How Taxel-based displaying devices can help visually impaired people to navigate safely

Ryad CHELLALI, Luca BRAYDA
TERA Department
Italian Institute of Technology
Via Morego, 30 15163 GENOVA,ITALY
Email: {ryad.chellali,luca.brayda}@iit.it

Cristina MARTINOLI
Istituto David Chiossone onlus
Corso Armellini 11, 16122 Genova
Email: martinoli@chiossone.it

Eleanore FONTAINE
ISIR Labs
Université Piere et Marie CURIE
Paris, FRANCE
Email: fontaine@robo.jussieu.fr

***Abstract*—This paper reports on the studies we are conducting to help visually impaired people in the challenging task of safely navigating in a partially or totally unknown environemnt. We present here some results showing how a single taxel-based display can participate to acquire geometrical information of the environment dealing with low level navigation. Specifically, we designed a mouse-shaped device, which allows users to navigate in a virtual environment mirroring real sites. In the design, we first quantify users tactile intrinsic sensitivity in terms of the well known JND (just noticeable difference). We then move to qualify the device in a simple height classification task. This allows to see how users utilize our device for the simplest low level navigation task, i.e. determining if a straight pathway is free of obstacles or not. In a third experiment, we test a combination of memorization and localization processes, namely objects recognition and reconstruction tasks. This help us to verify or/and establish hypotheses on how users construct a model of their surroundings while navigating. Finally we test a complex task including objects recognition and obstacles avoidance within a realistic environment.**

I. INTRODUCTION

For sighted people, vision is generally predominant over other senses to get access to information. Thus, in our society, visual information are frequently overtaking hearing ones to make man-space interactions easier. For the visually impaired, this predominance is highly disabling and leading to a problematic fulfillment of daily like tasks such as reading, item reaching and navigating.

For the first and since the 1970's [9], Braille keyboards are developed in order to ease the reading/writing process. Most recently, relief maps appeared to display 3D static information in public halls or subway maps (figure 1).

For navigation, the white cane is the most successful and widespread tool used to travel and move in new or partially known environments. As an extension of the human arm, the cane provides geometrical information about close space through tactile and haptic senses when physical contacts occur with objects and obstacles. Unfortunately, the white cane is very limited both in temporal and spatial resolution compared to vision. Many researchers have tackled this problem and efforts are still made to construct more advanced tools, mainly to extend the accessible space and to add new functions such as localization and navigation. Those tools are known as Electronic Travel Aid (ETA), they aim at supplying vision by using another sense like in [10], [11], [12]. Many other devices have been proposed on the market but they generally appear to lack of utility because of two main linked factors:

- They are invasive: they are heavy and too big. As well, they perturb some sensory channels like auditory and tactile [4], [5], [6]).
- They address inappropriate sensory channels: tactile channel is used to display matrices representing 3D images or haptic images, auditory channel gives explicit description [3], etc.

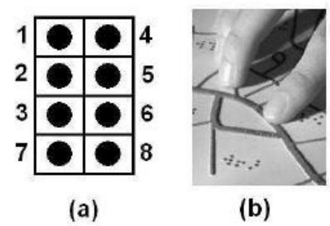

Fig. 1. (a) Braille cell and (b) relief map.

In most of systems presented in [2], [4], [7], users are carrying heavy loads like PC's for controlling both displaying surrounding description and 3D modeling or handheld tactile matrices. One can immediately realize that such systems are not very convenient and opposite to the blind persons expectations especially to be discrete. In addition, the display mode is generally not convenient too. For instance in [3], the auditory channel is used to describe the environment. Users thus loose this capital channel and they cannot use it for communication functions.

To avoid the previous limitations, some light solutions were proposed like in [6] . Unfortunately, these solutions need complex approaches like structuring the environment, i.e. one must add markers or pre-model the walking space. This paper introduces a new preliminary tactile and haptic device built at the IIT upon all these considerations. The final goal of this device is to be interfaced with a stereo vision device to ease blind people navigation. Nevertheless, the first step consists in experimentally evaluating it in order to understand the blind people needs and capabilities.

In the following, we describe the tests we made to assess the performances and the characteristics of the device. We present this device in Section II. In Section III we derive the minimal information the user can feel, i.e. the smallest stimulus users can receive. In Section IV we verify whether or not users can develop strategies to achieve the lowest level navigation task. In Section V part we verify higher level tasks, namely shape reconstruction and recognition tasks. This helps to verify whether the device could be used for higher level navigation tasks.

II. The DIGEYE®system

A. Design considerations

Here we describe the method we followed to built our device. In our approach, we started from the main constraint users highlighted, namely the weight. Following that, we divided the problem into two sub-problems. The first one is concerned with the display. The second one is concerned with information acquisition or environment modeling. For both we attempt to optimize the system by keeping fundamental functions and by reducing the needed computation power (smaller computer with less power consumption, small size display device, etc.). In fact, the two sub-problems are linked: regarding the nature of information to be displayed (acquisition) we have to address specifically one sensory modality (display) and *vice versa*, i.e. for a given task, one needs to know what information is important to describe the environment and how to "show" it. Within the scope of this framework, we drive our attention on what users can accept in terms of constraints, solutions and stimulations. This makes DIGEYE an iterative platform which is in constant evolution. Specifically, we started by studying human perception through the tactile channel and use results to optimize the device acquiring and processing the information. The first step was concerned with finding the right stimulation for achieving low level navigation or finding a free pathway of 3 or 4 meters for normal walking which is enough(close obstacle avoidance). The second step is concerned wih high level navigation or navigation to remote destinations beyond the immediately perceptible environment. If for the low level a free-cape based information is enough, additional needs must be satisfied for high level navigation. Typically, long distance recognition (landmarks for instance) is mandatory : this help user in self-localization and generation of long term trajectory. One can easily imagine that extending the working area and adding complex functions (landmark recognition and localization) has a counterpart which is not compatible with our constraints (more computational power and thus weight, etc.). Following that, we restricted our research to low level navigation and the close area sensing a display.

To do so, we designed a very simple tactile device for displaying close working environments. At its current version, the device serves only as a test tool to validate some hypotheses about needed low level navigation capabilities. The future one is under development and will meet users requests, especially in terms of usability, acceptance, comfort.

Fig. 2. The tactile device.

B. Tactile device brief description

We developed a device which looks like a mouse. Inside, we embedded a stepper motor, a controller, an absolute positioning sensor and a wireless communication link (figure2). The system is able to display heights function at any device-finger absolute position. Indeed, we can reproduce any given function $H = f(X, Y)$. We first capture the absolute position (X, Y) and send it to a distant computer through the wireless link. The computer derives the corresponding height $H = f(X, Y)$ from virtual 3D models that can be designed and easily included. H is sent to the embedded controller. This last activates the stepper motor and the attached stalk is rotated by an angle θ corresponding to H. This cycle runs at 500Hz.

For practical reasons, the working area is limited to a frame of dimension A4 (210mm*297mm). Out of this area no absolute position is delivered. Regarding the working frequency (500Hz), the stepper motor generates an audible noise. To avoid any direct or indirect bias (users can detect motor motions only by hearing) in the cognitive load, the users hold earphones and listen to a pink noise. By this immersion, the mechanical noise can be barely heard, i.e. reasonably under the threshold of the user concentration.

C. The virtual environment generator

To emulate a real 3D modeling sensor we developed a specific software. Indeed, we assume that we have a sensor able to give a 3D geometrical description of any real environment, such as a depth sensor: this can be based on LASER, Ultrasonic or on a stereovision system giving a disparity map. The software gives heights function of the cursor position corresponding to the absolute position of the user digit within the working area. To simulate real or test environments we used the OpenGL-SDL library. We first create objects and their geometry (facets based) under the open source BLENDER. We then export these objects to our software. Using an XML-based description, we can setup scenes by choosing, sizing and positioning the objects. We can also define through this description the ratio between real sizes and displayed sizes (the equivalence between real heights in mm and displayed ones H).

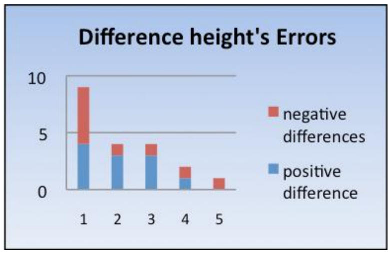

Fig. 3. Difference height error.

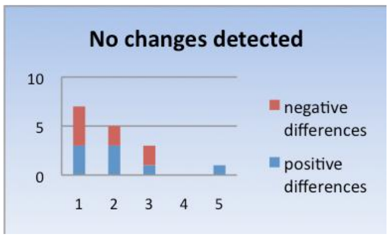

Fig. 4. No detections.

III. Just Noticeable Difference (JND) Experiment

A. Description

The goal of this experiment is to find the suitable dynamics of our device. In other words, we want to estimate the tactile sensitivity and derive the minimal stimulation users can feel in terms of height difference (ΔH). This will lead to establish the resolution or the granularity of the height representation.

15 native and late blind persons (9 females and 6 males) participate to the experiment. The procedure is the following: each participant j achieves three series of 10 heights display ($H_{i,i=1,10}$). Starting from a random position, a height is displayed and the user must distinguish between positive or negative displacements (the cursor rises or bends): for trial i, we start from H_i and move to H_{i+1} with $\Delta H = |H_i - H_{i+1}| = n * 120\mu m$, n is randomly chosen between 1 and 5. Between series, participants are let 1mn free to move or to discuss with organizers.

B. Results

The total number of answers is 450 (10 trials*3 series* 15 users). The total number of errors (wrong change direction assertion) is 20 (4.44%) (Figure 3)and the total number of false detections (users didn't feel any changes) is 50 (11.11%). As one can see on (Figure 4) the most significant errors occur for a difference of $\Delta H = 120\mu m$. As well, users didn't react mostly for the same $\Delta H = 120\mu m$.

We have also summarized errors positions during sessions, i.e. we count the number of errors occurring between the i^{th} and the $(i+1)^{th}$ trials (Figure 5). The next graph shows the corresponding histogram. The maximum is reached during the first 10 trials. For the last series, between the 25^{th} and 30^{th} errors are less than 1%.

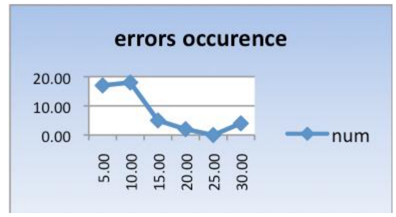

Fig. 5. Cumulated error with time.

C. Comments

Concerning skin sensitivity, we can see that the number of errors is maximum for a difference of $120\mu m$. This confirms what was demonstrated using another protocol in [1] and both results are equivalent. On the other hand and as expected, errors decrease for higher differences ($+/-600\mu m$). We have less than 1% errors of total trials. In addition, we can notice that the more users achieve trials, the less errors we have: 17 for the first 5 displays and 4 for the last ones. A discovery-appropriation (learning) process could explain this. Users discover first the device and establish a relationship between stimulations and their meanings. Once the model established, the stimulation is easily translated into equivalent height variation.

IV. Basic Navigation Memorization Task

A. Description

The goal of this experiment is to understand how users utilize the device in a simple task combining low level navigation and heights memorization. Indeed, for this task users generally develop strategies to discover heights and memorize their positions. This experiment is equivalent to a real life situation where one has to walk ahead and verify that the direct pathway is free of obstacles or to know where obstacles are, if any. Four aligned cubes are presented (see Figure 6). Cubes have four different heights $H_{i,i=1,4}$ with $\Delta H = \|H_i - H_j\| = 120\mu m$ (i.e. they have increasing equispaced heights). Users must classify them from the highest to the lowest. They can choose freely their own strategy for the classification task. The term classification is justified because this experiment is preceeded by a short preliminary learning phase where users touch a physical set of 4 cubes, which are a real scaled representation of the 3D model. Users has to perform 4 series of randomly generated configurations.

13 native and late blind people (7 females and 6 genders) participated to the experiment. This experiment took place just after the first one described in Section III.

B. Results

After 52 trials, we found 9 errors (17%). These errors are mainly due to an inversion between cube1 (H1) and cube2 (H2) as well as between cube3 (H3) and cube4 (H4) . The errors are correlated with the first experiment. For small differences, users are unable to feel these differences even if they are allowed to 'self-calibrate' with the ground plane (height=0). We noticed also that strategies can be totally

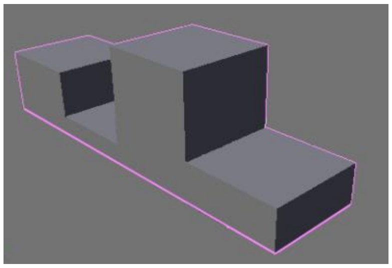

Fig. 6. The four cubes experiment, for heights classification.

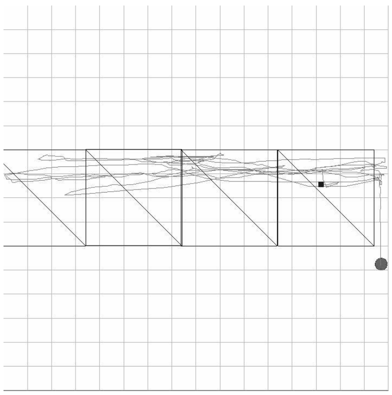

Fig. 7. Straight-line search.

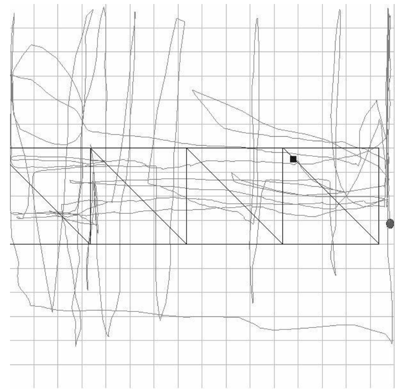

Fig. 8. Ground-based searc.

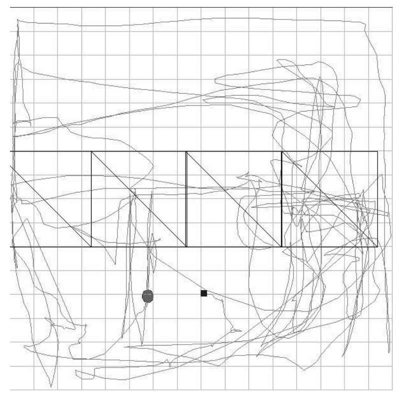

Fig. 9. Radom walk search.

different: some users follow a straight line and memorize height discontinuities (Figure 7), while others use the ground plane to have an absolute height for each cube (Figure 8). The third group uses a 'random walk' strategy: with moving the device randomly searching for discontinuities (Figure 9).

After analyzing individually all the achieved trajectories, we found that there is no correlation between the chosen strategy and errors rate. In addition, there was also no correlation between the configuration and errors: errors occur when cube1 and cube2 (alternatively, cubes3 and cube4) are neighbors as well as when they are separated by other cubes.

C. Comments

In this experiment we intend to verify whether heights memorization combined with a low level navigation task is effective, i.e. whether users create a map between taxel based sensations and a real world (preliminary touched) The first comment is concerned with exploration strategies. We found that users proceed following three main strategies:

1) Straight line,
2) Ground based search
3) Random walk

The first one is the most logical for most users (preliminary results with non-impaired people confirm this fact): one uses the straight line as the exploration pathway; the user memorizes height discontinuities and the relations between them. The approach seems to be 'relativist' against comparing heights between them regarding their absolute values.

In fact, some users adopt the second strategy: they always compare the current height with the ground plane: each cube's height is measured individually and its position memorized. Here the approach is 'absolutist' and an individual comparison with the ground is perceived as necessary.

The last one appears similar to a random-walk: users randomly move the device in all directions searching for discontinuities. Once found, a new search is achieved. Users do the same many times before giving the last answer.

The second comment concerns errors. In all conditions (cubes position and chosen exploration strategies) we have the same type and rate of errors. This is related to the first experiment: users are unable to feel a difference of $\Delta H = \|H_i - H_j\| = 120\mu m$. In all other cases, the memorization of heights is effective, regardless the chosen exploration strategy.

V. RECOGNITION AND RECONSTRUCTION

A. Description

For the last experiment, we aim at demonstrating two capabilities: shape reconstruction and shape recognition. By reconstruction, we mean that users freely discover a simple 2D shape by detecting its borders. By recognition, we mean that users have to associate orally described shapes with the explored shapes. For the experiment we use two objects, a circle and a triangle. Users first try to reconstruct the shape of each of them without any constraint about the exploration strategy. In the second phase, they are informed about the

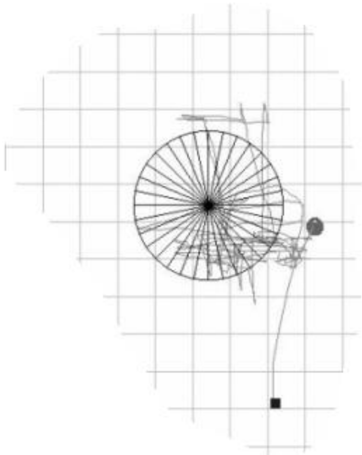

Fig. 10. User 1 circle: Edge following.

nature of the two shapes and have to guess which is the triangle and which is the circle.

Nine native and late blind people (5 females and 4 males) participate to the experiment.

B. Results

All participants have difficulties to identify the presented shapes. 4 correct answers are obtained (over 18 trials): 2 for triangles and 2 for circles. Mainly there are confusing shapes: squares (not included in the experiment) and circles, circles and triangles. Conversely, once users knew what shapes were presented, they designated correctly each of them except twice.

Here also, we noticed three groups of exploration strategies, depicted in Figures 10, 11 and 12. The first group performed an edge following strategy, i.e. once a discontinuity discovered, the users moved slightly the device searching for close discontinuities to construct incrementally the model. A second group used a 'Z' like scanning approach: users performed motions following parallel straight lines, perpendicular to the actual, virtual edge. The last group used a random walk exploration (as in the previous experiment).

C. Comments

The first results show that there is a big difference between the reconstruction task and the recognition one. For the first and regardless the chosen exploring strategy, users memorize the shape by aggregating taxels (all discontinuity points) and at the end, once the exploration finished, the explored shape is recognized. The obtained results suggest that the kind of information is not sufficient to built correct models: users are not able to correctly aggregate individual data to obtain the full model.

For the second task, users only have to verify hypothesis: knowing the presented shapes they just extract from their memory the salient points or what is supposed to be and generate the answer. Recognition seems to be easier than reconstruction. This happens because an a-priori model of the geometrical shape is known to the user. Of course, the degree of goodness of the model depends on user prior knowledge. Both results suggest that our device is more suitable for known environments where people know the present shapes than for discovering environments and objects.

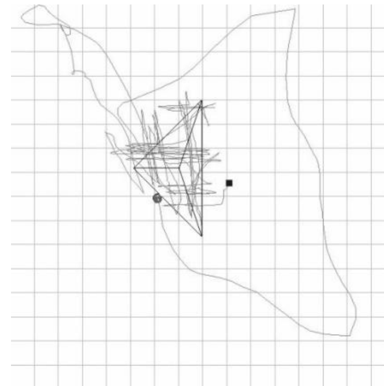

Fig. 11. User 1 triangle: 'Z' scanning.

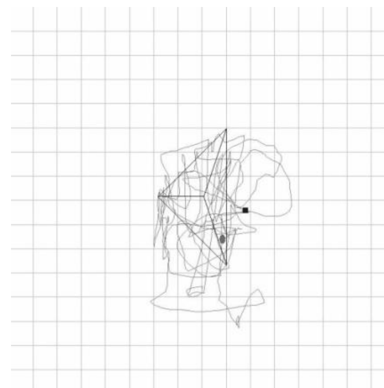

Fig. 12. User 2 triangle: random scanning.

VI. Complex navigation

To go deeper about our first hypothesis ("can our device serve to navigate safely?"), we tried with a single user a more complicated task. This test is not included within the primary protocol: we intend to test the user's behavior when facing a complex task such as path finding. Prior to the experiment, we described the environment and listed the objects in the scene: namely a table, a chair, a wall and stairs (Figure 13). After being asked to localize each object (Figure 14), the user completed the task with no mistakes. More surprisingly, when being asked to "walk" between the table and the chair together with avoiding to touch them, the user succeeded. This experiment was performed only by one participant and thus no generalization is possible. Note that this user made almost no mistake in all the preceeding experiments. However, the obtained results suggest that this participant has established an a priori model of the room and then he set all objects at the right position. The free pathway, depicted in Figure 15, is easily found because the room configuration is efficiently memorized.

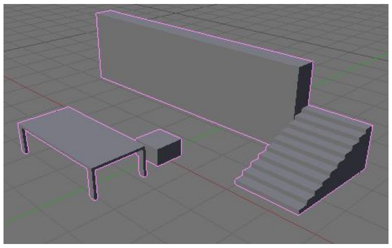

Fig. 13. The 3D model of the room.

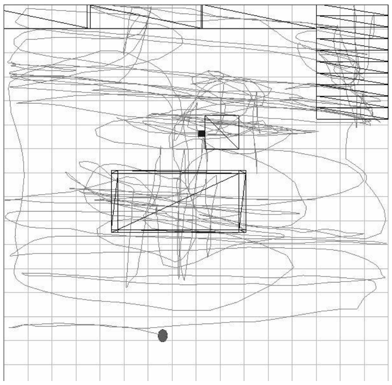

Fig. 14. Room discovery.

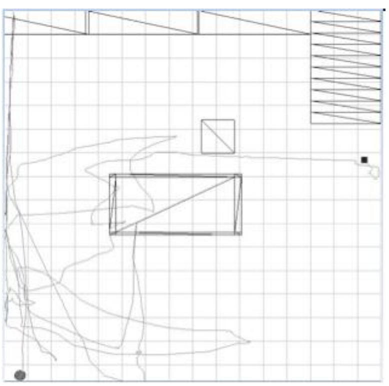

Fig. 15. Obstacle avoidance.

VII. CONCLUSIONS

In this paper we presented some preliminary results about a part of the system we are developing to help blind and visually impaired people to navigate safely. We started by qualifying the tactile display device. The obtained results are conform to those found in the past. With the second experiment, we found that the device can be efficiently used for straight line-based exploration: users can classify heights accurately when walking ahead.

Finally we showed that 3D objects recognition is possible if a priori knowledge is given to users. On the contrary, reconstruction tasks are difficult and our device seems of little help, at least in its current configuration. Indeed, for basic shapes, few users found the right shapes. A preliminar explanation, which needs to be confirmed in our future work, is that taxel-based information is not rich enough: users have to memorize the discontinuities positions. The aggregation process is too difficult for them in comparison with haptic images: for taxel-based information only a small part of the digit skin is involved in the reconstruction process, while for haptic images all the hand is used. This difference could explain the performances gap between the two approaches. However, our device can be miniaturized to a very small size (the new version is under a patenting process) while haptic images need at least some cm2 of active surface.

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