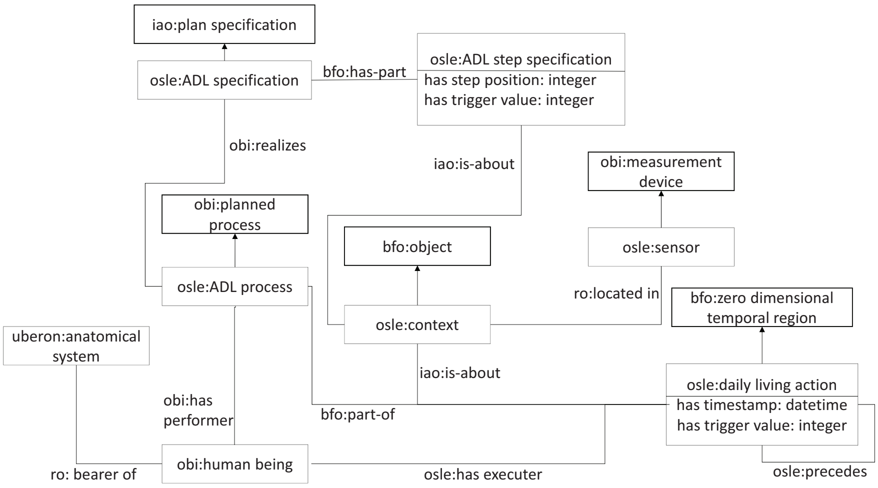

Figure 2: Ontology SmartLab Elderly class diagram.

all the words you can think of that start with that letter. You can't use proper names. You also can't say the same word with a different ending

Game 5. I want you to tell me as quickly as you can, words that belong to the category I'm about to say. For example, if I say cheater, you can say car, plane, boat,...

Regarding the small talks these are questions that are personalized for every user. These questions are formulated regarding two diffenrent sources of information:

- Questions about the user profile: What is the name of your younger granddaughter?, When is your son's birthday?...
- Questions about ADLs that performed in the last days. At this moment we have completed a only ADLs related with watching TV. Questions are about TV programs, TV grid, TV timetables and so on.

8 CONCLUSIONS AND FUTURE WORK

The final result of the proposed architecture would be the COgnitive Decline Alert kit (CODA kit) i.e. a group sensors, a central monitoring system and a smart speaker that can be installed in the elder's home. Our aim in this project is to develop a kit as simple and affordable as possible, but capable at the same time of capturing as much information as possible from the ADLs. Monitoring a senior at home requires the design and implementation of a smart environment, but We are convinced that the execution of many tasks cannot be evaluated solely with information obtained from traditional sensors. For this reason, a novelty of our proposal is the inclusion of conversational artificial intelligence agents (e.g., smart speakers) as a way to introduce some degree of interaction between the elder and the system over the course of execution of the tasks. The informal conversations led by these agents must be carefully designed with the aim of inferring useful information about the elder cognitive state. With this aim, we propose voice-based games to be played by means of the smart speaker. These games will use the information given by the user profile and the previous records of daily living activities to introduce questions about the user's everyday tasks, such as what TV programs they were watching last night or naive questions about their relatives. As a result of the inclusion of personalized information, it is expected to obtain both more engaging games and clues about memory functioning. Finally, it is necessary to validate the scalability of the architecture by monitoring a significant number of real homes. For this end, a minimum set of sensors and ADLs will be defined. At the moment of writing this paper, task "watch TV" is ready to be implemented in real homes by means of cheap sensors and a Raspberry Pi 3b+ plus a 4G communication module (Waveshare Hat SIM7600E) as base gateway. As a second stage will be the validation of the hypothesis that it is possible to identify cognitive decline, more concisely memory decline, by means of the integration of both OSLE and ANBO.

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