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Kognit: Intelligent Cognitive Enhancement Technology by Cognitive Models and Mixed Reality for Dementia Patients

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Abstract

With advancements in technology, smartphones can already serve as memory aids. Electronic calendars are of great use in time-based memory tasks. In this project, we enter the mixed reality realm for helping dementia patients. Dementia is a general term for a decline in mental ability severe enough to interfere with daily life. Memory loss is an example. Here, mixed reality refers to the merging of real and virtual worlds to produce new episodic memory visualisations where physical and digital objects co-exist and interact in real-time. Cognitive models are approximations of a patient's mental abilities and limitations involving conscious mental activities (such as thinking, understanding, learning, and remembering). External representations of episodic memory help patients and caregivers coordinate their actions with one another. We advocate distributed cognition, which involves the coordination between individuals, artefacts and the environment, in four main implementations of artificial intelligence technology in the Kognit storyboard: (1) speech dialogue and episodic memory retrieval; (2) monitoring medication management and tracking an elder's behaviour (e.g., drinking water); (3) eye tracking and modelling cognitive abilities; and (4) serious game development towards active memory training. We discuss the storyboard, use cases and usage scenarios, and some implementation details of cognitive models and mixed reality hardware for the patient. The purpose of future studies is to determine the extent to which cognitive enhancement technology can be used to decrease caregiver burden.

Introduction

Dementia is a mental disorder that is associated with a progressive decline in mental functions and abilities. Memory, thinking, language, understanding, and judgement are affected. While many older adults will remain healthy and productive, overall this segment of the population is subject to cognitive impairment at higher rates than younger people. There are two important directions of research: the use of AI to elders with dementia and the design of advanced assistive technology. We combine those two to form a new research field: *intelligent cognitive enhancement technology*. Cognitive assistance can be characterised as therapeutic, aimed at correcting a specific pathology or defect. Some of our implementations fall into this category. Enhancement is an intervention that improves a subsystem in some way other than repairing something that is broken or dysfunctioning. This is of particular interest because new intelligent user interfaces in the form of vision-based wearable devices give patients, and humans in general, new effective cognitive abilities (most notably in the area of information retrieval). However, "In practice, the distinction between therapy and enhancement is often difficult to discern, and it could be argued that it lacks practical significance." (Bostrom and Sandberg 2009)

Intelligent cognitive assistance and enhancement technologies may enable older adults to live independently for longer periods of time. In 2014, the Alzheimer's Association documented that approximately 10-20% of the population over 65 years of age suffer from mild cognitive impairment (MCI); in 2013, Americans provided billion hours of unpaid care to people with Alzheimer's disease and other dementias.[1]

The envisioned benefit is to improve independent and self-determined living. As institutionalisation has an enormous financial cost, intelligent cognitive enhancement technologies may also help to reduce healthcare system costs, while at the same time provide relief and more time for caregivers and family members. In Kognit, we focus on new computer-based technologies on the horizon that offer help for patients directly by supporting an independent and self-determined living and, indirectly, in the caregiving of dementia patients, to provide relief and more time for family members. Cognitive models and mixed reality should result in new cognitive enhancement technology (figure 1).

Our research about cognitive enhancement technology is supported by a number of clinical research and related works about memories of daily life activities, a design case study for Alzheimer's disease (Cohene et al. 2007), reality orientation for geriatric patients (Taulbee, Lucille R and Folsom, James C 1966), using validation techniques with people living with dementia, computer based technology and caring for older adults (Spry Foundation 2003), and non-pharmaceutical treatment options for dementia (Douglas, James, and Ballard 2004). The focus is on cognitive assistants (Cogs) interfaces that include sensor interpretation, activity recognition, pro-active episodic memory, and

[1] See http://www.alz.org/downloads/facts_figures_2014.pdf

mixed reality for helping dementia patients. We are concerned with artificial intelligence based situation awareness with augmented cognition for the patient. Technically, cognitive assistance technology is supported by mobile computing technology and recent advances in head-worn intelligent user interfaces (Ha et al. 2014; Sonntag and Toyama 2013; Toyama et al. 2014a; Sonntag 2014).

Storyboard

As neurophysiological and physiological monitoring becomes more commonplace in the work environment, researchers and engineers will leverage these inputs for increased performance across the entire decision making system (NRC 2014). In the Kognit storyboard, we try to include neurophysiological and physiological monitoring for the dementia caregiving task. This task can be characterised as help with instrumental activities of daily living (IADLs), such as household chores, shopping, preparing meals, or providing transportation. Furthermore, it includes arranging for appointments, and answering the telephone or text messages. Helping the person take medications correctly via reminders is also included. Additional tasks that are not necessarily specific tasks can have a broad impact as well. The goals of our cognitive models and mixed reality integration are: (1) assurance/monitoring, (2) compensation and/or training, and (3) assessment (figure 2). In the storyboard, we focus on

- Addressing family issues related to caring for a relative with Alzheimer's disease, including communication with other family members about activity plans (e.g., active participation in social and work life). Here, the MCI patient can still actively participate and even help his daughter in her shop. Or,
- Decision-making and arrangements "at the breakfast table" for respite for the main caregiver. Here, reality orientation therapy (ROT) can have a great impact. ROT refers to: discuss current events, or refer to clocks and calendars; place signs and labels on doors and cupboards; ask questions about photos or other decorations.

The storyboard's main purpose is, first, to provide guidance while implementing augmented and mixed reality applications, and integrating a companion robot's multimodal dialogue system. Second, to provide ideas for overall management help to avoid introducing inefficiency into user activities (patient and caregiver). We focus on compensation and training (figure 2 middle).

The storyboard[2] has four parts. First, speech dialogue and episodic memory retrieval from a timeline (figure 3). We use NAO from Aldebaran in order to continuously monitor and provide cognitive assistance in patients' daily activities. NAO is equipped with additional DFKI sensors to perceive its environment; humans can communicate with the NAO in natural language as NAO has integrated speech recognition and synthesis functionality. The implementation of the dialogue systems is based on (Sonntag and Schulz 2014).

[2]http://kognit.dfki.de/media (first video)

Second, monitoring medication management and tracking an elder's behaviour (figure 4). Third, eye tracking and modelling cognitive abilities (human factors, interfaces that meet elder's needs and capabilities, figure 5). Fourth, serious game development towards active memory training (figure 6).

Implementation

Several core artificial intelligence fields contribute to the technical implementation, namely plan generation and execution monitoring, reasoning under uncertainty, machine learning, natural language processing, intelligent user interfaces, robotics, and machine vision. Multimedia information extraction tasks from multiple input modes have to be performed: pen gestures, head-worn and companion video cameras, GPS signals, Bluetooth beacons, inward and outward eye tracker cameras, speech input, potential bio-sensors, and assessment parameters gained from logging serious games episodes. Together with location information and the identification of objects the user interacts with, activity recognition and activity performance monitoring towards cognitive status assessment and monitoring can be performed (figure 7). For technical implementations, we collaborate with colleagues from medical cyber-physical systems having expertise in sensor-network architectures[3], privacy and security, and process workflows.[4] Our own technical expertise lies in the areas of cognitive modelling and mixed reality for cognitive assistants. The combined goal is assisting cognitively impaired individuals to function. In the rest of this section, we discuss our technical infrastructure and explain how the individual modules and networked applications modules contribute to the idea of the cognitive assistance storyboard.

Cognitive Model

While using an eye tracker and image analysis modules, we developed a system that recognises everyday objects, faces and text that the user looks at. This system can be effectively used to support an individual user's memory by logging certain types of everyday information that the user perceives and tries to organise in his or her memory (Toyama and Sonntag 2015). In this implementation, an IBM Cloudant[5] database is filled with recognised episodic memory items in real-time. These can be retrieved by natural language queries which are posed to a companion robot (NAO). As a result, we can retrieve information about the location of lost items and loose contacts in the sense of ROT (Taulbee, Lucille R and Folsom, James C 1966). Then the robot can answer questions such as "where are my pills?" or "who did I meet yesterday in the shop?" The scenario's technical implementation (also see video) builds on earlier approaches to memory aids where for example the scheduling of reminders or cues for patients are performed (Wilson et al. 2001). As we focus on personal episodes of the patient's memory, suitable cognitive model implementation must provide either an adaptive reminder systems (Rudary, Singh,

[3]http://www.dfki.de/MedicalCPS/

[4]http://dfki.de/smartfactories/

[5]https://cloudant.com/

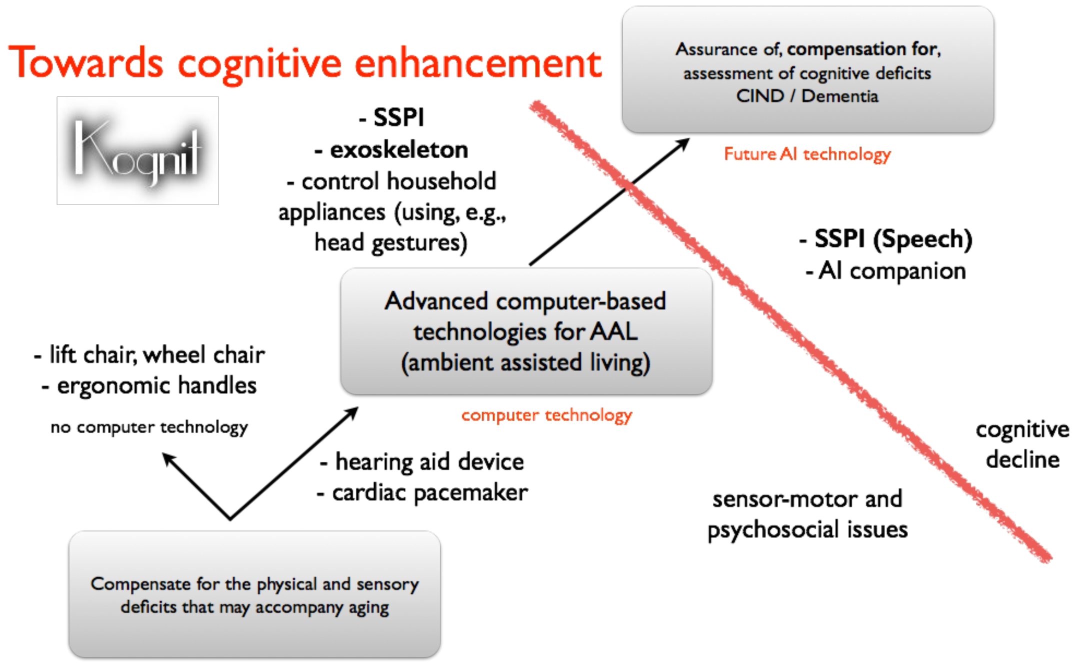

Figure 1: Towards cognitive enhancement

Figure 2: Goals of cognitive models and mixed reality integration: (1) assurance/monitoring, (2) compensation and/or training, and (3) assessment.

Figure 3: Speech dialogue and episodic memory retrieval

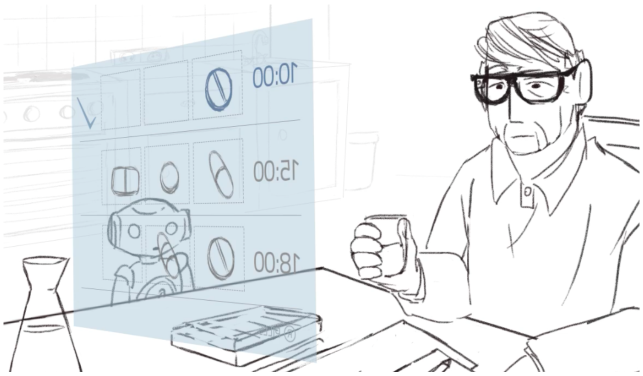

Figure 4: Monitoring medication management and tracking an elder's behaviour

Figure 5: Eye tracking and modelling cognitive abilities, smart pen interfaces

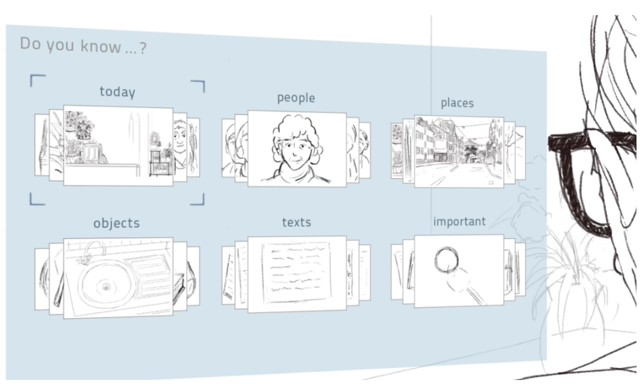

Figure 6: Serious game development

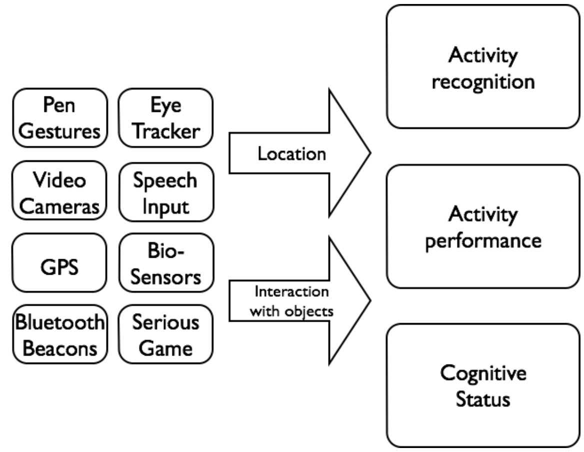

Figure 7: Implementation, based on (Pollack 2005)

and Pollack 2004) or proactive solutions based on similar situations and case-based reasoning. In addition, it has been recognised that, to be effective, cognitive orthotics should reason about what reminders should be issued and when (McCarthy and Pollack 2002). Recent advances in entropy and the predictability studies of life situations suggest that our daily lives follow strict statistical regularities, and our movement patterns are, to a large extent, predictable (Sinatra and Szell 2014) and can be modelled in a hierarchical fashion (Subramanya et al. 2006). It is to be mentioned that automatic cognitive models cannot have the quality of multimedia artefacts collected for a single person (Cohene et al. 2007), on the other hand, they can provide background knowledge for real-time tasks.

Our main Kognit scenario of cognitive model prototypes may include dialogical interaction, but specialises on vision-based communication though eye-gaze and visualisations to augment memory. A framework for improving context recognition and recall, where we try to demonstrate the ability to recall information with the example of a lost book page in presented in (Orlosky et al. 2014). We detect when the user reads the book again and intelligently present the last read position back to the user. Attention engagement and cognitive state analysis is another example (Toyama et al. 2015). The goal is to manage the relationship between virtual and real, creating a more cohesive and seamless experience for the user. We conduct user experiments including attention engagement and cognitive state analysis, such as reading detection and gaze position estimation in a wearable display towards the design of augmented reality text display applications. We also introduced a virtual reality environment that provides an immersive traffic simulation designed to observe behaviour and monitor relevant skills and abilities of pedestrians who may be at risk, such as elderly persons with cognitive impairments (Orlosky et al. 2015c).

Mixed Reality

Human factors and ergonomics require a fundamental understanding of user capabilities, needs, and preferences. Smart home technologies in the works are surveyed in

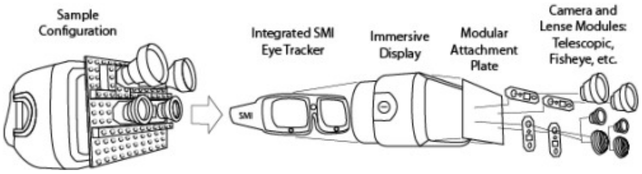

Figure 8: Mixed Reality Hardware Prototype

(Haigh and Yanco 2002). Our mixed reality prototypes of head-worn displays take ergonomics only to a certain extend into account. On the other hand, they allow for new, fully immersive user experiences. Figure 8 shows the general structure of our latest mixed reality hardware prototype, an example of a configuration that allows the user to merge a binocular telescopic video stream into a one-to-one field of view. It combines the SMI stereoscopic eye-tracker (later integrated directly into the display), the Oculus Rift DK2 head mounted display, a modular attachment plate used to interchange various camera-lens modules, and stereo camera pairs with telescopic, fisheye, and ultra-wide vision augmentation lenses (Orlosky et al. 2015b).

A natural interface for multi-focal plane head mounted displays using 3D gaze has also been developed (Toyama et al. 2014b): using a novel prototype that combines a monoscopic multi-focal plane HMD and eye tracker, we facilitate interaction with virtual elements such as text or buttons by measuring eye convergence on objects at different depths. Context-aware viewspace management is our third prototype (Orlosky et al. 2015a), a method that proactively manages movement of multiple elements such as e-mails, texts, and notifications to make sure they do not interfere with interpersonal interactions. To improve communication, i.e., sending digital messages (texting, emails), we propose the usage of a smartpen, where the patients write messages on normal paper with an invisible dot pattern to initiate handwriting and sketch recognition in real-time. The smartpen application is embedded into the human-NAO speech dialogue (Prange et al. 2015). Serious games developments with these mixed reality setups are currently developed. Related works suggest suitable serious games applications for patients with MCI (McCallum and Boletsis 2013).

Conclusion and Discussion

We have presented the Kognit project: intelligent cognitive enhancement technology by cognitive models and mixed reality for dementia patients. The storyboard we presented relies on several implementations of artificial intelligence technology, including episodic memory retrieval, tracking an elder's behaviour (e.g., drinking water), eye tracking, and modelling cognitive abilities. We discussed our storyboard and provided details of technical modules that implement some of the intended functions in research prototypes to be deployed into government and public sector applications in the upcoming years.

It is increasingly recognised that pharmacological treatments for dementia should be used as a second-line approach and that non-pharmacological options (e.g., cognitive assistants) should, in best practice, be pursued first (Douglas, James, and Ballard 2004). However, Douglas, James, and Ballard also remark that a person with dementia requires a moderate degree of intellectual insight in order to benefit from the non-pharmacological treatments. This describes the limits of our cognitive modelling and mixed reality approaches.

Cognitive assistants will have their place, but real utility requires integration with an entire ”smart environment” built by teams with experts in aging, cognition, mobility and home care. Considerations in selecting computer-based technology include, amongst others, the following two: (1) What agency, if any, has certified that the technology you are considering is effective and safe to use? (2) Does the technology protect the privacy of the older adult? These are grand challenges, but no contradiction to the idea of cognitive enhancement technology. The same challenges must be met when models are aimed at capturing features of both short term and longer-term variation.

Non-pharmacological treatments for dementia, however, are becoming increasingly well researched. Cognitive models and mixed reality for dementia patients should be explored more in the future. When caregivers report being stressed because of the impaired person's behavioural symptoms, it increases the chance that they will place the care recipient in a nursing home (source: National Alliance for Caregiving and AARP). Dementia caregiving is strongly linked to depression, anxiety, and burden in caregivers. This probably also holds for MCI (Seeher et al. 2012). Therefore, the Kognit project is to be understood as one of the possible future strategies for interventions (Acton and Kang 2001) to reduce the burden of caregiving for an adult with dementia. Using the NAO robot as a cognitive butler for ”daily routine” is just one of many other possible embodiments. We believe that ergonomic versions of mixed reality glasses for presenting additional help contents and guidance will have a role to play. They avoid introducing inefficiency into user activities and have the potential of usability or utility gains without compromising user and caregiver satisfaction. One pilot project a decade ago was to collect preliminary data on how electronic technology might be used to assist family members who are caring for a relative with dementia at home (Kart et al. 2002). Future directions should include new pilot studies with the subject of intelligent cognitive enhancement technology.

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