EXPERIMENTS IN VIRTUAL NAVIGATION AS A STEP IN THE DEVELOPMENT OF A NAVIGATION TOOL FOR BLIND PEOPLE

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Abstract: This paper introduces a formalized definition of an external space representation and proposes a virtual navigation paradigm as a mean for space integration from tactile snapshots. Rules for the design of indoor experimental environments to be used in virtual navigation are presented; they take into account posture modifications of the subject and the cognitive load of the elementary tasks inherent to physical navigation.

Keywords: Blindness, tactile representation of space, virtual navigation

1. Introduction

In our society environmental visual cues are becoming increasingly important and frequently more important than aural cues. For visually impaired and blind people, the lack of access to visual cues provides a barier to carrying out everyday activities.

As far as mobility is concerned, the most commonly used assistive devices are the guide dog and long (white) cane. Guide dogs allow blind people to safely navigate space, but often do not provide any information about the presence of an (overhanging) obstacle either close to the person or at a distance. In addition, training guide dogs is quite expensive. The considerably cheaper long cane enables trained users to be aware of the presence of an obstacle located on the walking surface and in the user's near space (up to 1.2 m for a long cane). However, the tactile feedback is very poor (at one point only): it requires the user to scan "a walking corridor" in near space and is inconsistent with a real dynamic environment. Like the guide dog, the cane does not allow the user to develop a mental global geometry of near space, which is a fundamental component of safe navigation and orientation (Blondot 2007).

When navigating, a sighted person uses exteroceptive and proprioceptive data to creates an internal representation of external space called a "cognitive map" in his/her brain (Tolman, 1948 ; O'Keefe and Nadel, 1978). This map generally encompasses all data pertinent to human-space interactions and, in the case of mobility, includes data about the position of obstacles relative to the person and the global layout of the user near space. This map is continuously updated during walking. The cognitive map is also the key element in decision processes in the brain to carry out motor activities and their effective execution.

However, in the case of blind people, this cognitive map is only partially correct as visual data are not integrated into it. Therefore, walking/navigation assistance is required to fill in the gap between the correct cognitive map developed by sighted people and the partial cognitive map built by blind or visually impaired people. Precisely filling in this gap is a complex task, as our vision registers more data then we require to carry out the particular immediate task. In the case of static space integration, technological assistance should provide support for understanding the near space topology and even its geometry. In addition it is often useful to decompose the mobility task into space perception (cognitive) elementary subtasks and determine which environmental (exteroceptive) cues are necessary to support the mobility of blind people. This enables us to propose technological assistance able to provide these cues to visually impaired people during walking and navigation.

Subsequent sections of this paper will try to implement this approach for the case of a static space integration task. Section 2 proposes a definition of the space integration task and basic space component parameters which are pertinent for mobility. Section 3 presents a brief overview of the tactile device which was used in the initial experiments in space integration, while Section 4 considers a new experimental environment (an apartment) for the virtual navigation and space integration tasks. Section 5 presents conclusions and suggestions for future work.

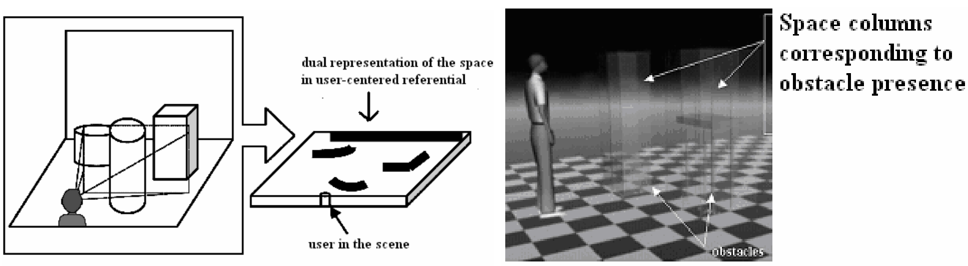
2. The Space Integration Concept.

At least two factors are important for human mobility: space concept (Section 2.1.) and space parameters useful for space perception (Section 2.2.)

2.1. On the space concept.

The term “space integration” indicates the possibility of reconstructing a structure of the whole, (global) space from its partial (local) views. The space structure is closely related to its observation level. The most popular space observation levels are: (1) space topology level where only the spatial relations between all the objects encompassed in the space are important, (2) space geometry, where a metric associated with the space is used to quantify the spatial relation(s) of all the objects, (3) cognitive space, where relation(s) between objects which are considered to be important for the execution of a given task have a meaning and could be quantified using an appropriate metric.

Therefore, in the case of cognitive space, or a task-filtered model of the space external to the person (Figure 1a), the external presentation sets up a virtual partition of the space into two subspaces at any instance ***t***, (Figure 1c): (1) a subspace which is composed of the objects considered pertinent for the execution of the given task and (2) a subspace which contains all other objects, which are defined as obstacles. This presentation of space can vary with the time ***t***, and with the observation point of the 3D scene.



a) b) c)

Figure 1. The observed space (a) dual cognitive presentation (c), and its binary tactile encoding (b)

Consequently, a possible “operational” (useful for implementation in a navigation assistant) definition of the external presentation of the space is as follows:

Definition 1.

An external presentation of a static space is defined as a set of four parameters:

{space virtual partition, reference frame, metric(s), time}.

A reference frame is a means of reporting pertinent relationship(s). (It is often called distance in the case of physical spaces.) A metric allows these relationships (such as, distance between observer and obstacles, or distance between obstacles, for example) to be quantified. If the reference frame is attached to the observer (its origin corresponds to the body reference frame), the reference frame is said to be body or ego centered. Otherwise, it is a system of external referencing (or allo centered).

For the effective (physical) displacement, only the "limits" of the virtual partition of space defined by the closest borders of the nearest obstacles[1] seen by the subject (Bruce, 1993, Figure 1b), are pertinent. Their gravitationa (orthogonal) projection defines a cognitive walking map (CWM).

Therefore, the space integration means a combination (fusion) of two synergetic "parameters" of the same task: the space organization perceived by the person and the tool (technological assistant) which provides a mean to access to a presentation of space.

A tool can support simultaneously several levels of observation of space.

A local view of space refers to a perception of the structure of space from a given observation point (in the case of a sighted person, it is frequently linked to the direction they are looking in). Local views can be supported by different types of displays, including the following: retina, photos, images, a surface which stimulates touch, sound data obtained during particular time interval.

2.2 Basic component parameters of space useful for mobility

A schematic representation of an indoor scene, such as an empty apartment, is mainly delineated by one, or sometime two, basic geometric components, the line segment and the semi-circle.

Each line segment has three "space" attributes : (1) position P relative to the person (R= right, L= left, F= in-front); (2) orientation O relative to the person (F_P = fronto-parallel, S = sagittal, D = diagonal (45°), A_D for cross diagonal (135°)); (3) distance D from the person (F = far, C = close). Each segment line has one "physical" attribute : its size S (small (S) or big (B)). Therefore, each segment is symbolically encoded by a set of four ordered parameters :< S, D, O, P>. For example, SCF_PL stands for small close fronto parallel segment located to the left of the subject.

In the space integration task for an apartment, only line segments will be considered.

Line segments and semi-circles are easily represented on a tactile device (Velazquez 2006a, Khodja 2004, cf. Section 3) with high fidelity (Figure 1b).

3. TactiPad, a Touch Stimulation Bistable Device

A touch stimulation device with a reference frame attached to it, which displays line segments and allows their spatial parameters to be extracted (cf. section 2.2.), can provide support for representing the structure of space (including its geometry) (Figure 2). This approach is based on the sensory substitution concept (Hatwell et al., 2000). A representation of the static space external to the person should implement the definition 1 (cf. § 2.1). The reference frame origine and metric(s) have to be supported implemented in hardware (dedicated portable computer or PAD). The presented space virtual partition (the person's cognitive walking map) displayed on TactiPad should be driven by dedicated (image processing and vision) software (running of the same portable computer/PDA) and continuously updated.

A 2D matrix of taxels, ie. tactile elements (or Braille points), could be used to provide support for the cognitive walking map or space (apartment) structure. An obstacle, such as a wall, is represented by the appropriate taxel in a raised position (coded as "1"), and its absence by a taxel in the down position (coded as "0"). In Figure 2 the raised taxel v(i,j) corresponds to an obstacle. Therefore, a binary code provided by a touch stimulation display could be manually explored to give a cognitive interpretation.

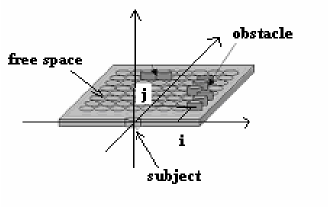


Figure 2. Space structure presentation on a touch stimulation interface with an attached reference frame.

The subject's position in the scene (Figure 1c) is represented by a notch in the edge of the tactile interface (Figure 2). This notch is also the origin of the reference frame attached to the space structure represented on the tactile display. This notch is essential as it allows a mapping between the subject's ego centered reference frame and the CWM reference frame attached to the tactile display. The reference frame and metric(s) attached to a tactile display allow the estimation of ego centered functions estimated by our brain during the walking/navigation (the location of line segments, distance estimation, …).

It should be noted that the proposed tactile interface provides both ego-centred and external referenced representations of the user's near space. The possibility of obtaining space integration from tactile snapshots and the likely quality of the resulting integration have to be evaluated using dedicated virtual navigation experiments.

Figure 3 shows an example of a real scene and its tactile representation displayed on the Paris 6 touch stimulation device, TactiPad (Velazquez *et al.* 2006b). Figure 4 shows the outlines of an apartment and tactile snapshots taken from the entrance to each room displayed on TactiPad (Fontaine, 2006).

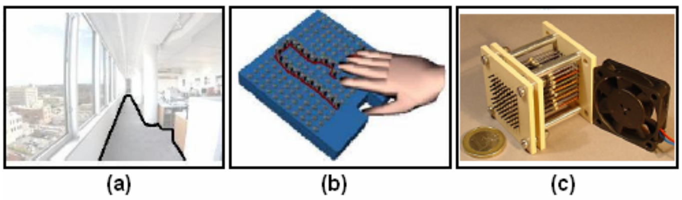


Figure 3, (a) information about the environment obtained from cameras and image processing, (b) tactile representation of the environment, (c) the tactile device (TactiPad, ISIR, University of Paris 6).

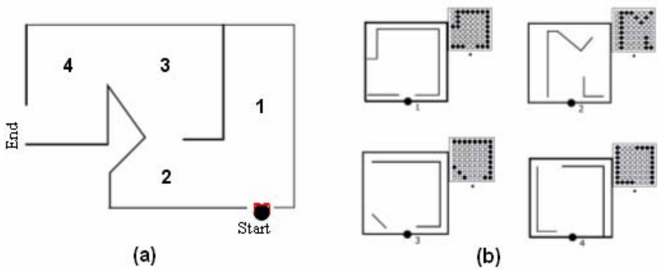


Figure 4. (a) The virtual apartment ; (b) the four subject-related tactile snapshots taken from the entrance of each room and displayed on TactiPad (Fontaine, 2006).

4. The Virtual Navigation Paradigm

Space integration (in this case of an apartment layout) consists of (1) understanding, (2) chaining and (3) memorization of the layout of each room, followed by (4) integration of a sequence of layouts in order to recognize the topology of the whole apartment (visual matching after the experiment).

In this first approach to space integration via apartment structure integration, only virtual navigation is considered, i.e. there is no physical displacement of the subject and the tactile snapshots are conveniently displayed on the tactile device (Figure 4).

The process of understanding room layout is based on extracting the attributes of the line segments delineating the room. The tactile layouts for space geometry and topology perception and understanding should be progressively learnt in order sharp increases in the associated cognitive load. When designing new layouts, account should be taken of the fact that the tactile layouts will be used during real navigation to change and/or update the presentation of the subject seen space. Cognitive load increases with the complexity and frequency of user posture changes during physical navigation.

Consequently, two parameters for apartment layout have been taken into account for progressive learning :

(1) apartment global geometry and body reorientation in the space, when (physically or virtually) exploring the apartment (Figure 5);

(2) room geometry (Figure 6).

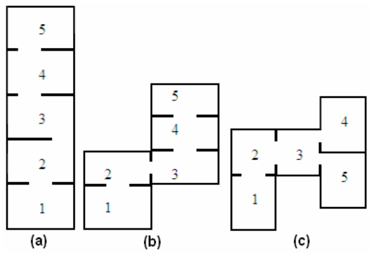


Figure 5. Examples of rectangular apartment layouts for progressive space integration.

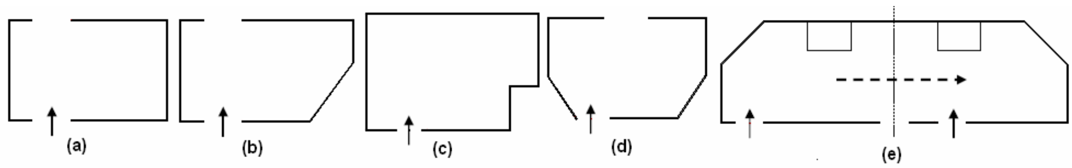


Figure 6. Examples of polygonal room layouts for progressive space integration

Figure 5 presents the layouts of three apartments (a-c) for apartment global integration ; there are no obstacles in these apartments. Each apartment is composed of line segments arranged in a rectangle (parallel to the body's main axis, sagittal and fronto-parallel). The cognitive processes associated with space integration for such apartments require (1) identification and ego-centered (central, right, left) localization of doors and (2) establishing the global layout of the whole apartment.

Apartment (a) is a series of five rooms arranged linearly in the sagittal direction. All doors are located in a plane parallel to the user's frontal direction but they have different spatial locations. Walking about this apartment consists of moving until the exit is reached. The global geometry of this apartment requires identification and ego-centered localization of the doors and knowing that the exit from one room is the entrance to the next one.

Apartment (b) is a series of five rooms arranged in two directions: sagittal (rooms 1 and 2 , then 3, 4 and 5) and fronto parallel (rooms 2 and 3). During navigation, the subject has to locate the door in each room and change his or her direction of movement (turn right, 90°) when going from room 2 to room 3.

The geometry of the apartment (c) is more complex: the first three rooms are arranged in an inverted letter L, room 3 communicates with rooms 4 and 5 and there is no door between rooms 4 and 5. When walking round this apartment the subject has to identify and locate doors, and also to memorize the two possible exits (doors) from room 3. It should be noted that the apartments in figure 5 use only two directions, sagittal and right. For completness of navigation and inter subject variability, similar apartments can be considered with (1) sagittal and left directions, and (2) sagittal, left and right directions.

Figure 6 presents five polygonal room layouts (a-e) which should be considered for navigation (virtual and physical) via PactiPad once the layouts of the apartments in Figure 5 have been mastered. These room are delineated by line segments which have diagonal and cross-diagonal orientations, as well as orientations parallel to the human body main axes. Room (a) is cognitively the simplest : there are only fronto-parallel and sagittal line segments (a rectangular arrangement), the exit is in front of the entrance (what should facilitate memorising the global space) and the room is empty. Room (b) is similar to room (a), except that there is an oblique (diagonal) wall to the right of the subject. In room (c) the oblique wall is replaced by a more complex arrangement of straight line segments and the exit is delayed. In room (d) there are two oblique walls (on the subject's right and left); the room exit needs to be located. The most complex room layout is that in figure (6e): in fact two rooms should be explored, which requires addtional memory. Two rooms have axial symmetry, other than the positions of their exits. This raises the question of whether is it possible to use this symmetry in combination with the small difference in layouts to represent the two rooms.

5. Conclusions

This paper has introduced a formalized definition of the space and a virtual navigation paradigm as an experimental means of space integration from tactile snapshots. A number of attributes of space have been identified, as they are important during the navigation for updating the representation of the subject's near environment. In addition, several rules for the design of space layouts for space integration during the (physical and virtual) navigation have been discussed. The space integration paradigm has been illustrated by the example of an apartment integration task, as this requires considering and mastering the nearest external space in order to carry out daily living tasks.

The progressive rather than sudden increase in cognitive load due to posture changes of the subject during navigation is a key element for correct integration of space. A number of proposed layouts for the whole apartment and each of its rooms have been presented. Other spatial arrangements including further directions and more complex layouts can be proposed using the suggested design principles; a further level space integration via navigation in an apartment can be obtained via the introduction of static obstacles.

Future applications of these results include the development of a data base of apartment layouts and the design of software for mobility instructors. Tests with blind and blindfolded subjects should be carried out in order to establish the congruence between tactilely explored and visually investigated spaces.

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References

Berthoz, A. (1997). *Le Sens du Movement*, Odile Jacob, 1997

Blondot, M. and E. Tesseir (2007), Navigation d'un déficient visual, Cours, Ecole des Guides de Chiens, Paris, 6 juin 2007.

Bruce, V. (1993). *La Perception Visuelle, Physiologie, Psychologie et Écologie*, P.U.G.

Hattwell, Y., A. Streri, E. Gentaz (2000). *Toucher pour Connaître*, Presse Universitaire de France, Paris.

Fontaine, E., R. Velazquez, M. Wiertlewski and E. Pissaloux (2006). Experimental evaluation of a new touch stimulating interface dedicated to information display for the visually impaired, In *Proc. CVHI 2006*, Kufstein, Austria.

Benali-Khoudja, M., Ch. Orange, F. Maingreaud, M. Hafez, A. Kheddar and E. Pissaloux (2004). Shape and direction perception using the vital: a vibro-tactile interface, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004)*, September 28 - October 2, 2004, Sendai International Center, Sendai, Japan, pp. 721-726

Maingreaud, F. (2005). *Une contribution à la perception de l'espace et son intégration dans une aide pour la navigation des déficients visuels*, Phd Thesis, Paris 6 University.

O'Keefe, J. and L. Nadel (1978). *The Hippocampus as a Cognitive Map*, Clarendon, Oxford.

Tolman, E.C. (1948). Cognitive maps in rats and men, *Proc. of Royal Academy*, vol. 55 no. 4, July 1948, pp. 189-208.
Velazquez, R., E. Pissaloux and M. Wiertlewski (2006a). A compact tactile display for the blind with shape memory alloys. In *Proc. 2006 IEEE International Conference on Robotics and Automation*, Orlando, USA.
Velazquez, R., E. Pissaloux and M. Wiertlewski (2006b). A compact tactile display for the blind with shape memory alloys, 2006 *IEEE International Conference on Robotics and Automation (ICRA)*, Orlando, Fl, USA, May.