Towards Sensorimotor Navigation Support for People in the Early Stages of Alzheimer’s Disease

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Abstract—This article outlines the concepts of a navigation assistance system for people in the early stages of Alzheimer’s disease (AD). Disorientation and getting lost behavior are early signs of AD that often show before other symptoms of the disease. By focusing on the highly specific cognitive deficits associated with the disease, the proposed system aims at providing AD patients with the safety of a navigation system, while explicitly avoiding unnecessary assistance and creating an over-dependency on the technology. Using a gesture-driven user interface combining a simplified map and photographic imagery, the system will help to reinforce the link between visual scenes and the underlying spatial representation, which is impaired in AD patients. The system will guide the attention of a user to important salient and autobiographically important landmarks and train routes between them, which helps the user to build up and train a more resilient sensorimotor spatial representation.

I. INTRODUCTION

Dementia and other age-related cognitive disorders constitute a challenge not only to social and financial policymakers. With a worldwide prevalence estimate of 29.3 million patients and estimated societal costs of US$ 315.4 billion in 2005 [1], dementia in particular has become a growing problem as a result of the increasingly aging population. Current prognoses estimate that the number of people affected will double every 20 years [2]. Dementia is a complex illness with a wide range of symptoms and associated impairments that may occur in different combinations in a specific patient. Especially patients with Alzheimer’s disease (AD), the most prevalent subtype of dementia, have problems mastering their daily life autonomously, even in early stages of the affliction.

Not only people with dementia, but also their caregivers suffer from these deficits. Taking care of a person with dementia, formal or informal, is recognized as a burdensome task often leading to negative psychological, social and physical consequences [3]. Cognitive prosthetics and pervasive health-care technology promise to offer significant relief to affected persons and their caregivers by strengthening self-reliance and social inclusion while decreasing the need for intervention by carers. Technology focused on providing needed assistance thus have the potential to significantly improve the quality of life of the affected.

Two major problems affected people are encountering are impaired attention control and disorientation, both impeding spatial navigation. This article outlines the steps necessary to develop a training and assistance system to help people with these deficits build a more resilient representation of the environment. While AD is a rapidly progressing disease, the goal of this system is to help people in the early stages of the affliction to maintain their autonomy without suffering from getting-lost-behavior.

A. Alzheimer’s disease and spatial cognition

People with AD, especially in the early stages of the disease, often suffer from highly specific problems in single areas, even if a general decrease in cognitive performance is not yet observable. With respect to spatial cognition as one problematic area, the relationship between the various cognitive deficits amongst AD sufferers is currently investigated from many perspectives. While high-level functions such as abstract thinking, language and attention, which play a major role in navigation are affected, lower-level motor- and visuospatial functions [4] are also often impaired to a high degree. Recently, a strong connection between attention and navigation deficits has been discovered [5]. An interesting example of the specificity of the cognitive impairments of AD patients is the recent identification of an inability to link the perceptual recognition of a scene to the basically intact representation of locations and their connectivity [6].

B. Cognitive impairments and interaction design

These highly specific cognitive deficits have to be reflected in a navigation support system, both in the underlying spatial representation, as well as the user interface. Combinations of topographical maps and photographic images are one possibility to train the linking of visual scenes with the underlying cognitive representation of space. While the abstract and coarse qualities of the environment can be communicated with a simplified map, photographs of landmarks can help the user by providing the necessary details for successful navigation. The advantages of image-based pedestrian navigation have been shown in various studies, as stand-alone systems (e.g. [7]) or supplementing map-based systems [8]–[10]. By complementing a map-layer with contextual images and providing an intuitive, non-technological gesture metaphor to switch between the two granularities, the link between the perceived visual scene and the surroundings can be reinforced. The user can be effectively assisted with contextual instructions referencing familiar landmarks instead of being spoon-fed high-level spatial information as it would be the case with turn-by-turn instructions in common GPS navigation systems.
II. RELATED WORK

A. Navigation assistance for people with dementia

A recent approach in the field of assistive technology is to enforce the patient’s use of residual skills by restructuring tasks so that the remaining abilities can be used in place of those that are most impaired. This enables the user to address a wider range of activities autonomously [11]. The activation of residual skills places such systems on the fine line between prolonging the user’s independence and building up an over-dependency on the technology itself [12].

In recent years, many projects emerged that conducted research on assistive devices for people with dementia [13]. Cognitive prosthetics and technical cognitive rehabilitation systems were approached from many perspective by different scientific communities. Among the most holistic concurrent concepts for an assistance system is the European COGKNOW project. Employing a user-driven development strategy, the system aims at providing memory support, support to manage activities of daily life, support to maintain social contacts, and an enhanced feeling of safety. These areas have been identified based on a review of literature about subjective needs of dementia sufferers, and have later been verified during the heavily user-participatory development cycle [14].

While current research on navigation assistance systems for people with dementia displays the feasibility of wayfinding systems for this user group [15], many projects only take into account the basic symptoms of affected people by simplifying the provided instructions and reducing the induced cognitive load. However, current systems are restricted by the absence of a disease-related model of the individual user and the environment. While this may not be necessary for very basic wayfinding tasks, it is highly important for the design of a support system that takes into account the residual skills of its user.

B. Image-based navigation for pedestrians

First image-based navigation systems for people with early-stage dementia rely on simple photographs [7]. A study showed that photographs reduce the time healthy people as well as people with cognitive impairments1 require to complete navigation tasks. In an experiment focused on visual route presentations healthy adults were successfully guided along waypoints by a system using simple photographs [16].

Panoramic images improve upon image-based navigation by offering contextual information about the surroundings but require interaction techniques enabling the user to easily utilize the additional value. A feasible option is to use orientation sensors, e.g. a digital compass, to register the panorama with the physical world [17]. This allows the user to look around in the images by moving the device and turning his body. This idea is based on so called spatially-aware displays [18]. Spatially-aware displays are displays knowing both their physical position and orientation in space. They ‘[…] serve as a bridge or porthole between computer-synthesised information spaces and physical objects’.

Peephole displays extend the concept of spatially-aware displays with a positional mapping between the virtual information space and the physical world [19]. By augmenting the space around the user, peephole displays enable the use of spatial memory and reduce the required mental effort. Dynamic and static peepholes can be distinguished [22]. While static peepholes are classical panning and zooming interfaces whereas the user moves the dynamic information space behind it, the user interacts with dynamic peephole by moving it over a static information space.

In experiments with interaction prototypes using panoramic photographs for healthy people both peephole interfaces performed better than simple photographs while none of the both outperformed the other [21].

C. Multimodal navigation

Several studies have shown the supportive value of geo-tagged images for pedestrian navigation. Augmenting a map and auditory instructions with images [8] as well as a combination of maps and textual instructions with images [9] have been introduced. While in the first system the map view is replaced by the image view in special situations, for example at intersections, the second system requires the user to manually switch between both modes. Furthermore, photographs have been used in a guiding system for older people [10], [23]. Although in a first field experiment subjects stated they would like to use both images and audio messages, in a second experiment auditory hints to landmarks performed significantly worse than photographs.

Experiments regarding the acquisition of spatial knowledge with a step-by-step navigation system based on simple photographs with visual hints and auditory instructions showed that people acquire knowledge about landmarks but no survey knowledge of the environment [24]. A follow-up study confirmed these results even if the user was confronted with contextual information about the route itself.

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1Assuming that young children have similar spatial abilities as adults with cognitive impairments, the system has been evaluated with subjects aged 8 to 9. [7]
D. Remote viewing

The term remote viewing refers to the virtual exploration of areas in close proximity (e.g. a block of houses) that are not currently visible to the user [25]. A challenging aspect of remote viewing in particular as well as virtual exploration in general are mobile interaction concepts for navigation in 3d space with multiple degrees of freedom. While restricted and guided movements in the virtual world are a way to make navigation more intuitive, a central challenge is the balancing between freedom in movements and efficiency [26]. Interaction based on physical tilting and swiping gestures using a combination of mobile devices and various sensors are a way to interact with virtual environments [27]. The intuitive pitch gesture may be suitable as an interaction technique for virtual exploration as well as pedestrian navigation. It further can be combined with the peephole display metaphor.

III. DESIGN PROCESS OF THE SYSTEM

The major design goals of the assistive device are twofold. Firstly, the assistance offered to the user should be targeting only cognitive deficits commonly associated with AD. This means that unnecessary spoon-feeding of high-level information and instructions should be avoided if a specific task can be managed by the user without help. Secondly, the device should not impede but increase the acquisition of spatial knowledge whenever possible. Common navigation systems provide abstract, goal-directed instructions to the user. This reduces the need for the user to concentrate on the environment. The system should help the user to orient himself instead of increasing the dependency on the system itself.

A. Transfer experiments

Existing empirical results about spatial disorientation in people with AD have mostly been gathered in laboratory setups with very simple stimuli, e.g. a white wall circular area with laser pointer dots as stimuli in the adaption of the Morris Water Maze experiment in [28]. By nature, these results are hard to transfer to natural environments and are not directly useable for the design of a complex assistive device. Some high-level observations have been made in real-world navigation experiments with AD patients, however, these results often suffer from the uncontrollable nature of outdoor environments. To overcome the limitations of both approaches, virtual reality (VR) setups are a feasible tool [29]. Persons with dementia were not found to have problems operating a joystick or with simulator sickness [30].

Within the scope of a pilot study, we investigated the influence of visual complexity and distractions on orientation performance (fig. 3&4). The experiment consisted of a virtual reality (VR) setup navigated by subjects suffering from mild cognitive impairments and probable early AD, as well as healthy adults. Subjects were asked to memorize the position of a visible beacon within the boundaries of a circular lawn surrounded by a traffic roundabout and various uniform building structures. Three highly salient buildings (in terms of architecture, height, color and affordance of the building) were placed around the circular area to provide visual cues for orientation. After the subjects indicated they had memorized the position of the visible beacon, it was hidden and the position and direction of view of the subject in the VR was randomly chosen. Subjects were asked to move to the previously learned position of the now invisible beacon. The accuracy and performance of subjects was measured and an eye tracker was used to analyze visual attention during the trials.

Additionally, the effects of landmark-based spoken instructions to help subjects with orientation were evaluated. The preliminary results provide evidence that while added distractions in the environment decrease the subject’s orientation, repeated spoken reminders to use salient landmarks for orientation counters these effects and helps with successful and more accurate localization. These initial findings emphasize the importance of top-down attention control and raise the question if the observable disorientation may be partly caused by a lack of visuospatial attention control – which can be targeted by an assistive device taking over the task of selecting relevant stimuli.

B. User model and model of the environment

A representation of the spatial properties of the environment that is suitable for a navigation device usable for people
with cognitive impairments is one that fulfills a number of properties. The representation needs to reflect the highly specific problems in spatial cognition of the user group and the individual severity of these problems, so it does not provide users with unneeded spatial information. Furthermore, the representation has to enable the system to make up only for these deficits by translating a route into a description that is both understandable and memorizable by a user with a given set of cognitive deficits.

A map-like representation is unsuitable for this task, especially for people with AD. A sensorimotor representation like in [32] is much more likely to be intact in these users and can serve as a cognitively inspired representation reflecting the residual skills of the user. This representation describes a route as a set of environmental features (e.g. landmarks) connected by motor actions (fig. 5). The idea of a sensorimotor representation as a basis for a navigation system for people with AD has been further elaborated in [31].

By extending this basic representation with explicitly individual components, i.e. the autobiographic importance and the visiting frequency of places and routes, the training system will be able to adequately conceptualize individual as well as disease-related components of the user’s view of landmarks. The user model and the model of the environment form a hybrid representation describing the user’s perspective on the environment. To compute the position of needed orientation points, the system approximates possible representations of paths the user is likely to memorize and distinguish from similar paths.

C. User interaction design

One of the major problems of AD patients with respect to spatial cognition is a deficiency of linking visual scenes to the surrounding spatial configuration [6]. In order to stabilize and train this link, a support system should provide both the visual scene and spatial information in a hybrid display. A promising approach that fulfills this requirement is the intuitive combination of maps and scene imagery on mobile navigation devices.

Additionally to spoken instructions referencing landmarks, the user has the possibility to see both the spatial layout and a panoramic image of the next waypoint. This concept has been developed for the use case of pedestrian navigation as part of a study of various interaction prototypes [20]. In this concept, georeferenced photographic images are placed on a map in a 3 dimensional space. A physical gesture – the dynamic peephole – allows the user to rotate the current view, while another gesture – the pitch gesture – allows the user to see the map while holding the device horizontally and switch to the images by holding it in an upright position.

A prototype based on these concepts for the virtual exploration of images on mobile devices addresses the problem of spatial input for navigating 3-dimensional space [33] by matching the interpretation of the user’s touch gestures to the current orientation of the device. This approach has been extended to allow for both rotation and translation touch gestures in both orientations with single touch gestures and with the help of additional user interface elements with multi touch gestures.

These interaction concepts allow the user to virtually explore the planned route before, while or after the actual navigation. If the user feels lost and the map alone cannot provide the user with enough information, images of visually salient places not currently visible to the user may provide helpful cues for a successful reorientation.

Further adaptions to the targeted user group will be necessary in order to make the interaction concepts accessible, which will be discussed in chapter IV.

IV. PRELIMINARY PROTOTYPES AND EVALUATIONS

A. Route planning

A prototypical route planning system is currently being developed. Based on the routing engine of OpenTripPlanner\(^2\), a sensorimotor route planning algorithm is being implemented.

\(^2\)The OpenTripPlanner project, http://opentripplanner.com/, last access: 02/13/13
which optimizes routes not only for time and length, but takes into account the navigational complexity. Based on environmental features and landmarks, possible routes are represented as basic sensorimotor triplets consisting of two features and the connecting motor action. Features can be selected from a POI database or user-specified to allow for individually targeted routing. The density of landmarks along the route, and consequently the motor actions, is dependent on the severity of the cognitive impairments of the user.

B. Pedestrian navigation with maps and images for healthy people

We developed a prototypical pedestrian navigation system relying on maps and images for modern smartphones. The prototype shows a pre-rendered map including preselected points of interest (POIs) and cylindrical panoramic images as well as so called image disks (see fig. 7). Furthermore, the prototype renders paths to guide the user from one point to another. By using built-in sensors the prototype implements our interaction ideas as follows: on the one hand the prototype rotates the view automatically based on the device’s bearing in the manner of a restricted peephole display. On the other the user can switch between the map view and the image view by pitching the device.

![Fig. 7. Map view and image view of the prototype](image)

We are currently in the process of evaluating the system in a within-group field experiment with healthy people against traditional maps and simple photographs. The goal is to investigate, if people benefit from combinations of maps and images. Our hypothesis is that combinations of maps and images outperform navigation systems relying on only maps or photographs regarding usability and user experience. Furthermore, we want to investigate, if the pitch gesture is an easy and intuitive way of switching between the map view and the image view and appropriate for the scenario of pedestrian navigation.

C. Communicating navigation instructions to persons in the early stages of Alzheimer’s disease

In a pilot study as part of his diploma thesis, Sebastian Raible is currently evaluating different options for communicating routes using landmark images and arrows. He extended the existing prototypes with a possibility to add images of autobiographically important places and individually salient landmarks to the map view. This can be used by AD sufferers and caregivers alike to individualize the images displayed to the user.

We plan to further improve the system by allowing for remote viewing of the last and the currently targeted turning point without complex interactions. Simple buttons or physical gestures can replace the touchscreen gestures necessary in current prototypes.

D. Evaluation

While navigation systems are still commonly evaluated by performance measures such as wayfinding time or accuracy, in the particular use case of a navigation assistance device targeted at a cognitive training of spatial knowledge, these measures are not as meaningful. The acquisition of spatial knowledge is a much more informative measure and can be collected en-route using the psychogeographical data collection framework Cognitive Surveyor [34].

V. CONCLUSION

The proposed concept for the development of a navigation assistance system is based on the idea of assisting a user only with the highly specific, AD-related cognitive impairments instead of providing high-level spatial information as in current navigation systems. One example of these cognitive impairments of people with AD is the impeded linking of spatial representation and visual scenes. A user interface that combines a simplified map with landmark images accessible by intuitive physical gestures is a feasible way to communicate this relationship. Spoken instructions referencing landmarks generated by a route planning engine with an underlying sensorimotor spatial representation help to provide only relevant information without creating an over-dependency on the assistive device.

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