Assessing Real World Imagery in Virtual Environments for People with Cognitive Disabilities

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***Abstract*—People with cognitive disabilities are often socially excluded. We propose a system based on Virtual and Augmented Reality that has the potential to act as an educational and support tool in everyday tasks for people with cognitive disabilities. Our solution consists of two components: the first that enables users to train for several essential quotidian activities and the second that is meant to offer real time guidance feedback for immediate support. In order to illustrate the functionality of our proposed system, we chose to train and support navigation skills. Thus, we conducted a preliminary study on people with Down Syndrome (DS) based on a navigation task. Our experiment was aimed at evaluating the visual and spatial perception of people with DS when interacting with different elements of our system. We provide a preliminary evaluation that illustrates how people with DS perceive different landmarks and types of visual feedback, in static images and videos. Although we focused our study on people with DS, people with different cognitive disabilities could also benefit from the features of our solution. This analysis is mandatory in the design of a virtual intelligent system with several functionalities that aims at helping disabled people in developing basic knowledge in every day tasks.**

Keywords — cognitive disability; Augmented Reality; training in Virtual Reality; navigation

I. INTRODUCTION

People with cognitive disabilities exhibit several limitations, both in intellectual functioning and in adaptive behavior. For people with cognitive disabilities, it is usually hard to gain new skills because of their slower intellectual processes and their limited access to learning. Thus, building a system that could help them to acquire and maintain skills is extremely important for enhancing their autonomy and self-determination.

One of the most significant activities for daily living is the ability to know where you are and to navigate towards a certain destination [1]. Achieving competence in this skill plays an important role in human development, increasing the independence and level of inclusion. Being able to navigate involves route planning and decision-making, based on knowledge of landmarks and knowledge of routes. While most of the individuals can acquire this ability easily, things are different in the case of people with cognitive disabilities. The cognitive limitations of these people and the reservations of their families are obstacles to their independent travel. Moreover, urban settings and public transportations are often designed for this user group. Hence, when addressing their navigation difficulties, we need to consider two aspects: an educational component that could allow individuals with cognitive disabilities to train and learn, and an intelligent component that could provide assistance by enhancing the real environment with additional information. Development of navigation skills is the first case study supported by our proposed system, but the implementation also allows the further development of social, safety and literacy skills.

During the last decades, Augmented and Virtual Reality (AR and VR) have started to be used in many training and learning scenarios, as they allow gaining knowledge and skills in a safe and controlled environment. As VR provides control over the multisensory feedback and physical properties of the user's environment, it enables the analysis of the user's behavior in standardized situations. In training, VR has not only the advantage of providing a safe environment with standardized scenarios, but it also allows the guidance of user by providing additional information. All these features have the potential to create a promising addition to traditional learning and training.

So far, traditional therapies used to deal with motor and cognitive disabilities have had limited success. The state of the art proposes several reasons for this limitation: 1) the very nature of these disabilities (i.e. movement limitation, attention deficit, or cognitive impairments) that makes these people unable to repeat a functional activity, or 2) the lack of intervention context variability, that does not allow them to adapt to different training conditions. These reasons turned the scientific interest towards using VR systems, to create exercise environments in which auditory and visual feedbacks could be systematically manipulated, in order to allow for individualized training.

The remainder of the paper is structured as follows: in Section 2 we discuss the current state of the art in the use of

VR/AR as assistive tools. Then, in Section 3 we describe the general system architecture and the main modules responsible for data acquisition. Section 4 explains the actual status of our implementations. In Section 5, we report on a preliminary study, we conducted on a focus group of people with cognitive disabilities. Section 6 presents an overview of the results, while in Section 7 we discuss the findings and observations we made and we describe our future steps.

II. Related Work

During the past few years, there has been an increased interest regarding the use of Virtual Environments (VEs) for the creation of systems that act as assistive aids for people with cognitive disabilities, such as autism, Down Syndrome (DS) etc. They provide solutions by creating teaching/learning tools, in which people with cognitive disabilities can easily interact with real life objects, while trying to accomplish the task that was assigned to them or practicing skills that could have been risky in real life conditions.

Several aspects of this technology have been partially used in solutions meant to provide instructions for people with disabilities in a series of community skills: grocery shopping ([2], [3]), operation of a debit card machine or ATM machine [4], ordering at fast food restaurants [5], and purchasing [6], bus transportation skills [7]. However, navigation abilities have been just partially investigated. Real world navigation could be alternated with training in an environment where users can perform a large number of repetitions, while she/he is exposed to different types of feedback and she/he is evaluated for each trial. Moreover, it is well known that immersive environments enhance motivation, which is a key factor in training.

However, despite the research that has been carried out in this field, there are still many aspects that remain elusive about training in VR. Learning in a VE brings specific challenges related to the way training is performed and to the transfer of knowledge in the real world. In the present study, we use a carefully designed approach to balance science and practicality. Our goal is to explore specific changes happening in the user's behavior during and after interacting with different feedback types present in our system. This information could be further generalized and used in designing VEs that address the issue of training people with cognitive disabilities for everyday typical situations.

Because our exploratory study is oriented towards people with DS, we further present the related work investigating different navigation issues for this type of cognitive impairment. The majority of experiments conducted on people with DS have included small-scale spatial tasks only. However, there is considerable evidence that different parts of the brain are involved in processing spatial information at different scales [8]. Pennington et al. [9] conducted an experiment in which the participants were asked to find an invisible platform located in an arena surrounded by 4 walls. The results indicated a low level of performance, reflecting poor use of cognitive maps in the case of people with DS.

Wayfinding abilities in individuals with DS were investigated in VEs and natural settings with similar results. One study took place in a maze VE with 3 buildings and 17 landmarks [10]. Participants were showed two routes and afterwards they were asked to retrace one of them until they have learnt it. The results confirm the findings in [11]: participants with DS were able to learn the route, even though they needed more trials. In [12], the authors chose a natural setting and a group of participants with intellectual disabilities that were first guided along an unfamiliar route. Then, the users had to guide the experimenter, while pointing to the elements they found useful for remembering the route. Results showed that people with intellectual disabilities are not efficient in the landmark selection, selecting non-permanent and non-unique landmarks.

All these findings suggest the importance of building an intelligent system, with learning and assisting functionalities for traveling. This system should provide different types of feedback that have the potential to ease the learning process. The offered feedback should point to permanent and unique landmarks, Moreover, information about specific significant landmarks should be present also on a mobile device in order to offer immediate support. The learning phase should be divided in rehearsal and assessment sub-phases. Training in the VR environment should be alternated with real world training that will allow people with cognitive disabilities to transfer the knowledge they gained on the stationary system.

III. Virtual and Augmented Reality System for Training and Assistance

Our research is framed by the project POSEIDON (PersOnalized Smart Environments to increase Inclusion of people with DOwn's syNdrome) [13]. POSEIDON focuses on bringing some of the latest technological advances to increase inclusion in our society of a specific group of citizens - people with DS, and tries to answer questions posed in the Ambient Assistant Living (AAL) community before about inclusion and the role of AAL beyond the current focus on supporting independence for the elderly [14, 15].

Our solution aims at giving priority to the preferences and strengths of people with DS, in order to create technology that is more appealing and useful to them. People with DS, along with their relatives and other potential users, are given the opportunity to co-design this solution within POSEIDON. Our belief is that this will increase the chances of producing a solution, which is really useful for the intended beneficiaries. Our project gathers the direct participation of companies, research centers and Down Syndrome Associations primarily from Germany, Norway and the UK. However the consortium is willing to gather the opinion and attract participation of all EU countries and possibly from other parts of the world as well.

A. *A general view of the system*

The proposed VR system will be interconnected with a tablet/mobile phone and with an interaction device (mouse, Kinect, interactive table). Its aim is to provide support for planning tasks, or for context-based learning. Thus, a consistent version, in terms of the basic functionalities and interface features, has to be developed. The offered support consists of: a VR application for home use, meant to train users to navigate in a given environment, and several AR applications meant to enhance the experience in the real world by adding extra information at home or on the way to a destination. The system (see abstract representation in Figure 1) consists of:

- **A full version** (used on a stationary system). This includes high quality graphics, an immersive virtual environment and all advanced options. The application runs on a standard desktop system located at the house of the cognitively disabled person. This version will be able to communicate with different devices. Examples that promote alternative ways of interaction with the user, besides the typical mouse and keyboard, are the Kinect sensor and the interactive table (see Figure 2). The system is accessible to both primary and secondary users (caregivers) with different functionalities. Secondary users are able to upload audio-visual material in order to customize the system for the user's needs. Based on this configuration and customization, primary users are able to learn and rehearse different aspects of a certain route.

- **A light version** (used on portable platforms, such as the user's tablet/mobile phone). This includes only the basic functionalities that allow the user to undertake a task effectively, without being confused by the fact that he/she interacts with a portable device. Therefore, it is of extreme importance that the interface features of this version, as well as of the full version described above remain the same to avoid confusion. The caregivers should not be able to interfere with the light version, but they should have the possibility to know the physical position of the person with DS at any time, in case help is required.

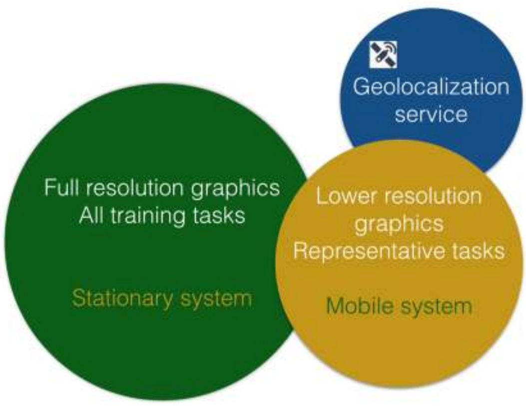

Figure 1. An abstract representation of the system

We should however emphasize here, that in order for such an intelligent virtual system to succeed in being an educational and assistive tool, there is a need for interaction and collaboration between the members of the technical and clinical communities.

We envision the modules of our system as described in Figure 3. Our solution is a multi-agent framework with common and specific functionalities for the mobile and stationary system.

The main operating modules can be grouped into three categories: data input, user interaction and system control. For the stationary system data input consists of data from Google Directions API, customized information as added by the caregiver in a Geographic Information database and user's preferences. The mobile system has additional components under this category: the satellite based geopositioning system, orientation sensors, and a module for processing images connected to a data interpretation module. The landmarks are detected through pattern-matching, using image processing libraries. The user and system interact via gesture recognition for input and various types of feedback for output.

B. Stationary system

Independence when traveling is a result of both route knowledge and real time assistance. Our proposed stationary system is responsible for the learning/training process. As we are unable to predict the user's behavior and severity of her/his condition, our VR system provides various functionalities and interaction options. Thus, each user (person with DS or caregiver) can customize it to his/her needs and preferences.

The stationary system represents the core of our solution. It is based on VR technology and displays a route identified by a start and an end point. The training environment provides real navigation information allowing users to explore routes as a collection of significant steps. The routes are built realistically using Google Street View API. Google Maps Street View provides panoramic 360-degree images. Google Maps Street View covers over 3000 cities in 51 countries. Each Google Street View panorama is an image or set of images that provides a full 360-degree view from a single location. These images are displayed as textures of 3D objects we built in Unity 3D (www.unity3d.com). All the implementation is done in C#.

The virtual trip can be enhanced with customized information, provided by caregivers. In the customization process, caregivers can use services like Google Places or Panoramio, or personal information (e.g., photos, videos, images). All the features concerning the routes, the surroundings, and the recommended guidance should be collected and stored. They should be displayed to the user during on-site guidance, but also in the preliminary preparation of a journey, using the VE on the stationary system. This customization is a preliminary planning phase

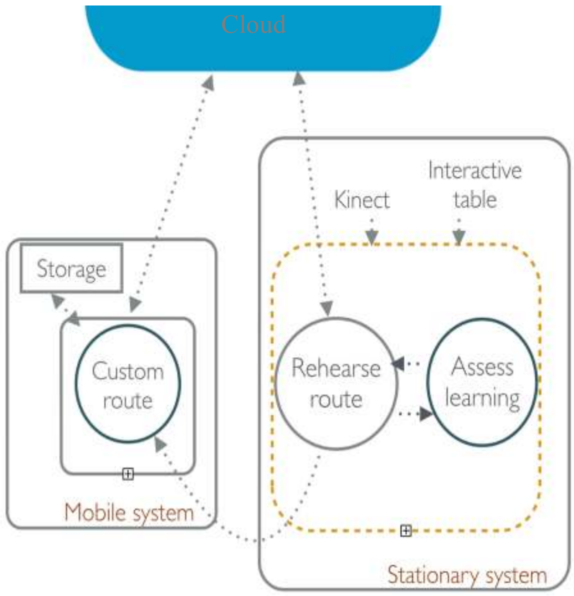

Figure 2. System architecture

meant to improve the cognitive representation of the environment for our proposed system. The need for this preliminary customization phase comes from the fact that the preparation and execution of the activity need to be interconnected.

The training process is triggered by calendar notifications issued at a customized time before each trip. Every route is uniquely identified by the pair [start point; destination]. Then, each step composing the route is characterized by specific configurable information. All this data is serialized and stored in the cloud in a topological data structure using JSON objects. When the primary user initiates the navigation on a chosen route, the information is downloaded and stored on the device. The system allows also caching upcoming images based on gesture recognition prediction.

We have chosen to represent the environment using Street View images because the goal of our system is to prepare people with cognitive disabilities for traveling independently in the real world. Thus, our hypothesis is that the environment in which they learn should be as realistic as possible, to avoid confusion. The additional landmark information and the written indications provided by the caregivers should be representative for the specific steps of each route.

Interaction with the system is also customizable. One of our proposed solutions for interaction is an interactive table that uses a mix of capacitive proximity sensors for detecting the free-air gestures, while an acoustic approach using microphones is used to detect events on the surface of the table. Users could select between using this device or the keyboard and mouse approach.

C. *Mobile system*

Although training in a Virtual or Augmented Reality has several advantages, the information used for learning should be available also during the navigation process. This could prevent people with cognitive disabilities to face dangerous situations in real life, when a specific knowledge has not been transferred from the VR environment. Thus, when aiming at enhancing the independence of traveling and self-determination of people with cognitive disabilities, it is important to provide an AR position-based system.

This system relies on external signals such as GPS outdoor and UWB indoor, to compute user position and orientation in LLAH coordinates (latitude, longitude, altitude, heading).

The user’s position is estimated using a similar technique to the one described in [16] by combining satellite data from a Global Navigation Satellite System (GNSS) and position

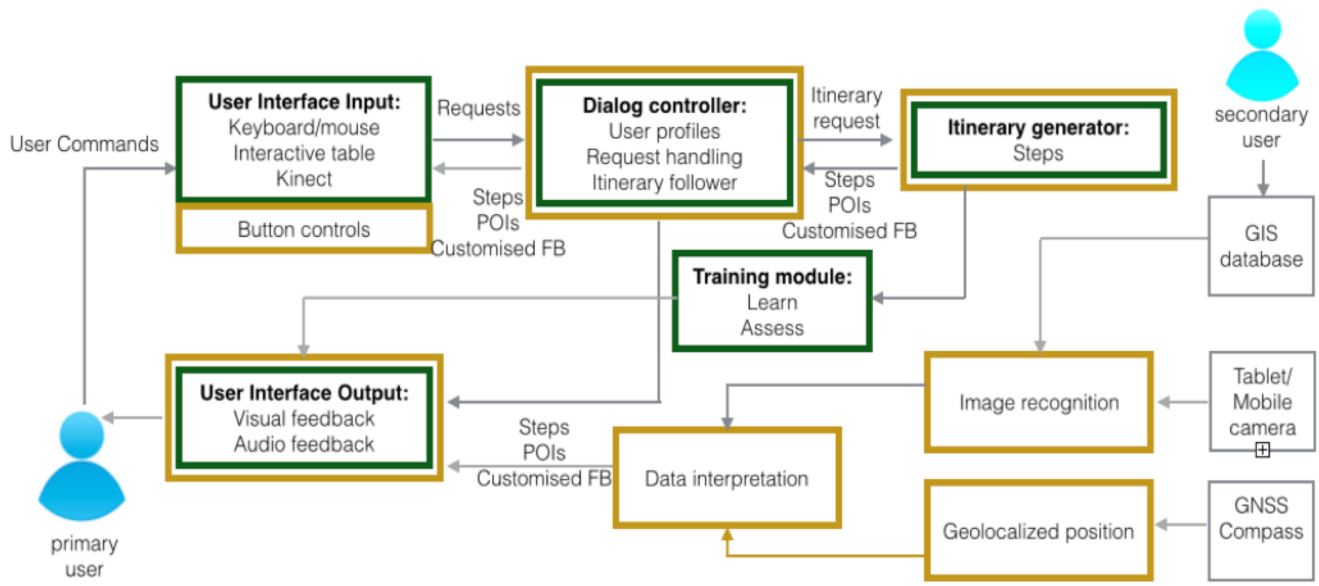

Figure 3. Main system modules

estimations based on visual reference points (here the landmarks added by the caregivers) with known geographic coordinates. The position of the user can be estimated with a high precision based on the database that contains embedded coordinates of these landmarks.

This database providing geographical information should be adapted for our target group and must be rendered during preparatory planning. As a result of inquiries and interviews conducted with both primary and secondary users, we identified several objects that need to be included in the database: **landmarks** - places that could help the user in making a decision or in confirming her/his position, **dangerous points** - places that require extra attention, **points of interest** - places that are potential destinations or that can help the user in gaining a better understanding of the environment.

We address the main objectives of the mobile system by combining input data from satellite-based geolocalization with custom data stored in the geographical information database. Guidance is provided using visual rendering and specific audio metaphors for each class of objects.

IV. Curent System Status

During this phase of implementation we focused on developing the main functionality of the stationary system. We considered this necessary for building a first prototype that allows us to run preliminary tests with the target users and to observe their behavior.

System interaction is done via keyboard and mouse. We designed the user interface so that it matches user's requirements and system functions. The interaction is easy and intuitive and allows for customization depending on the user's characteristics.

The system is synchronized with Google Calendar and gets notifications about approaching events when the users need to navigate to a new location. The rehearsal phase is triggered and the user can explore the route to that location. In the next phase, the knowledge about the route is assessed.

In the assessment phase, users are asked to recognize and identify different aspects characterizing a customized route (e.g. heading for each step, photo, written indications). Their score is increased or decreased depending on the correctness of their answers.

The next step is the development of the mobile system following the proposed architecture and the intensive testing of our solution with the target user group.

V. Preliminary Study

In order to understand how people with cognitive disabilities perceive a navigation environment enhanced with customized feedback types, we conducted an experiment with people with DS. The present experiment was designed to investigate what kind of elements do people with DS remember in the proposed navigation environment. Our hypothesis was that they would not be able to choose relevant landmarks that will allow them to identify places during day and night-time and under different weather conditions. In other words, our predictions were that they would not be able to recall elements of a specific route or the succession of steps where they need to make a decision. We propose that there is a need for customized feedback and our experiments discussed later support this point.

In order to identify 1) specific issues that could appear during the navigation and 2) the characteristics the landmarks should have in order to be recognized, we conducted a preliminary study on a focus group of 13 people with DS. One of the outcomes is related to the potential of the application in helping people with cognitive disabilities in learning and exploring routes to new places. We were interested to find out: 1) Are they able to identify places using our navigation system? 2) What kind of landmarks do they use for identification? 3) Is the identification affected by weather

Figure 4. The VE used for the preliminary study (6 steps/4 images of landmarks: 1 non-permanent, 1 permanent, 2 of different weather conditions/6 written indications)

conditions or the moment of the day (daytime/night-time)? 4) After navigating on a short given route, are they capable to remember the succession of the steps? 5) What type of feedback is more easily remembered?

A. *Motivation*

It is not trivial to identify what kinds of landmarks are more suitable and useful within an environment. Adults and children select different object as landmarks along a route. The selection of reliable landmarks improves during childhood [17]. It is important that people use different types of landmarks when navigating: close landmarks that are located near decision points indicating that a change of direction can take place, and distant landmarks that can be used for orientation.

Spatial knowledge can be enhanced when users are allowed to actively explore an environment. During self-initiated exploration, people develop efficient strategies for selecting appropriate landmarks.

People with cognitive disabilities lack the possibility to actively explore the environment. They are limited to a passive experience, being accompanied by adults all the time [18]. As a consequence, they do not have the opportunity to correct their errors. This reduced autonomy leads to a poor spatial knowledge.

Exploring our realistic VE could not only help them to navigate on a given route by learning the steps they need to follow, but it can also allow them to actively explore a given environment while focusing on specific landmarks. Thus, practicing on the stationary system could also give them access to an environment where everything is usually controlled by caregivers. In these conditions they could acquire and process environmental knowledge.

For this to succeed we need additional information about their perception of the environment and about the landmark selection process. We focused on static images but also videos showing 360 degrees images representing successions of steps that compose a route. We wanted to identify changes in their behavior when the information is presented in different ways.

B. *Participants*

Thirteen participants with DS participated in the study. The mean age of the group was 26.4 years (SD = 3.12). There were 5 men and 8 women in the group with different levels of cognitive disability. The majority was able to follow familiar routes. They were interested in independent traveling and they were using buses and trains on journeys longer than 30 minutes. The participants gave their consent to take part in the exploratory study after they were informed regarding the nature of the experiment. All participants were living in London.

C. *Materials*

The study was conducted in two phases. First we performed a contextual inquiry using Street View images. In the second phase we presented a VE composed of Street View images, and additional information: heading, photos of landmarks and text instructions. The VE consisted of a route composed of six steps and was projected on a 1.50m x 1.20m screen. The distance between the screen and the participants was between 2-3m.

D. *Procedure*

In the first phase (Landscape recognition), participants were asked to match and identify Street View images of different known and unknown places. In the second phase (Memory for landmarks and Route learning), they were presented a VE displaying not only navigation information, but also customized additions. The VE presented a route composed of 6 steps, situated in a part of London unfamiliar to the participants, described in Figure 4.

E. *Landscape recognision*

For the first task, we presented Street View images representing the same places in different weather (sun, snow) or moment of day (day/night) conditions. The participants needed to match these photos while giving reasons for their actions and intents. Afterwards, we asked them to identify places in the vicinity of their current location. As an observation, we want to specify that we carried out the study at a Down Syndrome Association where the subjects are participating every month to a meeting.

Figure 5. The proposed itinerary and the additional information

F. Memory for landmarks

The participants with DS were guided through the environment three times. The environment was allowing for 360 degrees images where the user could rotate to investigate different aspects of the journey. We asked the participants to take their time and pay attention to all the surroundings and to the additional information. After the exploration process, we asked them to identify from a set of photos, the landmarks characterizing the route. We have also investigated how they recall written indications. These investigations were important to determine what sort of information is more useful in this kind of environment.

G. Route learning

The last task was to arrange the steps in order, from the start point to destination, as they have experienced them during the VE exploration (see figure 5).

VI. RESULTS

The results we obtained during this session bring interesting insights related to how people with DS understand environments. They are summarized in Figure 6.

An important observation is that seven participants did not complete all the tests we designed for these experiments, because of various reasons: tiredness or the fact that they felt discouraged after the first set of questions. This emphasizes the importance of a reward based assessment phase.

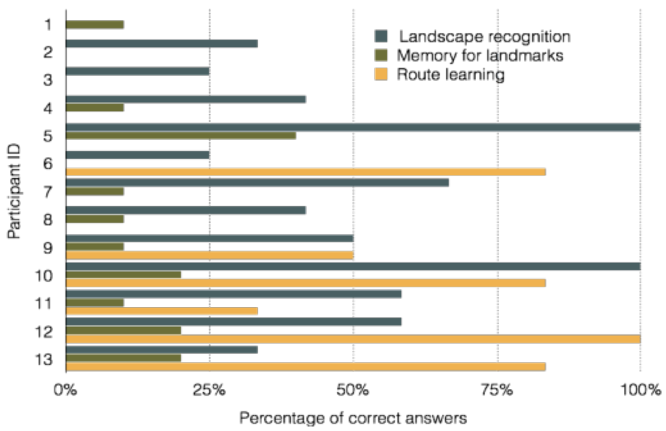

Figure 6. Results obtained by 13 young adults with DS in our preliminary study

A. Landscape recognition

The majority of subjects were not able to recognize photos of the same street during day and night or under different weather conditions. From the discussions we had with them, we observed that this happened because they chose for orientation non-permanent landmarks (buses, cars, clouds).

The two subjects with a maximum score had another approach. They were able to identify stationary, permanent landmarks (e.g., crossing, building with a specific design) and to combine them in order to identify the requested landscapes.

These findings supported the idea of building a 360 degree environment where the users can explore the surroundings. Providing just a static image of their correct orientation limits the information they can recall in the assessment phase or in the real world.

B. Memory for landmarks

The subjects scored less in landmarks and messages recognition than in landscape recognition, as depicted in Figure 6. Possible reasons could be related to the insufficient number of route repetition or to the size of this information. Once again, they remembered faster the photos of non-permanent and irrelevant landmarks like buses. However, the image of a church was also identified by many of the subjects. We consider as a possible reason the fact that the image was augmented by a descriptive message. Thus, combining several types of feedback could have a positive effect on their memory of the route.

C. Route learning

When asked to identify and arrange the steps chronologically, from start to destination, 4 users were able to identify the correct sequence with a high precision. These results are encouraging, showing that even if they do not select reliable landmarks, they are able to remember a route by combining all the offered elements.

One of the users recognized the neighborhood of the presented route. He is a player in a football club located in that area; hence he goes there every week. When asked what made him identify the place he specified several landmarks: a school, a pub, a shop located on the same street. We find this encouraging because it shows that people with DS are able to make connections between the real world and our presented environment.

VII. DISCUSSION AND FUTURE WORK

In this paper we presented the framework of a supportive system meant to teach and assist people with cognitive disabilities in everyday tasks. For illustration we have chosen a navigation task.

In order to identify how people with cognitive disabilities perceive VEs that emulate real environments based on Street View images, we carried out a preliminary exploratory study on a focus group of young adults with DS. This study was meant to provide us details about the usefulness of different types of feedback and about their interaction with the system.

Results have shown that people with DS have problems in identifying landscapes under different traffic/daytime/weather conditions. They chose unreliable and temporary landmarks. This finding suggests that the system should be enhanced with information that can help them choose more appropriate landmarks.

The users have improved their results when repeatedly faced with the challenge of learning a route. This outcome suggests the potential for a system, where people with cognitive disabilities are able to exercise how to reach a specific destination. Moreover, when adding the AR component, our solution could provide the cognitive disabled user with important, useful contextual information for spatial cognition including landmarks also when she/he is outside. The users will be able to explore the environment in a safe way, while getting indications about the landmarks they should look for.

The users who scored better in the route learning phase had good results also in the landscape recognition phase. All the users got low scores in the memory for landmarks phase. Possible reasons could be the size of the customized photos or the fact that they did not rehearse long enough. Our hypothesis is that this performance will be improved through the assessment mode that will follow the rehearsal mode.

The fact that some of them refused to answer all the questions should be also taken into account in building the next prototype, especially in the design of the assessment mode. Lack of feedback does not motivate them enough to continue while negative feedback discourages them. This finding emphasizes the importance of an assessment mode aimed at developing knowledge for people with cognitive disabilities.

This is still work in progress and we are currently extending the system capability and assessing its efficacy to translate the knowledge to the real world in identical or similar situations. For this, learning and assessment phase should be tested at home until the user gets promising results. These results would indicate the acquirement of route knowledge. Once this happens, our aim is to train people with DS to apply this knowledge in everyday life situations.

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REFERENCES

[1] B. a Taylor, C. E. Hughes, E. Richard, H. Hoch, and A. Rodriquez Coello, “Teaching teenagers with autism to seek assistance when lost.,” *J. Appl. Behav. Anal.*, vol. 37, no. 1, pp. 79–82, 2004.

[2] P. R. Alcantara, “Effects of Videotape Instructional Package on Purchasing Skills of Children with Autism,” vol. 61, no. 1, pp. 40–55, 1994.

[3] C. Linda, D. L. Gast, and J. Langone, “Computer-Based Video Instruction to Teach Persons with Moderate Intellectual Disabilities to Read Grocery Aisle Signs and Locate Items,” pp. 224–240.

[4] P. a. Alberto, D. F. Cihak, and R. I. Gama, “Use of static picture prompts versus video modeling during simulation instruction,” *Res. Dev. Disabil.*, vol. 26, pp. 327–339, 2005.

[5] L. C. Mechling, L. S. Pridgen, and B. a Cronin, “Computer-Based Video Instruction to Teach Students with Intellectual Disabilities to Verbally Respond to Questions and Make Purchases in Fast Food Restaurants,” *Educ. Train. Dev. Disabil.*, vol. 40, no. 1, pp. 47–59, 2005.

[6] K. Ayres and J. Langone, “Intervention and instruction with video for students with autism: A review of the literature,” *Educ. Train. Dev. Disabil.*, vol. 40, no. 2, pp. 183–196, 2005.

[7] L. Mechling and E. O’Brien, “Computer-based video instruction to teach students with intellectual disabilities to use public bus transportation,” *Educ. Train. Autism Dev. Disabil.*, vol. 45, no. June, pp. 230–241, 2010.

[8] M. Hegarty, D. R. Montello, A. E. Richardson, T. Ishikawa, and K. Lovelace, “Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning,” *Intelligence*, vol. 34, pp. 151–176, 2006.

[9] B. F. Pennington, J. Moon, J. Edgin, J. Stedron, and L. Nadel, “The neuropsychology of Down syndrome: evidence for hippocampal dysfunction.,” *Child Dev.*, vol. 74, no. 1, pp. 75–93, 2012.

[10] Y. Courbois, E. K. Farran, A. Lemahieu, M. Blades, H. Mengue-Topio, and P. Sockeel, “Wayfinding behaviour in Down syndrome: A study with virtual environments,” *Res. Dev. Disabil.*, vol. 34, no. 5, pp. 1825–1831, 2013.

[11] H. Mengue-Topio, Y. Courbois, E. K. Farran, and P. Sockeel, “Route learning and shortcut performance in adults with intellectual disability: A study with virtual environments,” *Research in Developmental Disabilities*, vol. 32. pp. 345–352, 2011.

[12] Y. Courbois, M. Blades, E. K. Farran, and P. Sockeel, “Do individuals with intellectual disability select appropriate objects as landmarks when learning a new route?,” *J. Intellect. Disabil. Res.*, vol. 57, no. january, pp. 80–89, 2013.

[13] J. C. Augusto, T. Grimstad, R. Wichert, E. Schulze, A. Braun, G. M. Rodevand, and V. Ridley, “Personalized Smart Environments to Increase Inclusion of People with Down’s Syndrome,” in Proceedings of 4th International Joint Conference on Ambient Intelligence, 2013, pp. 223–228.

[14] J. C. Augusto, M. Huch, A. Kameas, P. Maitland, Julie and McCullagh, J. Roberts, A. Sixsmith, and R. Wichert, Handbook on Ambient Assisted Living. IOS Press, 2012.

[15] J.C. Augusto, "AAL4DS(Can AAL Technology Help People with Down's Syndrome to Live Better Lives?)," in Proceedings of AALForum 2012, 2012

[16] B. F. G. Katz, S. Kammoun, G. Parseihian, O. Gutierrez, A. Brilhault, M. Auvray, P. Truillet, M. Denis, S. Thorpe, and C. Jouffrais, “NAVIG: Augmented reality guidance system for the visually impaired: Combining object localization, GNSS, and spatial audio,” *Virtual Real.*, vol. 16, pp. 253–269, 2012.

[17] E. H. Cornell, D. C. Hadley, T. M. Sterling, M. a Chan, and P. Boechler, “Adventure as a stimulus for cognitive development,” *J. Environ. Psychol.*, vol. 21, pp. 219–231, 2001.

[18] N. Foreman, “Spatial Cognition and Its Facilitation in Special Populations,” Applied Spatial Cognition: From Research to Cognitive Technology, pp. 129-178, 2006