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Space Cognitive Map as a Tool for Navigation for Visually Impaired.

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Abstract.

Human navigation is based on space mental representations built from several sensory data. This paper investigates the interaction between the visual and tactile modalities during navigation within the experimental platform "perception-movement". A new space representation for navigation and its visual-to-tactile coding are proposed. Four experiments have validated this new coding through some basic navigation tasks. Results obtained show that it is possible to integrate the proposed space representation into a portable navigation tool which could be useful for navigation assistance of the blind/visual impaired.

Keywords: navigation, space dual representation, cognitive walking map, touch stimulating interface, cognitive travel assistance (CTA).

1. Introduction.

Navigation is one of the most important man-environment interaction modes and it is far from being well understood. Indeed, neither the space concept nor its task-based internal/external representations are well defined.

The space model useful for a specific interaction (task-based or task-filtered space representation) refers to establishing an environment's appropriate stable concept. For walking or navigation, space-temporal physical invariants (such as objects, [Poi05], [Gib 79] [Ber97], [Jac01]) are usually perceived via an egocentered interaction through our different senses. All objects identified and localised in subject's nearest space define his cognitive map (in Tolman's sense, [Tol 48]).

However, the cognitive maps built by the impaired (handicapped, elderly, spatial neglecting,…) people are different from those built by healthy subjects. In the case of the blind/visually impaired, data obtained from vision are not pertinent (even absent) during the space cognitive map construction process. Consequently, any walking/navigation assistance should provide external means that could fill in the gap, at least partially, between cognitive map space representation of healthy and visually impaired (or blind) subjects. Such assistance, the cognitive tavel assistance (CTA), will provide means for independent and safe navigation for handicapped people.

Indeed, the current navigation assistances (ETAs: electronic travel aids) are mainly reactive, "stimulus-reaction" based systems (white cane, guide-dog, Mowat's sensor, Borensteins' guide cane, Farcy's TomPouce and Télétact, Nottingham Obstacle Detector, Key's SonicGuide or SonicGlasses, …) [Mai 05], [Vel 03]. Existing ETAs do not support a nearest space global representation (which includes overhanging obstacles,…), do not allow to establish locally the navigation strategy (prepare to turn left or right, …) and to be aware of dynamic obstacles,…

Cognitive Travel Aids (CTA) constitute an alternative solution.

This paper addresses the evaluation processes of a new visuo-tactile space representation which can be integrated in CTAs named “Intelligent Glasses” (IG, Figure 1) that supports a subject nearest-space certain simplified representation.

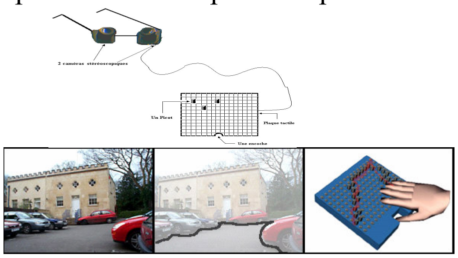


Figure 1. Intelligent Glasses system (IGS).

The rest of the paper is organised as follows. Section 2 addresses the proposed nearest space representation filtered by the walking task and its tactile coding. Section 3 presents the “perception-movement” platform designed for experimental evaluation of the proposed space representation. Section 4 addresses experimentations, while Section 5 analyses the results obtained and concludes with future research directions.

2. 3D scene cognitive map model for walking.

2.1. Cognitive walking map concept and its external representation.

At any time the walking task induces a partition of the subject’s nearest space (Figure 2a and c) into two subspaces (a dual representation): a subspace defined by obstacles and an obstacles-free subspace. At a given instance t, the “frontiers” of these two subspaces are defined by the subject’s nearest obstacles borders (Figure 2) ; these borders may vary dynamically with subject’s view point and with time. Therefore, cognitive walking map (CWM), a subject nearest space representation at the given instance t, is defined as a triple :

{space_partition, reference frame, metric}.

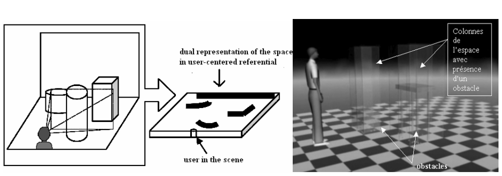


Figure 2. Space virtual partition by walking task.

The reference frame determines the relationships between elements partitioning the space (obstacles in the case of walking/navigation), while metric allow to quantify this relationship.

2.2. Hardware support for a cognitive walking map external representation.

A 2D matrix of taxels (tactile surface), ie. tactile elements (Braille contact points), could be the basic element of the cognitive walking map external representation (Figure 3). A taxel(i,j) has two positions: up (coded “1” : an obstacle in the position (i,j)), and down (coded “0” : no obstacle in the position (i,j)). A taxels’ matrix can be integrated into a touch stimulating device (a new man-machine interface) for manual**,** non constrained exploration.

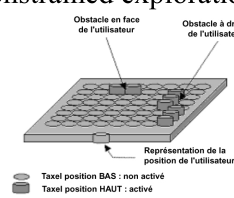


Figure 3. Tactile surface.

The subject’s position in the scene is represented by a notch on the tactile interface (an original solution of our space representation, cf. Annexe): it allows a bijection between the subject’s egocentered and the touch stimulating device reference frames (fundamental for ego-centered function estimations). The proposed space tactile representation is simultaneously ego- and allo-centered.

It should be mentioned that the navigation cognitive map binary code is simple and reduced to its essence. A rapid scanning of the touch stimulating surface allows tactile investigation of the whole map.

3. “Perception-movement” experimental platform for evaluation of tactile cognitive walking map.

Figure 4 shows the experimental instrumented platform (a dedicated 7 x 7 square meters room), containing a set of fixed, but possible to shift obstacles; subjects navigate therein. A specifically built tracking system detects the subjects spatial position and gaze direction from there it deduces the part of plate-form seen by subject and obstacles localized there. The used touch stimulating device ViTal (CEA/LIST, France ; figure 5) encompasses 8 x 8 vibrating microcoils which can work up to the speed of 400 Hz. The microcoils distance is 5 mm [Vel 03].

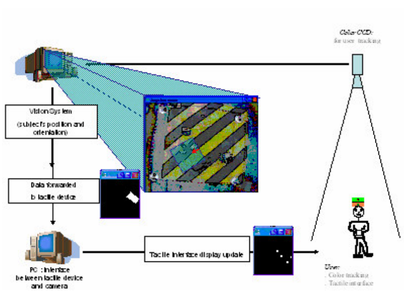


Figure 4. Space exploration with VITAL interface.

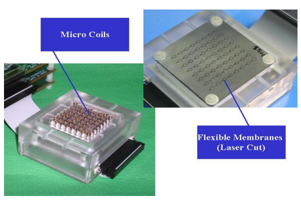


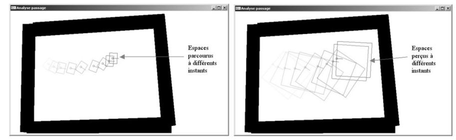
Figure 5. VITAL, CEA/LIST vibro tactile device.

4. Experimental validation of the cognitive dynamic map.

The appropriateness of the dynamic walking cognitive map, and its binary coding to the walking task execution was evaluated via 4 experiments involving healthy blindfolded voluntary subjects (10 females, 7 males) totally naïve about the task. Tasks involve:

- obstacle awareness (Exp 1),
- construction/comprehension of an extra-personal space via (1) homing (return to the starting point, Exp 2)), and (2) distance estimation (Exp3) ;
- construction of a global space allocentered perception/comprehension.

Experiment 1 estimates the efficiency of the tactile device to assist a subject in obstacle navigation. Two measures quantify tactile device pertinence: the explored space (Figure 6a), the subject's perceived (space displayed on tactile device during the navigation, Figure 6b).



a) *b)*

Figure 6. Subject's explored surface a) ; subject's perceived space b)

Experiment 2 estimates the efficiency of the tactile device to let the subject perceive the global space (its geometry and topology) during the homing task with one obstacle avoidance (10 minutes navigation, (Figure 7).

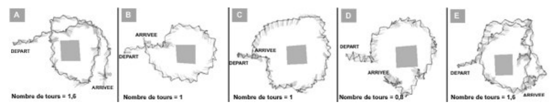


Figure 7. 5 subject walking trajectories involving different navigation strategies.

Experiment 3 estimates efficiency of the tactile device to let the subject estimate an allocentered distance between two obstacles and to decide whether he/she can go through (Figure 8).

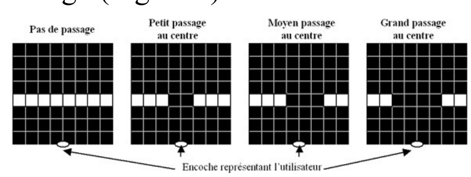


Figure 8. Allocentered distance estimation.

Experiment 4 estimates the efficiency of the tactile device as assistance for global space (geometry/topology) memorization and recognition. Once experiment 1 finished, the subject selected the most probable schematic representation of the explored space from six choices proposed (Figure 9).

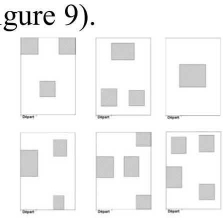


Figure 9. Schemas of 6 space arrangements for recognition after the navigation.

5. Comments on collected results and conclusion.

From the statistical results obtained, it is possible to conclude that all subjects had a good awareness of the presence of an obstacle as the number of contacts is low with respect to the large part of the explored space.

Results of Experiment 2 show that the proposed cognitive map displayed on a tactile device allow to optimize the space investigation (50% of the whole space has been investigated in order to perceive 94% of the space displayed on the device).

ANOVA results show that learning improves by 50% the whole localization (for 3 different whole sizes) and localization time; this improvement is independent of the subject's age (ranging from 21 to 60 years old).

Only 50% of the subjects have recognized the correct global space geometry. However, it should be mentioned that the space geometry memorization has not been requested in the beginning of experiment 1 (walking with obstacles avoidance only).

It should be mentioned that the subjects declared to be familiar with the tactile interface after a 2-3 minute usage; young subjects used frequently the "try-error" strategy in order to extract the pertinent data for performing the task, while older subjects tried to understand which data the tactile device provided prior to its usage. The weak tactile surface space resolution (5mm intertaxel distance) and vibratory stimulus have been main complains related to tactile device quality.

Results gathered from different experiments show that the proposed cognitive map for navigation in space and its coding provide data pertinent for some walking tasks for blindfolded healthy subjects; these results should be confirmed with blinds and visually impaired subjects.

The tactile device realization should be improved in two directions : (1) replacing the vibrating stimulus by bistable (Braille-like) stimulus, (2) increasing of the tactile surface spatial resolution (reduce the taxel inter-distance to 1mm). All experiments should be performed with blind subjects using bistable touch stimulating devices [Vel 05].

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ANNEXE.

The IGS system differs from Bach-y-Rita's system by at least three characteristics: (1) the tactile surface encompasses the subject position in the represented scene : a notch on the surface border ; this notch is essential : it allows subject to estimation ego centered distances (to obstacles) ; there is no subject representation on Bach-y-Rita's TVS/TDU ; (2) the IGS uses stereovision system what allows to provide to subject information on his/her distance to obstacles ; (3) the IGS vision system extracts projective (vision) data on the observed scene but its translated into Euclidean data (distance) immediately exploitable by subjects ; TVSS/TDU provide a tactile representation of the observed scene image with all optical illusions included ; therefore, the TVSS/TDU are much more a new (tactile) language than a geometric/topological representation of the observed scene.