A Robotic Environment for Cognitive Assessment

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***Abstract*—Dementia is a broad category of brain diseases that is defined as a decline in memory and other cognitive abilities, severe enough to impede carrying out activities of daily living (ADLs). There is currently no cure, and accurate diagnosis and effective intervention is hampered by a lack of widely available, reliable, and effective forms of assessment. This paper presents an overview of ongoing research to develop a framework for continuous assessment of users' cognitive abilities based on observed performance of ADLs using non-intrusive sensing, robotic and AI technology. The ultimate goal is to pave the way for robotic and other assistive systems constantly in tune with the needs of their users, as they will be designed using the psychological insights of cognitive trajectories of normal and pathological ageing.**

***Index Terms*—Cognitive Assessment, Dementia, Cognitive Assistance, Ambient Assisted Living, Robotic**

I. Introduction

The goal of this work is to create an interactive robotic environment able to carry out continuous and fine-grained profiling of the users' cognitive status by observing and assisting them during specific Activities of Daily Living (ADLs).

Spotting cognitive deterioration early and finding correlations between cognitive and functional ability over time are key enablers for better informing diagnosis and personalised, continuous, and pro-active interventions [2], ultimately leading to more successful and sustainable treatment [1]. However, cognitive assessment today is usually performed by trained clinicians using standardised pen and paper clinical tests [3]. A specialist typically sees a patient every 6 months or annually [1], leaving large periods of time between assessments.

A number of technologies have already been proposed to assist people with cognitive impairments and reduce caregiver burden. For instance, both the COACH and the CogWatch [7] systems employ sensors and artificial intelligence (AI) techniques to observe and guide older adults suffering from dementia or from the effects of a stroke through an ADL using multi-modal feedback (such as audio/video prompts). User acceptance and thus effectiveness of these technologies relies on their ability to fit the different situations, varying preferences and changing needs of their users, However, continuous customisation remains a significant challenges in the field, which hinders widespread adoption [4].

Our approach is informed by psychologically valid assessment practices. We envisage that the system described here could be hosted in a clinic, initially, as a walk-in testing facility, where patients' cognitive abilities can be assessed for their ability to remember and correctly execute pre-defined ADLs in a specific context (a test kitchen). However, the same system should be flexible enough to be eventually fitted in individual homes, to promote the completion of personally meaningful activities in naturalistic contexts – ideally to inform caregiving strategies, and enable the continuous and fine-grained personalisation of other assistive technology.

II. Related Work

Ecological Momentary Assessment (EMA) is one example of a technology-enabled system designed to reduce dependency from clinicians time. With EMA, patients use phones or tablets to update the clinicians on a regular basis by completing a questionnaire remotely. Technologies like EMA mitigate biases in the clinical setting, and aid in tracking the changes of cognitive decline over time [1]. However, they require active and diligent patient participation. Crucially, like their pen and paper counterparts, their results may not correlate to ADL performance.

This issue of adherence to periodic assessments is a significant barrier to the wider adoption of this type of cognitive assessment. The MARIO project [5] has shown an increase in the adherence by using a physical robot to prompt questions to the users. Demonstrating promising results in terms of increased acceptance and potential benefits of robots employed as part of dementia care practice [5].

Virtual Reality (VR) systems have also been proposed, as they can be used to place the users in easy-to-control virtual scenarios. A particularly interesting example is the VR Kitchen assessment [6], upon which our approach is based. The assessment is itself informed by the Kitchen Task (KT) [8], in which people are assisted by an expert while performing pre-defined tasks in a test kitchen. KT involves evaluating the cognitive processes that affect task performance and recording the level of cognitive support necessary for successful completion of meaningful tasks. VR settings in general make it very easy to create repeatable conditions and record users' behaviours. However, they have been found to poorly reflect real world performance for the user group, especially because the sensory perceptions and motor skills exercised in VR are significantly different from those at play in a real environment [2].

III. System Architecture:

Figure 1 illustrates the modular architecture of our system, and highlights the research questions we are investigating for its realisation, namely:

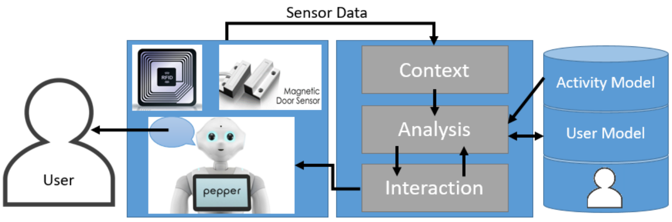

Fig. 1. Proposed architecture for automatic cognitive assessment

C - Context Awareness.. How to track primitive actions ("pick spoon", "move mug to worktop"...) and complex activities ("make tea", "make sandwich"...) by interpreting data captured from heterogeneous sensors in actual environments? Different settings may warrant different approaches. For instance, it would be possible for a walk-in-testing facility to sense human-object interactions by attaching wireless sensor devices to all relevant objects, and also install fixed cameras or employ a robot assistant using optical and depth cameras to track human actions. The same approach would be too costly, unpractical and/or undesirable for a home setup, where solutions should employ non-intrusive and simpler sensors, and also adopt machine learning techniques, such as Hidden-Markov Models (HMMs) to infer events from incomplete or incorrect observations.

A - Analysis. How to decide what (if any) assistance needs to be provided, and consequently infer the cognitive health of the user? The component will employ a user model - essentially a model of users' cognitive capabilities - and planning techniques to infer possible user's errors by analysing the differences between expected and observed steps, before deciding whether to assist the user. This may involve providing clues or issuing prompts, but also requesting some information from the user, especially in cases when the system does not have enough confidence on the exact problem this is experiencing, but also to leverage information that can be extracted from the verbalisation aspect. The component will then need to update the user model, by weighting the type of errors, but also the type of assistance that was necessary for the user to complete each task.

I - Interaction. How to interact more effectively with the users? Rather than pre-recorded audio/video feedback, we are developing a conversational agent to support multiple, bi-directional conversation flows, and plan to investigate the effectiveness of both a voice assistant and a social robotic embodiment. The latter will cover different roles: An observer and assistant, providing clues, prompts and reminders, but also to motivate and help the user to carry out and complete the test. We will investigate suitable affective agent architectures, to leverage expressive moods and emotions as an integral part of social interaction, and Reinforcement Learning (RL) techniques, such as Partially Observable Markov Decision Process (POMDP), to tailor interaction style to each individual.

IV. Methodology and Evaluation Strategy

Testbed - The system described in this paper is being developed at the Robotic Assisted Living Testbed (RALT) hosted at Heriot-Watt University, Edinburgh Centre for Robotics. The testbed is a 60m^2 fully sensorised smart home hosting a number of assistive technologies and domestic robots.

Co-Design – Workshops and focus-groups will be used to bring together stakeholders (patients, carers, healthcare professional) with the research team, to inform the design of successive prototypes. A series of user studies will be carried out to evaluate their technical effectiveness, feasibility, reliability, acceptability and usability.

Prototype – An initial prototype has been developed using the smart kitchen and the humanoid robot Pepper (from Softbank Robotics) in the testbed. The OpenHAB smart home middleware is used to collect information from sensors installed in the smart kitchen. These include occupancy and magnetic switch sensors to detect users' presence and opening/closing of drawers, and an energy monitor, to detect the use of kitchen appliances (coffee machine, kettle, toaster). The main application (a finite state machine where state transitions are triggered by binary sensor events) is executed on top of the Robotic Operating System (ROS). The robot assumes the role of the occupational therapist, instructing and assisting the user in carrying out the assessment

Next steps – Work is ongoing to record a dataset to enable further development of the context awareness and analysis components. The dataset will include sensor data from both the smart home and the robots' 3D and optical cameras, together with video footage of volunteers carrying out multiple assessment sessions. A first user study is also being planned, to gather information on users' experience and interaction requirements, including a body of training examples to develop the conversational agent.

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