Digitization of Landmark Training for Topographical Disorientation: Opportunities of Smart Devices and Augmented Reality

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Abstract: Navigational abilities and wayfinding are important skills for participation in society. Landmark-based navigation is considered as an important basic wayfinding strategy. This strategy is used as the underlying concept for a rehabilitation training for people with topological disorientation. A digitization of this approach is proposed based on a smartphone application employing Augmented Realty concepts. This application allows to describe routes based on landmarks and a training of the defined routes. It is developed in an agile, interdisciplinary research process taking especially usability and privacy aspects into account.

1 INTRODUCTION AND BACKGROUND

Navigational ability is typically an individual-related, developed skill, affected by multiple factors like age, sex, level of education and even emotional states. Daily problems that might occur during wayfinding are often solved intuitively by continuing to walk until a familiar or characteristic place has been recognized. During the process of navigation spatial information is perceived from multiple types of sensors (e.g. visual, vestibular, proprioceptive). Further many cognitive functions contribute to wayfinding like visual perception, short- and long-term memory, mental images, attention, awareness and executive functions. Two perspectives are important during this process: The egocentric perspective describes if objects are perceived from a personal and local point of view, while the allocentric perspective considers relations between objects (e.g. the school is north of the library). These perspectives do not exclude each other but have complementary roles that interact with each other (Claessen, 2017).

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Further strategies for wayfinding, based on differing knowledge, are ranging from basic landmark based navigation to route knowledge, up to a survey-level navigation (Gupta et al., 2020).

Navigational problems are often caused by external factors. Moreover primarily people with cognitive impairments have difficulties in orientation and wayfinding due to problems with, or lack of spatial skills. Often less intuitive problem solving strategies are used when a person gets lost, e.g. no alternation of the current route, or not taking alternative routes into consideration at all (Delgrange et al., 2020). Since wayfinding relies on many different cognitive abilities, research has been very complex and not well-advanced (Sohlberg et al., 2007; Gyselinck et al., 2009). Difficulties can result from limited concentration abilities, changes in context (e.g. construction works) or discomfort of being lost resulting in a passive attitude. Additionally, map-like perspectives require a substantial mental transfer. Consequences are anxieties resulting in avoidance of moving independently and developing even more dependencies for being accompanied (Gupta et al., 2020).

Different types of impairments concerning wayfinding exist and were classified by (Claessen, 2017) to their underlying category. Landmark-based navigation impairment includes difficulties with processing landmarks, or environmental sceneries. Further location-based navigation impairments exist,

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(a) Bad landmark due to similarity and short lifespan.

(b) Good landmark due to cultural heritage and longevity.

Figure 1: Differences between good and bad landmarks.

where difficulties occur in processing landmark locations and the relations between them, while being able to visually identify these landmarks. Patients struggling with connecting locations to another show a path-based navigation impairment. Problems recalling paths in new, as well as in familiar environments are prominent. Furthermore patients rely only on spatial information resulting in distorted maps and inaccurate description of routes similar to patients with location-based navigation impairments. Lastly navigation impairment might occur due to other conditions e.g. spatial disorders, neglect, deficits in visuospatial perception, spatial disorientation, memory impairment, etc.

As already mentioned, research about people with cognitive impairments is limited as well as research regarding rehabilitation. Missing knowledge is resulting in a lack of effective rehabilitation training, that meets spatial demands (Sohlberg et al., 2007; Gyselinck et al., 2009). Since many cognitive functions are used during navigation, probably not all areas are affected by impairments and could be used and trained for compensation. Present approaches rely on investigating defined routes instead of focusing on conveying universal wayfinding strategies (Claessen et al., 2016).

Landmarks are an important basic concept for wayfinding and provide a great potential for navigation services (Amirian and Basiri, 2016). Some target groups, like people with intellectual disabilities (Gupta et al., 2020), have in addition problems in identifying reliable landmarks.

In the following sections we will concentrate on landmark based navigation as a central basis for wayfinding.

Good landmarks are long-living, preferably with a high visibility and have a distinctive appearance (see Figure 1(b)). On the other hand bad landmarks are characterized by high interchangeability and a short life span while being often very eye-catchy or not being distinguishable at all (see Figure 1(a)). The quality of environmental elements qualifying as good or bad landmarks has already been discussed in (Lorenz et al., 2021).

Classical approaches for landmark training rely on people using printed and laminated pages with step by step instructions. Usually these instructions were written in simple language containing pictures of buildings close by and arrows to indicate directions. Slight changes in appearance or differences in positions are already problematic due to positional changes, different lighting conditions or seasonal changes. If uncertainties arise, a supporting person will be called because of the anxiety of being lost triggered by e.g. a building painted in a different color or similar changes while other identifying features remained unchanged.

Nakamura and Ooie (Nakamura and Ooie, 2017) tested the improvement of supporting public transport via pictures of the surrounding area via smartphone, providing additional feedback to reduce nervousness.

Smartphones are already widely used and their influence is growing. In addition smartphones are also common among people with intellectual disabilities

(Morris et al., 2017) and offer a wide variety of sensors as well as functions, eliminating the need of specialized hardware, e.g. smartglasses as the Hololens. Therefore a huge potential exists to use these already existing devices to support wayfinding and create training applications.

In this context we are focusing on people with intellectual disabilities as they often suffer from executive dysfunctions, struggle with attentiveness and are easily overwhelmed. An approach for a landmark training using mobile devices (smartphones) is proposed. Augmented Reality (AR) will be used to reduce mental barriers. In this paper the prototype of such an application is described including the creation of routes and the following training mainly based on landmarks.

2 RELATED WORK

Nowadays smartphones are the foundation for several navigational applications, e.g. Google Maps, Apple Maps, OpenStreetMap, etc. Typical parts of such turn-by-turn navigational systems can be categorized as positioning, planning and communication. While communication mostly relies on map views and instructions including information concerning the distance to the next turn, adapted approaches using Augmented Reality (AR) already exist (Rehrl et al., 2012). People with disabilities are often not able to use these classical approaches and further problems with maps and the mental transfer between places, corners and the real world arise (Delgrange et al., 2020). Additionally first approaches based on landmarks as central elements are proposed by Gupta et. al. (Gupta et al., 2020). Navigational systems for people with disabilities exist as well, but are mainly focused on visual impairments resulting in audible feedback (Rivest et al., 2018; Davies et al., 2010). One approach features Global Navigation Satellite System (GNSS), e.g. GPS based on audible and visual feedback supporting people with intellectual disabilities going by bus, further showing current environmental features to reduce insecurities and emphasize on the correct bus stop (Davies et al., 2010). Augmented reality brings new potential to navigational systems employing high quality tracking due to the use of visual odometry (Yoon et al., 2019). Additionally to ease the complexity of mainly relying on visual odometry for localization, markers (Fusco and Coughlan, 2018; Elgendy et al., 2019) as well as beacons (Delnevo et al., 2018) can be used typically indoors, while GNSS can be employed outdoors.

Due to the nature of AR enriching the view with additional elements, navigational approaches using AR outperform classical approaches in comprehensibility for people with (intellectual) disabilities resulting in less assistance required (McMahon et al., 2015). With the help of AR barriers can be lowered, as well as new possibilities for interventions are provided, fostering autonomy especially for people with intellectual disabilities (McMahon et al., 2015; Smith et al., 2017; Bridges et al., 2020). Additionally AR has positive effects on learning outcomes (Bower et al., 2014) and encourages self-regulation as well as self-determination (Cihak et al., 2016; Smith et al., 2017). Nonetheless even with AR most approaches focus on visual impairment (Yoon et al., 2019; Ko and Kim, 2017; Al-Khalifa and Al-Razgan, 2016; Elgendy et al., 2019) . In addition, marker are used for indoor localization (Fusco and Coughlan, 2018; Elgendy et al., 2019), and also for specific instructions (Ko and Kim, 2017; Al-Khalifa and Al-Razgan, 2016). Furthermore it was shown, that AR as a technology provides great potential regarding wayfinding and orientation (Ko and Kim, 2017). User feedback is in general very positive (Yoon et al., 2019). Smart glasses as e.g. the Hololens offer a handsfree AR experience but are significantly more expensive, often limited by built in sensor technology (e.g. lack of GPS sensors) or have to be used in combination with smartphones. Nonetheless navigational approaches using smart glasses utilizing tactile, audible and visual assistance exist, but mainly focus on people with visual impairments as well (Zhao et al., 2020).

In general landmark based navigation outperforms turn-by-turn navigation if used by pedestrians. Approaches using local landmarks, that are only visible from the current location, are great for new environments, e.g. used by tourists (Amirian and Basiri, 2016) but often require object detection, therefore increasing complexity (Wakamiya et al., 2016). Global landmarks on the other hand are visible from far away and outperform classical navigation systems as well, while only showing a general direction, or being visible itself. The effects of showing a general direction were investigated by Wenig et. al. (Wenig et al., 2017) utilizing a smartwatch. Further global landmarks increase the capability of creating a mental map while being unmodified and significant.

Lastly the usability for people with disabilities is considered important. While they are highly motivated to interact with the digital world (Rocha et al., 2017), usability is essential and dependent on the quality of the application as well.

Since digitized trainings in the area of landmarks and wayfinding are promising but were mainly investigated for people with visual impairments, a training for people with intellectual disabilities provides a huge potential.

3 CONCEPT OF LANDMARK-TRAINING APPLICATION

Participants tend to rely on poor landmarks, uncertainty, or getting lost. In the following a concept and prototype for a landmark-based navigational training is proposed to support autonomous wayfinding. The application encompasses two central parts: The creation of routes and the following training of routes. These two stages are integrated in a mobile application. Before participants can train routes, these routes have to be defined and created in a previous setup-stage typically in collaboration with a supporting person. A central focus of the work presented here is the usability from the point of view of people with intellectual disabilities.

3.1 Route Elements

Generally a route consists of a *start* and a *goal* with multiple *landmarks* in between. While in principle start and end point could be interchangeable, some buildings might not be visible from afar or due to differences in perspectives. Since the application expects straight lines between points, additional *waypoints* are introduced, to ensure a better navigation for e.g. curved roads. Waypoints provide additional information making the distance between the user and the designated path more precise. Further it should be considered whether waypoints could also provide visible hints for users. Experiences showed that participants tend to feel lost when the next landmark is not directly visible. Therefore using additional landmarks on curved or even long roads should be considered, preferably one landmark should always be visible. All these points are intended to be visualized via AR markers.

Additionally *assistance points* are introduced to mark locations and give hints for safety reasons. Assistance points can be reinforced with a short message that will be displayed if the location is reached. We emphasize the conciseness of the information with a strict character limit to ensure conciseness and understandability. Furthermore the AR sight of the app will be disabled and only the message will be displayed until the area is left. Furthermore a confirmation button to close the dialog might be needed if no general direction is present afterwards. An overview of specific points and their necessary parameters is presented in Table 1.

3.2 Route Creation

During the setup-phase preferably a guiding person walks the route together with a participant. Some experience with the route might be gained already and fear could be slightly reduced. Moreover the guiding person should actively involve the participant in choosing relevant routes and define route elements in a collaborative manner.

At first a start point has to be defined consisting of the current location with an associated name. While walking the designated path, appropriate local landmarks can be selected and documented in the application by pressing the corresponding button (see Figure 2(a)). In addition to a name and positional information (via GNSS), a picture of the landmark is required. Adequate positions might be hard to reach, therefore not optimally placed points can be altered or refined via a map view (see Figure 2(b)).

Further along the route landmarks can be identified and defined via the mobile app by the guiding person in collaboration with the disabled person while passing by. Also the need of additional waypoints should be directly considered in conjunction with the participant. Another benefit of having to actually walk the route together with participants is the identification of potentially critical traffic situations. Assistance points could be placed there to give participants safety guidance. Lastly upon reaching the destination, a route is completed with a goal marking the end point of a route. Routes including names, positions, and additional data as pictures can be altered at any time. Also the order of points can be changed and points can be deleted or added to adapt to changes or to address manual fading-out strategies in the training process.

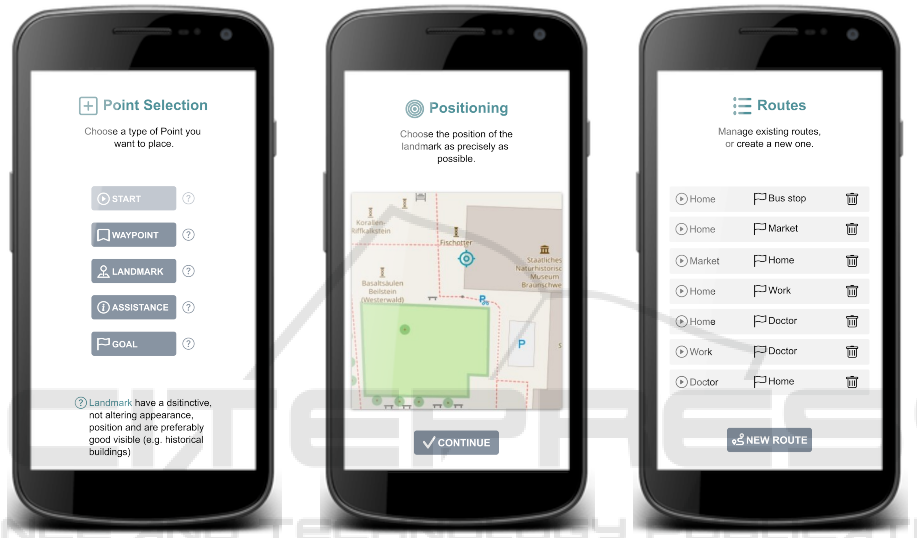
All steps of route creation can be prepared in advance (e.g. taking pictures and checking for sufficient landmarks) and realized completely in a workspace environment using a computer, however undergoing this experience together with participants might lead to important additional details resulting in a huge benefit during training if routes are created on location.

3.3 Route Training

While supporting and encouraging autonomy in general during navigation, we primarily focus on the improvement of wayfinding abilities of participants as well as training of the general concept of landmark-based navigation and the identification of valid and

Table 1: Different available points per route and their parameters.

Type of point	Icon	Description	Parameters
Start		Start point of a designated route	Name, Position
Goal		End point of a route	Name, Position
Landmark		Position of a good local landmark used for navigation	Name, Position, Photo
Waypoint		Technical, not visible point, that is used by the app for better route extrapolation (e.g. curved roads)	Position
Assistance		Critical point along the route that might need additional assistance and caution (e.g. crosswalks, crossroads, etc.)	Name, Position, short message



(a) Selection for different point types.

(b) Precise adjustment via a map is possible.

(c) Overview of currently saved routes.

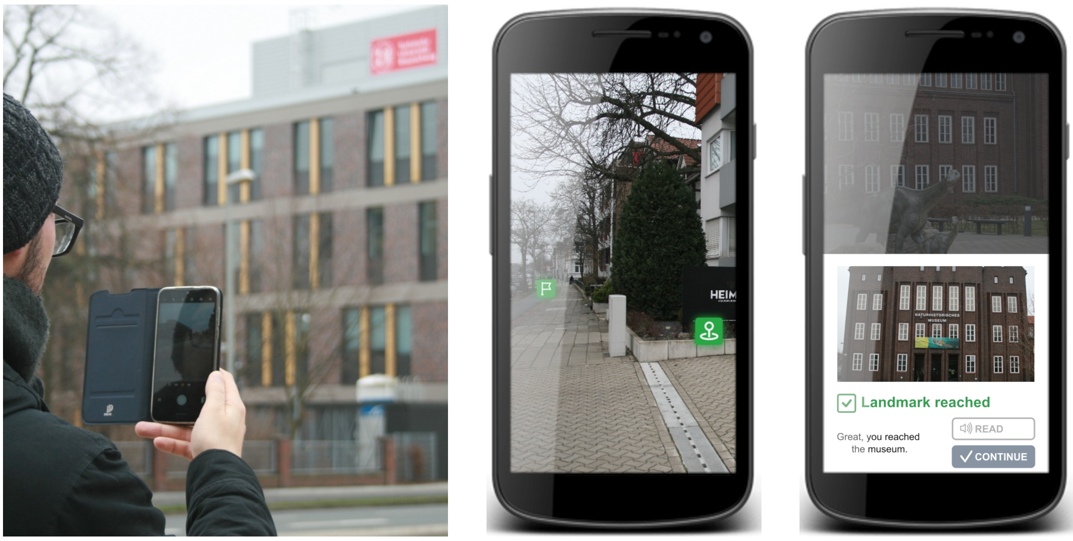
Figure 2: Different views for route creation landmark-training.

feasible landmarks. To reinforce immersion, landmarks are embedded into the environment via AR markers (see Figure 3(b)). This view contains 2 markers, one for the current landmark and another one for the end point resp. the next landmark. As soon as a landmark or the goal of the route is reached, audiovisual feedback will notify participants (see Figure 3(c)). The focus of participants should be directed to long-lasting features and away from eye-catching aspects like advertisement.

With the benefit of increased immersion and embedding AR elements into the environment, markers might be out of sight in the current viewport during a turn, if a directional change has to be made, or the smartphone is accidentally facing the wrong direction. To provide further transparency and reduce the need of searching the surrounding thoroughly if a marker is not visible in the current view, arrows on the side of the screen serve as rotational hint.

Although the existence of multiple markers at a time might be useful, the need of searching for the next one as well as the amount of information displayed should be reduced to a bare minimum at each time to avoid irritation. Nonetheless participants might leave the designated path unintentionally. If a certain distance away from the points of the route is exceeded, a notification will be shown and an arrow will be pointing back to the route itself, where the navigation to the next landmark continues. The distance to the route when sending notifications is crucial and has to be chosen carefully. Additional waypoints can support this information for more complex road design.

Besides leaving the designated route, participants might not be able to find the route again based on the guidancy of the application and continue the route without assistance. To address given circumstances it is useful to ask the participant if everything is all right



(a) Participant holding smartphone. (b) AR Marker embedded into environment showing Landmark and Goal direction. (c) Notification Landmark reached.

Figure 3: Views of the landmark-training application.

or help is needed, if no movement is detected. To this end, the timing is crucial since participants might be distracted and demotivated by frequent notifications nor do we want to distract focus from traffic lights or walk ways. If a participant feels stuck, there will be a possibility to contact a predefined guiding person. While a permanent visible help button might be easily accessible, we abandoned this idea due to potential over usage or accidental usage.

Due to the intrusiveness of AR, safety is one of our main priorities. Therefore the application should be less intrusive and only show a bare minimum of elements with minor transparency effects to not obstruct the vision of the user. Several approaches for safety measures in AR navigation exist e.g. showing a safety notification at the beginning of the route, or locking the whole application while the user is moving. We decided not to lock the app while participants move, since stopping every time to assure oneself that the next landmark is still in the right direction is to disrupting. Instead we integrated assistance points that display additional notification that users should pay attention to the environment right now to use e.g. crosswalks or wait at traffic lights.

4 DISCUSSION & CONCLUSION

The prototype described here is developed in an agile approach within an interdisciplinary research group. All elements in this first prototyping phase were thoroughly discussed and conceptualized, but still have to be evaluated with participants. Results of these evaluations and additional ideas from participants are used as a basis for further prototypes in the agile development.

Another central focus of the research process is the consideration of privacy for participants via a privacy by design approach. This is especially important for AR technologies. Advanced AR features as e.g. object detection are mainly realized by sending the corresponding data to a cloud service where machine learning based classification tasks are realized, instead of performing these operations on the smartphone itself. Since to this end raw data as photos or voice recordings are sent to a cloud service, this raises significant privacy concerns. For this reason an AR framework that does not employ cloud services is used. Also for the use of sensor data of smartphones in general, as e.g. capturing location data or voice data, privacy risks need to be analyzed and privacy respecting solutions need to be conceptualized.

People with topological disorientation are often not able to use classical navigational devices or maps. Augmented Reality provides a promising alternative by adding elements directly into the environment while additionally still being aware of the surroundings. While the application can be used as a compensational tool, the training approach has to be evaluated as well, including fading-out strategies.

The prototype presented here is the basis of further participatory research where especially usability and understandability are focused. Aspects for further improvements might include customizable icons for start and goal points for better understanding. Moreover based on the current location, routes with a start point nearby could be filtered beforehand, minimizing the amount of available routes in the route selection view significantly. Another important aspect is to foster the motivation of participants. Here the integration of gamification elements in the training process will be considered to be an important area of future work.

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