Multisensory Virtual Environment for Supporting Blind Persons' Acquisition of Spatial Cognitive Mapping – a Case Study I

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RUNNING HEAD: MULTISENSORY VIRTUAL ENVIRONMENT

ABSTRACT

Mental mapping of spaces, and of the possible paths for navigating through these spaces, is essential for the development of efficient orientation and mobility skills. The work reported here is based on the assumption that the supply of appropriate spatial information through compensatory channels (conceptual and perceptual), may contribute to the blind people's spatial performance. A Multisensory virtual environment simulating real-life spaces was developed, and an evaluation case study aiming to unveil a blind person ability to navigate this environment has been conducted.

RATIONALE

The ability to navigate spaces independently, safely and efficiently is a combined product of motor, sensory and cognitive skills. Normal exercise of this ability has direct influence in the individuals' quality of life. Mental mapping of spaces, and of the possible paths for navigating these spaces, is essential for the development of efficient orientation and mobility skills. Most of the information required for this mental mapping is gathered through the visual channel (Lynch, 1960 [1]). Blind people, in consequence, lack this crucial information and face great difficulties (a) in generating efficient mental maps of spaces, and therefore (b) in navigating efficiently within these spaces. A result of this deficit in navigational capability is that many blind people become passive, depending on others for continuous aid (Foulke, 1971 [2]). More than 30% of the blind do not ambulate independently outdoors (clark-Carter Heyes & Howarth, 1986 [3]).

Research on blind people's mobility in known and unknown spaces (Dodds, Armstrong & Shingledecker, 1981 [4]; Golledge, Klatzky & Loomis, 1996 [5]; Ungar, Blades & Spencer, 1996 [6]) indicates that support for the acquisition of spatial mapping and orientation skills should be supplied at two main levels: perceptual and conceptual.

At the perceptual level, the deficiency in the visual channel should be compensated with information perceived via other senses. Touch and hearing become powerful information suppliers about known as well as unknown environments. In addition, haptic information appears to be essential for appropriate spatial performance. Haptics is defined in the Webster dictionary (1993 [7]), as "of, or relating to, the sense of touch". Fritz, Way & Barner (1996 [8]) define haptics: " tactile refers to the sense of touch, while the broader haptics encompasses touch as well as kinaesthetic information, or a sense of position, motion and force." Haptic information is commonly supplied by the cane, for low-resolution scanning of the immediate surroundings, by palms and fingers, for fine recognition of objects' form, textures, and location, and by the legs regarding surface information. The auditory channel supplies complementary information about events, the presence of other people (or machines or animals) in the environment, materials which objects are made of, or estimates of distances within a space (Hill, Rieser, Hill, Halpin & Halpin, 1993 [9]).

As for the conceptual level, the focus is on supporting the development of appropriate strategies for an efficient mapping of the space and the generation of navigation paths. Research indicates two main scanning strategies used by people: route and map strategies. Route strategies are based in linear (therefore sequential) recognition of spatial features. Map strategies, considered to be more efficient than the former, are holistic in nature, comprising multiple perspectives of the target space (Fletcher, 1980 [10]; Kitchin & Jacobson, 1997 [11]). Research shows that blind people use mainly route strategies while recognizing and navigating new spaces (Fletcher, 1980 [10]).

Advanced computer technology offers new possibilities for supporting visually impaired people's acquisition of orientation and mobility skills, by compensating the deficiencies of the impaired channel (Mioduser, Lahav, & Nachmias, 2000 [12]). Research on the implementation of haptic technologies within virtual navigation environments reports on its potential for supporting rehabilitation training with sighted people (Giess, Evers & Meinzer, 1998 [13]; Gorman, Lieser, Murray, Haluck & Krummel, 1998 [14]), as well as with blind people (Jansson, Fanger, Konig & Billberger, 1998 [15]; Colwell, Petrie & Kornbrot, 1998 [16]).

The work reported in this paper follows from the assumption that the supply of appropriate spatial information through compensatory sensorial channels, as an alternative to the (impaired) visual channel, may contribute to the mental mapping of spaces and consequently, to blind people's spatial performance. The main goals of this study are:

1. The development of a multisensory virtual environment enabling blind people to learn about real life spaces which they are required to navigate (e.g., school, work place, public buildings).
2. The systematic study of blind people's acquisition of spatial navigation skills by means of the virtual environment.

In the following sections, a brief description of the virtual learning environment will be presented, as well as preliminary results of a case study of a blind person's learning process with the environment.

THE ENVIRONMENT

As part of the research project reported here, we developed a multisensory virtual environment simulating real-life spaces. This virtual environment comprises two modes of operation: Developer/Teacher mode, and Learning mode.

Developer/Teacher mode

The core component of the developer mode is the virtual environment editor. This module includes three tools: (a) 3D environment builder; (b) Force feedback output editor; (c) Audio feedback editor.

<u>3D environment builder</u>. By using the 3D-environment editor the developer can define the physical characteristics of the space, e.g., size and form of the room, and type of objects (e.g., doors, windows, furniture pieces)

Force feedback output editor. By this editor, the developer is able to attach Force-Feedback effects (FFE) to all objects in the environment. Examples of FFE’s are vibrations produced by ground textures (e.g., stone, parquet, grass), force fields surrounding objects, or friction effects.

Audio feedback editor. This editor allows the attachment of sounds and auditory feedback to the objects, e.g.: “you re facing a window”¨ “turn right”, or realistic sounds (e.g., steps).

Figure 1 shows the environment-building-editor screen. The developer mode allows the researcher or teacher to build navigation environments of varied levels of complexity, according to instructional or research needs.

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Learning mode

The learning mode, or the environment within which the user works, includes two interfaces: User interface and Teacher interface.

The user interface consists of the virtual environment simulating real rooms and objects to be navigated by the users using the Force Feedback Joystick (FFJ). While navigating the environment the users interact with its components, e.g., look for the form, dimensions and relative location of objects, or identify the structural configuration of the room (e.g., location of walls, doors, windows). As part of this interactions the users get haptic feedback through the FFJ, including foot-level data equivalent to the information they get while walking real spaces. In addition the users get auditory feedback generated by a "guiding computer agent". This audio feedback is contextualized for the particular simulated environment., and is†intended to provide appropriate references whenever the users get lost in the virtual space. Figure 2 shows the user-interface screen.

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<u>The teacher interface</u> comprises several features serving teachers during and after the learning session. On-screen monitors present updated information on the user's navigation performance, e.g., position, or objects already reached. An additional feature allows the teacher to record the user's navigation path, and replay it aftermath to analyze and evaluate the user's performance. Figure 3 shows one user's monitor data, and her navigation paths within the room's space and around some objects..

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CASE STUDY: FORMATIVE EVALUATION OF THE FORCE FEEDBACK VIRTUAL ENVIRONMENT

A pilot formative evaluation of the virtual environment was conducted in the form of a case study of one blind person working with the Force-Feedback-based tool. The case study's goals were to collect information on three main aspects:

1. The user’s response to FFJ, and the type of FFE’s that were of high effect on his navigation performance.
2. The user's ability to identify structural features of the environment and objects located in it. Two issues were addressed:

- User's recognition of the room's space and objects.
- User’s difficulties in the identification of the objects’ shape and size.

3. The user's ability to navigate the virtual environment. Two issues were addressed:

    - Features in the environment that support immersion sensation.
    - User’s navigation paths within the environment.

Procedure

The subject in this case study, A.., is a forty nine years old congenital blind. He has been a computer user for more than eleven years. The case study consisted of two stages: Force Feedback (FF) evaluation stage, and navigation (in the virtual environment) stage.

In the Force-Feedback evaluation stage a series of probes were administered, at which different Force-Feedback-Effects were tested by the subject. Data on the subject’s reports was collected by direct observation of his performance, and by interview questions. This evaluation stage lasted about half an hour.

At the beginning of the second stage, the navigation, the subject received a short explanation about the features of the virtual environment to be explored and how to operate the FFJ. The series of tasks which were administered at this stage included: (a) free navigation; (b) directed navigation; (c) tasks focussing on emerging difficulties; and (d) a task aimed to evaluate auditory feedback (human feedback in this preliminary version), referring to orientation, turns, and proximity to objects. This stage lasted about forty-five minutes. At the end of this session an open interview was conducted.

Three data-collection instruments were used in this study. The first was a log mechanism built-in in the computer system which stored the subject’s movements within the environment. In addition the whole session was video recorded. The third data collection instrument was an open interview.

Results

Features related to the Force feedback joystick manipulation and effects

A. Learned to work freely with the force feedback joystick within a short period of time. During the first session A. made an cardinal recommendation: to define a (virtual) force field around objects and in front of the walls. By this force field the user can feel attraction or repulsion whenever he approaches an object or an obstacle, therefore getting considerable support for his navigational maneuvers.

The force feedback effects that were clearly perceived by the user and considered by him as highly efficient, were high resistance force, bumps vibrations and strong friction resistance.

Identification of environmental components

A. could easily identify when he bumped into an object, wall, or arrived to one of the room's corners. Supported by FFE's, and auditory feedback (both realistic sounds and verbal indications), A. was able to identify without particular difficulties large objects (more than 4 cm. side-length or diameter in the screen), but faced considerable difficulties in identifying the smaller ones. With small objects, and without the support of force-fields, the subject got lost in the virtual space.

Navigation

A. learned in a very short time how to walk in the virtual environment using the FFJ. A. responses in moving within the environment were rapid and secure, as shown in the recorded log of his navigation in Figure 4. Figure 4 shows the intricate paths generated by A. in one navigation task. The recorded trajectory unveils situations at which the user got trapped in corners, lost referential landmarks in the space, or in contrast, made persistent attempts to grasp an object from all angles.

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During his walking (the virtual environment) A. started to count footsteps, and by this he started to build his own referential framework regarding the location of the objects, the estimated distances among them, and structural features of the room (e.g. location of doors or windows).

DISCUSSION

This Case Study aimed to unveil features of FF-based virtual environments that may support blind people's navigation within these environments, and eventually contribute to their construction of spatial cognitive maps. Several features were found of particular importance for the design of effective virtual environments:

Objects' dimensions. Bellow a given threshold (about 3 cm. circular envelope), the user showed difficulties in performing accurate maneuvers with the FFJ around an object, and in effectively identifying these objects.

Force fields around objects. These attraction/rejection fields resulted of crucial importance to support the user's perception of the objects' (virtual) envelope.

Friction effects along the walls. The recognition of structural components (e.g., walls, columns) is crucial for the construction of an appropriate map of the whole space. The inclusion of appropriate FFE's for these components (e.g., friction, texture) is of great assistance and support for the recognition and mapping process.

Sensors in objects' corners. These additional aids activate auditory feedback whenever the user enters its effect field, therefore supplying important information with regards to the objects form (e.g., a cube, a cylinder), or aspects of its envelope (e.g., a corner, a turn).

Navigation speed. In the case study we have observed that adjustment of speed (faster, slower) was done in relation to context (e.g., walking in open space as opposed to exploring an object's contour), or to the degree of confidence of the user with the FFJ. It is recommended that the interface should allow the adaptation of the navigation speed to the needs and degree of expertise of the user.

Manipulation/feedback correspondence. Haptic and auditory feedback are the main resources available to the user for navigating the virtual space. Sensible time lags between an action (e.g., a step forward) and the corresponding feedback were of negative effect upon the user's ability to maintain a consistent (mental) image of the space. Appropriate timing and fine-resolution correspondence is essential for the recognition and efficient navigation of the environment.

Final remark

The prototype of the FF-based virtual environment and its preliminary evaluation reported in this paper, are part of an ongoing research project aimed at studying the contribution of the work within multisensory virtual environments to blind people's cognitive maping of spaces and acquisition of orientation skills. Following the pilot evaluation, an empirical study involving 30 subjects who are asked to navigate virtual as well as (corresponding) real spaces is currently being conducted. Our long term goal is to consolidate the body of knowledge required for the development and implementation of multisensory tools, which may assist blind people in cognitively mapping spaces (e.g., workplaces, learning spaces, public buildings) which they are required to navigate.

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Figure caption

Figure 1. 3D environment builder

Figure 2. The user interface

Figure 3. The teacher interface

Figure 4. Subject's navigation in the environment

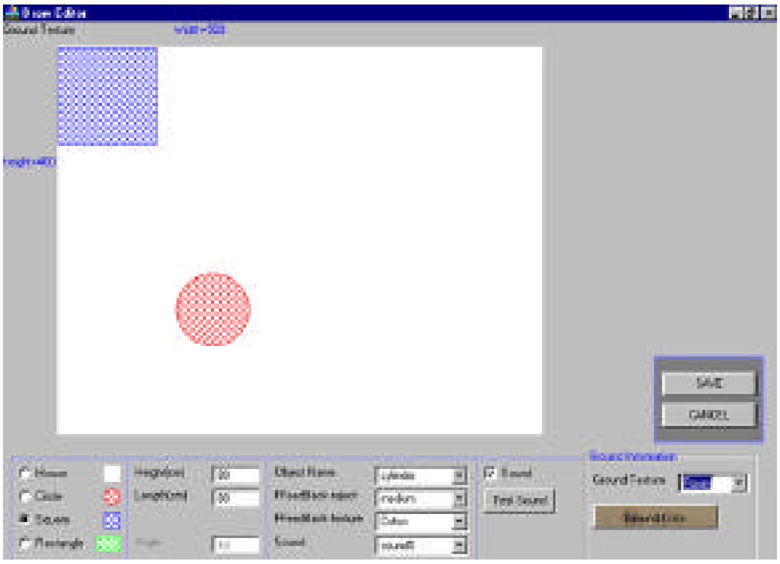

Figure 1. ***3D environment builder***

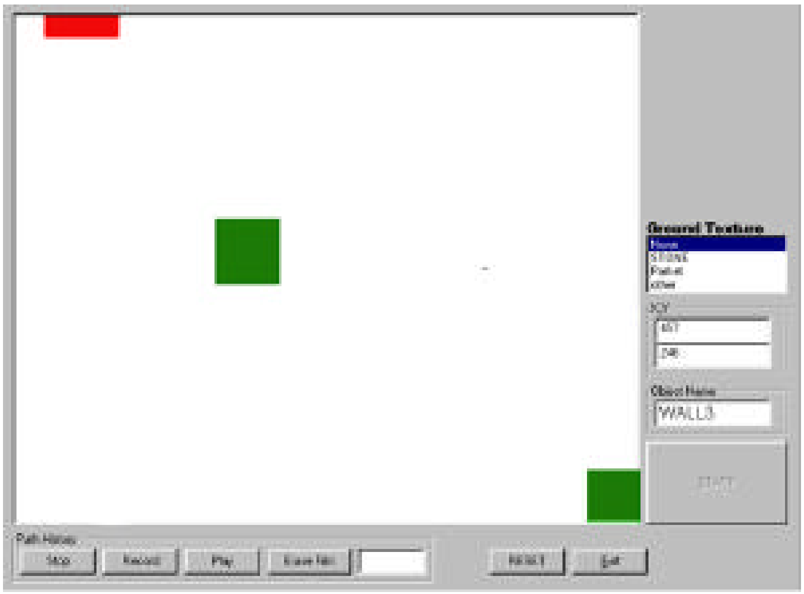

Figure 2. ***The user interface***

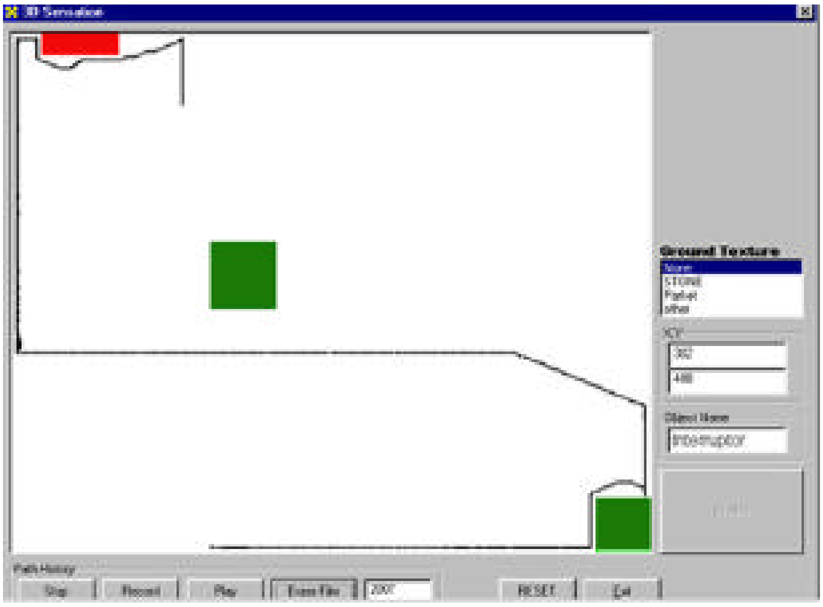

Figure 3. ***The teacher interface***

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