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Biomimetic Image Processing for Retinal Prostheses: Peripheral Saliency Cues

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Abstract — **Retinal prosthesis recipients may still have degraded vision, such that additional information about their surroundings may help them perform certain tasks. We evaluate a system that provides cues that point towards important objects. Using a simulated vision grid of 6 x 10 pixels, subjects perform object location and mobility tasks with and without the help of cues. The velocity of head movement in degrees per second and the time taken by subjects to finish the tasks are recorded. Results show that a cueing system may help to reduce and organize the head movements of the subjects, whereas a time benefit exists in object location but not in mobility tasks.**

I. INTRODUCTION

An intraocular retinal prosthesis aims to provide some vision to patients blinded by retinitis pigmentosa (RP) or age-related macular degeneration. In these diseases, the photoreceptors in the retina degenerate over time, leading to a gradual loss of vision. However, other retinal cells remain relatively intact, although remodeled to a certain extent. Retinal prostheses comprise a microlectrode array that is attached to the retina; based on external camera information, this array is stimulated electrically, which in turn activates the relatively intact cells of the retina [1]. Several devices are currently under evaluation in human clinical trials.

Due to limitations in the size of the devices that can be implanted, the microelectrode array covers only the central 10 to 20 degrees of the retina. This implies that at best, the implant recipients will be able to see and perceive information only in the central 10 to 20 degrees of the visual field. Information beyond this in the peripheral areas of the visual field will not be available, which can hamper subject mobility. To provide some degree of information from the peripheral visual field, we evaluate the use of a cueing system with normally sighted volunteers using simulated vision. The cueing system is based on a saliency algorithm that detects salient features in the peripheral regions of the subjects. This algorithm [2] features a more efficient implementation based on the original saliency model [3].

Several studies have been carried out with normally sighted volunteers using simulated vision, as well as with visually impaired subjects. Cha, *et al.* [4] suggested that a 25 x 25 pixel array and a 30 degree field of view should be sufficient for a cortical prosthesis to provide useful mobility in environments that may not require a high degree of pattern recognition. In their experiments, subjects walked through a maze with obstacles using simulated vision, and the walking speed as well as the number of body contacts with the obstacles and walls were measured. Dagnelie, *et al.* [5] studied normally sighted subjects using 4 x 4, 6 x 10 and 16 x 16 pixel grids to perform mobility tasks in both office and virtual environments. Again, time, navigation errors and number of contacts were recorded. Results suggested that the 16 x 16 grid showed good performance capabilities. However, with practice and learning, a 6 x 10 grid may also provide basic way-finding abilities to the blind. Hayes, *et al.* [6] also used 3 similar grids with normally sighted volunteers. The tasks tested required eye-hand coordination, object identification, and reading tasks. Again, the best performance was achieved with a 16 x 16 grid, but a 4 x 4 grid sufficed for simple shapes.

Turano, *et al.* [7] showed that RP patients sampled three times the visual field sampled by normally sighted subjects when walking an unfamiliar and obstacle-free route. Also, the majority of the fixations by RP subjects were in the downward direction, to objects on the walls, or to the intersections of the wall and the floor, whereas for normally sighted subjects the majority of the fixations were on the goal. Given that RP destroys peripheral vision first, this study suggests impaired mobility with loss of peripheral vision.

Geruschat, *et al.* [8] studied the gaze patterns of visually impaired and normally sighted subjects while they performed a high-risk activity of crossing a street. Normally sighted subjects fixated on the traffic light or on the vehicles when crossing the intersection at the right time, or a little early, respectively. Visually impaired subjects for the most part fixated on the vehicles only. Velikay-Parel, *et al.* [9] studied 3 groups of visually impaired subjects with different visual fields and visual acuities when they performed a mobility task through 3 different mazes. They observed a significant difference in the average time taken by the groups to pass through the different courses based on their visual acuity and visual field. However, the groups did not significantly differ in the average speed and number of contacts.

Using a cueing system, we hope to organize the sampling of the visual field by the subjects in such a way that they gather more information with fewer head movements. Also, excessive head movement to understand the visual field can in most cases lead to disorientation for the subjects. Our goal is to reduce the head movements of the recipients by guiding them towards meaningful information. Using cueing, we also hope to improve upon the time required by subjects to accomplish different tasks.

II. METHODS

Simulated vision was provided to the subjects through an eMagin Z800 Head Mounted Display (HMD) and scene camera system from Arrington Research, Inc., Scottsdale, Arizona, USA. The HMD has a diagonal field of view of about 40 degrees and the camera has a field of view of close to 60 degrees. Custom software to simulate artificial vision was used. Simulated vision was provided in the form of a grid of 6 x 10 pixels in approximately the central 14 degrees of the HMD. The central 14 degrees of the image captured by the scene camera was reduced to a circular pixel arrangement. Random electrode dropouts of up to 30% were simulated in order to account for failed electrodes that retinal prosthesis recipients may experience. The number of gray levels was set to 8. The electrode duty cycle was set to 0.8, and the gap between the pixels was 0.5° and 0.8° in the horizontal and vertical directions, respectively.

For the cueing system, a saliency detection algorithm based on color saturation, intensity, and high pass information was used [2] to detect important regions in an image frame. The algorithm processes the image frame from the scene camera on the HMD for these different kinds of information, and detects the most salient regions in that frame. Based on the first few (3 to 5) salient regions, subjects can be cued towards the directions of these regions using directional cues. This algorithm implementation is based on the bottom-up saliency detection algorithm of Itti, *et al*. [3].

Two different experiments were carried out: (1) a seated desk task, and (2) a mobility task. For both experiments, subjects had to perform the tasks with and without cues. Trials consisted of no-cue trials followed by cue trials. Cues were provided in the form of white blinking dots in the HMD outside the 6 x 10 pixel grid. The cues would blink in one of 8 directions (top, down, left, right, top-left, top-right, bottom-left and bottom-right) with respect to their central region of vision. For the case with no cues, subjects used head movements in a highly individualized fashion.

Three subjects for Experiment 1 and four subjects for Experiment 2 were involved. Subjects had a measured visual acuity of 20/30 or better with normal vision, or with vision corrected using lenses. The visual acuity testing was carried out using a Snellen visual acuity chart.

Experiment 1 Procedure: Subjects were seated at a desk. They were instructed to find one, two, or three objects placed on the desk. A circular roll of tape was placed on the desk, which acted as the central reference for the subjects to start and end the trial. For the cueing case, subjects came back to this center when asking for cues every time. When using cues, subjects were asked to wait for a cue and then move their head in the direction indicated by the cue to find the objects. The time taken by the subjects to finish the task with and without cues was recorded. Fifteen trials with each subject (except subject S) for the cue and no-cue cases were carried out, with 5 trials each for the one, two, and three object cases. Figure 1 shows the set up for this experiment with 3 objects on the desk.

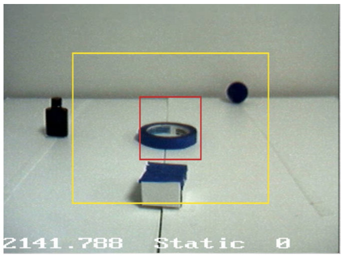

Figure 1: Set up with 3 objects for desk tasks with simulated vision. The red square shows the central 14 degree region (diagonal) provided in pixellated form to the subjects as simulated prosthetic vision, and the yellow rectangle shows the field of view of the HMD.

Experiment 2 Procedure: Subjects were asked to navigate through a set of chairs towards a target. Thirteen chairs were arranged in an otherwise empty room (approximately 15 m x 15 m). Subjects started on one side of the chairs, and the target (a red rectangle 61 cm x 72 cm) was placed on a wall opposite the subject. Subjects were allowed to get used to the simulator system for a few minutes before the trial began, in order to have them familiarize themselves with how the chairs, target, and the room layout looked in simulated vision. The number of trials was different for all subjects. Initially, only timing data was recorded, after which head movement data and timing data were recorded for the rest of the trials. Head movement data was recorded using the IS 1200 VisTracker from Intersense, Inc. The head movement data in the horizontal (X) and vertical (Y) directions was analyzed. Figure 2 shows the set up for the experiments. The photograph on the top shows the image captured by the scene camera, which is input to the algorithms. The photograph on the bottom shows the simulated prosthetic vision that the subject viewed in the

HMD. The image area in the red box is shown to the subject in a 6 x 10 grid.

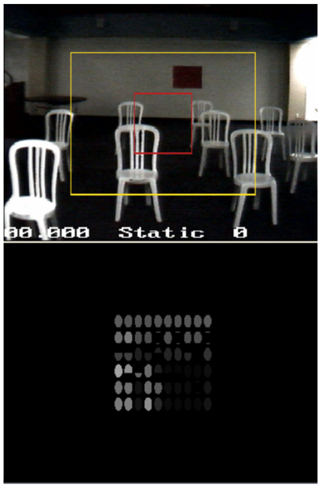

Figure 2: Top Image: Setup of mobility tasks with a path laid out with chairs and a target at the end of the path on the wall. The red square shows the central 14 degree region (diagonal) provided in pixellated form to the subjects as simulated prosthetic vision, and the yellow rectangle shows the field of view of the HMD.

Below: simulated prosthetic vision as seen by the subjects in the HMD, which is the pixellated version of the information in the red square in the top image.

III. RESULTS

For Experiment 1, the average time for all subjects for the cue and no-cue settings for the 1, 2, or 3 object cases is shown in Figure 3. A paired t-test ($p < 0.0001$) for the time was done for each subject between the cued and non-cued trials. Subject S was not tested with 1 and 2 objects for the no-cue case. The statistical test shows that with cueing, subjects take significantly less time than with no cueing to finish the tasks (Figure 3). As the number of objects increases from 1 to 2 or 3 objects, the time taken with cueing increases, as more cues are asked for by the subjects, but is still significantly less than the time taken with no cues.

For Experiment 2, Figures 4(a), (b), and (c) show the timing in seconds, as well as horizontal and vertical head movements in degrees per second, respectively, for all subjects. For the horizontal head movement graph, values greater than 45 degrees/sec have been clipped to 45 to provide better resolution for the other data points. Data was combined from all subjects and a paired t-test was carried out between the cue and no-cue trials. Head movements in both the horizontal and vertical directions for the cueing case are significantly less than for the case with no cues ($p < 0.05$). No significant difference between the trials with and without cues for the time analysis is observed.

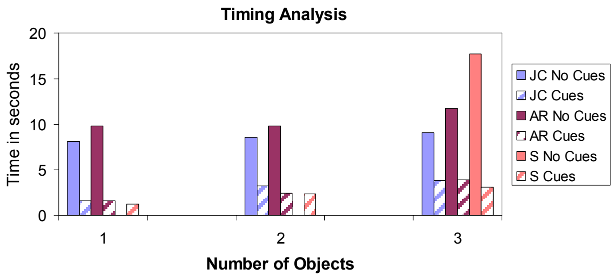

Figure 3: Average time in seconds for 3 subjects (JC, AR, and S) when performing desk tasks with and without cues

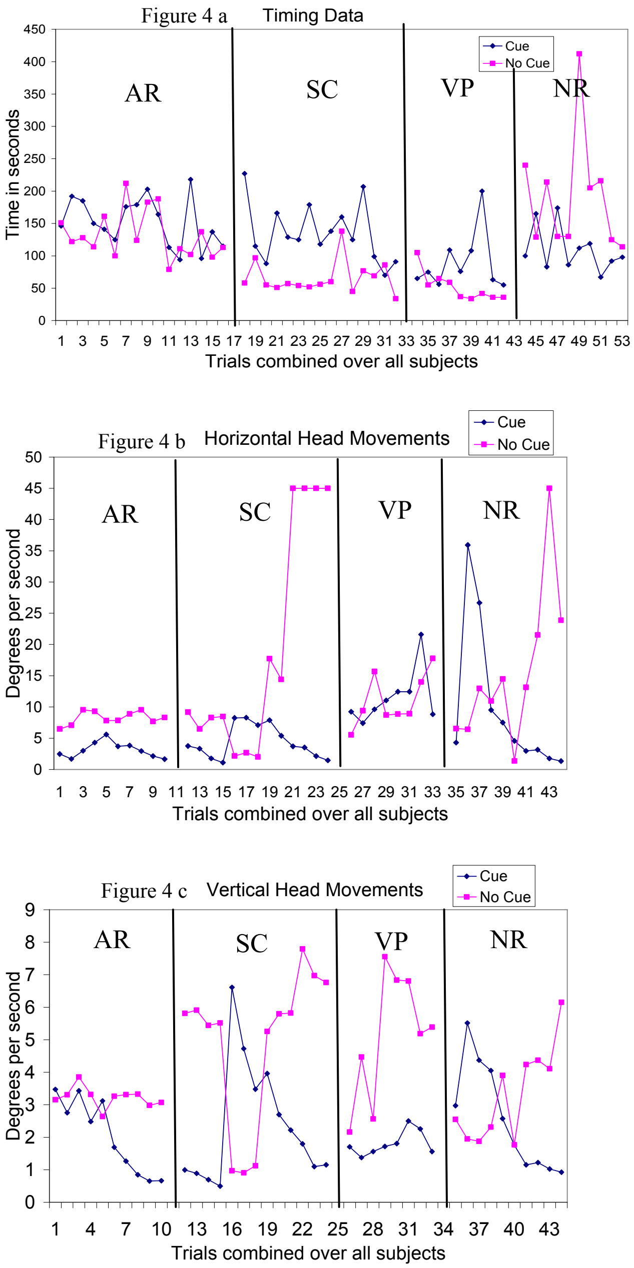

Figure 4: (a) Time in seconds, (b) horizontal head movements in degrees per second, and (c) vertical head movements in degrees per second for subjects AR, SC, VP, and NR (naive)

IV. DISCUSSION

Experiment 1, although based on a very controlled situation, shows that if a cueing system were pointing a subject towards the object/region of interest, subjects can use the cue to find the object in less time compared to when they are not using cues. Each subject adapted a different head movement strategy when performing tasks. This suggested that when performing mobility tasks, subjects may again adopt different strategies for both the cueing and no-cueing cases. Also, as proposed by Turano, *et al.*, visually impaired subjects sample a larger visual field than normally sighted subjects. To assess whether cueing can help organize head movements, head tracking was assessed in Experiment 2.

For Experiment 2, subjects adapted different strategies when performing the mobility tasks with and without cues, as observed in Experiment 1. This accounts for the large variability in the inter-subject data. Also, there was no clear learning curve observed for any of the subjects. One possible reason might be that the boundaries beyond the path of the chairs were open, so that subjects sometimes got lost in the boundaries and took a while to realize that they are moving in the wrong direction. With cues, the subjects learned that if 2 to 3 cues didn't lead them towards the chairs, they are possibly moving into the boundaries, and that they should turn around and find the chairs. For some subjects, the task took longer with cues. The cueing process takes a finite amount of time, with the subject asking for a cue, the system processing the image frame and blinking the white cue dot on the screen, and the subject deciding whether or not to follow the cue. With multiple cues used during one trial, this time adds up, and made the cueing trials slightly more time consuming that the no-cueing trials for some subjects. Also, as mentioned above the various approaches taken by subjects matter, and some subjects tried to use the cueing to their advantage and finish tasks sooner than with no-cueing. More trials with each subject will be needed to determine if learning reduces the task time when cues are used.

With the two different experiments, we observe that the advantages offered by a cueing system may differ based on the kind of task at hand. In a relatively uncluttered environment, which is common for blind subjects to have in their homes, simple tasks like finding objects on a table can save the subjects time. However, when using the cueing system while performing mobility tasks, the subjects may experience a reduction in the head movement required in order to gather information.

The approaches adopted by subjects when using the cueing system also play an important role in how effective the system is for the subjects. Based on a subject's height, for example, their viewing angle with respect to the ground may be different, which in turn may change the visual field captured by the camera for each subject. This means that specific cues provided to different subjects will be different, and this can lead to a difference in performance. Also, the mobility task used here is not difficult for the subjects once they get used to the simulated prosthetic vision, which takes 2 to 3 trials. The reason behind this is that the chairs they must pass through are easily seen in the simulated prosthetic vision and are easily distinguishable. Because of this, some subjects do not find the need to use the cueing system. However, most subjects qualitatively find the cueing system useful so that they can orient themselves. Real world environments, in which the algorithm could cue subjects to regions that are not easily identified by them in the simulated prosthetic vision might show that the cueing system is more useful than what we see here. These experiments will guide future work for further testing of the peripheral cueing system.

V. CONCLUSIONS:

A cueing system using saliency for retinal prosthesis recipients to guide them to important regions/objects in their peripheral visual field may help them in organizing their head scanning movements and in orienting themselves when faced with unfamiliar surroundings.

VI. ACKNOWLEDGMENTS:

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