Monitoring Navigational Strategies and Idle Time in Real and Virtual Environments: An Experimental Study

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Abstract. A between groups experiment was carried out to compare navigational strategies in a real environment and in a photorealistic computer graphics simulation of that environment. In this paper, a study that compares a real-world task situation to its computer graphics simulation counterpart is presented. The computer graphics simulation is based on photometry data acquired in the real-world space and is displayed mainly on Head Mounted Displays utilising either monocular or stereo imagery and interaction interfaces such as either the common mouse or head tracking. 105 participants across five conditions were exposed to the real and computer graphics environment and completed a spatial memory task. Participants across conditions were monitored (using software or hardware according to condition) in terms of their navigation patterns and idle time while horizontally rotating around their viewpoint, placed in the centre of the experimental room. An overall main effect was revealed. Relevant statistical analysis showed that the amount of idle time for the participants in the HMD stereo head tracked condition was significantly higher than those in the real-world ($p<0.01$) condition.

1. Introduction

When interfaces such as head tracking are incorporated in experimental designs which also include more traditional interfaces of 3D interaction such as the mouse, unravelling the effect of the actual navigational interface on task performance in Virtual Environments (VEs) is significant. The variability of interaction interface between conditions should be taken into account, therefore, monitoring participants' navigational patterns provides an aid towards this direction. Participants across conditions could be video–recorded (in the real-world or during their interactions with a synthetic world on the screen) during exposure, allowing in most cases for a qualitative analysis of navigational patterns. A numerical analysis, though, makes monitoring more formal and subject to detailed statistical analysis.

A between groups experiment was carried out to compare navigational strategies in a real environment and in a photorealistic computer graphics simulation of that environment. In particular, a study that compares a real-world task situation to its computer graphics simulation counterpart is presented, utilising a spatial memory task. The computer graphics simulation is based on photometry data acquired in the real-world space and is displayed mainly on Head Mounted Displays utilising either monocular or stereo imagery and interaction interfaces such as either the common mouse or head tracking. 105 participants across five conditions were exposed to the real and computer graphics environment and completed a spatial memory task. Participants across conditions were monitored (using software or hardware according to condition) in terms of their navigation patterns and idle time while horizontally rotating around their viewpoint, placed in the centre of the experimental room.

2. Proprioception Contributions to Navigation in Virtual Environments

Traditional input interfaces such as mouse-like interfaces are often compared to more 'intuitive' interfaces such as head tracking [8], [5]. Generally, navigation depends on realising self-position and orientation by piloting, path integration and orientation. Piloting relies on the observation of known landmarks and the ability to identify the spatial relationship between the landmarks and the observer. Path integration involves monitoring of the velocities or accelerations experienced while travelling. Integration of these cues will result in the navigator's perception of current position relative to the starting point of the journey. *Proprioceptive* information reflects the movement of body parts relative to one another. It is necessary for co-ordinated bodily actions and is gained though mechanical receptors in joints and within the vestibular system but also through vision [1]. The vestibular system is centred on the organ in the inner ear involved in the transduction of angular acceleration of the body into nerve impulses.

An experimental study by Grant & Magee [3] investigated the contribution of inadequate proprioception to disorientation caused by immersive VEs towards transferring the spatial knowledge acquired to a real world task. Participants were provided with interfaces to a VE that either did (a walking interface) or did not (a joystick) afford proprioceptive feedback similar to that obtained during real walking. The two groups explored a large complex building using a low resolution HMD. Their navigational abilities (orientation and ability to find the shortest path to a given destination) within the actual building were compared with those of control groups. These studied a map, walked through the real building or received no prior training. Results showed that the walking interface conveyed no benefit on the orientation task performed during training in the VE but it did benefit participants when they tried to find objects in the real world. In another relevant study, Slater et al. [6] used foot movements to toggle the participant's state between standing still and moving forward at a fixed velocity. This system proved to promote a higher sense of perceived presence. In a more recent study, Usoh et al. [7] replicated the Slater et al. [6] study adding real walking to the walking-in-place and the push-button-fly interface. This study confirmed the previous findings with subjective presence higher for real walking than walking-in-place involving, though, a weak overall effect of condition. Real walking was found to be significantly better than both walking-in-place and flying as a mode of locomotion. These studies did not examine spatial perception and navigational tendencies related to each interaction interface involved.

3. Experimental Design

Five groups of 21 participants were recruited to participate in this study from the University of Bristol, UK undergraduate and M.Sc. student population and they received course credits for their participation. 80% of the subjects from each group were male. All use computers a great deal in their daily activities. Participants were randomly assigned to each group. A between-subject design was utilised balancing groups for age and gender. Participants in all conditions were informed that they could withdraw from participation at any time during the experiments and they were naïve as to the purpose of the experiment. Participants had either normal or corrected-to-normal vision. According to the group they were assigned to, participants were exposed to the environment for three minutes, in one of the following conditions:

1) In reality, wearing custom made goggles to restrict their FoV, allowing for monocular vision; referred to as the real-world condition.
2) Using a photorealistic computer graphics simulation on a monocular head-tracked HMD; referred to as the HMD mono head tracked condition.
3) Using the same application on a stereo head-tracked HMD; referred to as the HMD stereo head tracked condition.
4) Using the same application on a monocular HMD with a mouse interface; referred to as the HMD mono mouse condition.
5) Using the same application displayed on a typical monocular desktop monitor with a mouse interface, wearing the same restrictive goggles as in the real-world condition; referred to as the desktop condition.

The participants completed a spatial task (accurate memory recall of elements of the space) after three minutes exposure time to the environment. Their viewpoint was set in the middle of the room and they could rotate horizontally on a full circle around that viewpoint and vertically approximately on a half circle. The FoV and resolution was the same across the technological conditions.

The real environment consisted of a four by four meters room (Figure 1). The computer graphics representation of the real environment was created using the 3D Studio MAX modelling suite and Lightscape radiosity software. The geometry in the real room was measured using a regular tape measure with accuracy of the order of one centimetre. A photometry instrument (Minolta Spot Chroma meter CS-100) was employed to measure the chromaticity CIE(x,y) and luminance (Y) values of the light and materials in the real room. The CIE (1931) colour space is based on colour matching functions derived by human experimentation and it incorporates the trichromacy of the Human Visual System (HVS). The Minolta chroma meter is a compact, tristimulus colorimeter for non-contact measurements of light sources or reflective surfaces. The illuminant (light source) was measured by placing a white sheet of paper in a specific position. Most of the materials (walls, objects, shelves, floor, plugframes) were measured at the same position. To ensure accuracy, five measurements were recorded for each material, the highest and lowest luminance magnitudes were discarded and an average was calculated of the remaining three triplets.

The Lightscape radiosity rendering system uses RGB tristimulus values to describe surface characteristics. The values obtained for the illuminant and surfaces in the scene with the chromameter needed to be converted from luminance and chromaticity co-ordinates to tristimulus RGB values. Measured chromaticity values were converted to RGB triplets by applying a matrix based on the chromaticity co-ordinates of the monitor phosphors. For the final measurements the illuminant had to be taken into account. Measuring a diffuse surface under a given light source results in Yxy values include the contribution of the light source itself. Incandescent bulbs are quite orange and fluorescent light is quite green, however, the HVS perceives light in relative values and not as absolute measurements such as the ones out of the chromameter. The colour constancy attribute of the HVS, generally, corrects for this effect and is responsible for humans perceiving a white sheet of paper as white under a wide range of illumination. If a participant is *immersed* into a synthetic space on a display, theoretically, this should be true as well, however, the small size of the displays prevent it from happening. In relevant calculations for simulating real-world illumination in a synthetic world, therefore, colour constancy needs to be corrected in the rendering process since the HVS does not function as in the real world due to the nature of the displays.

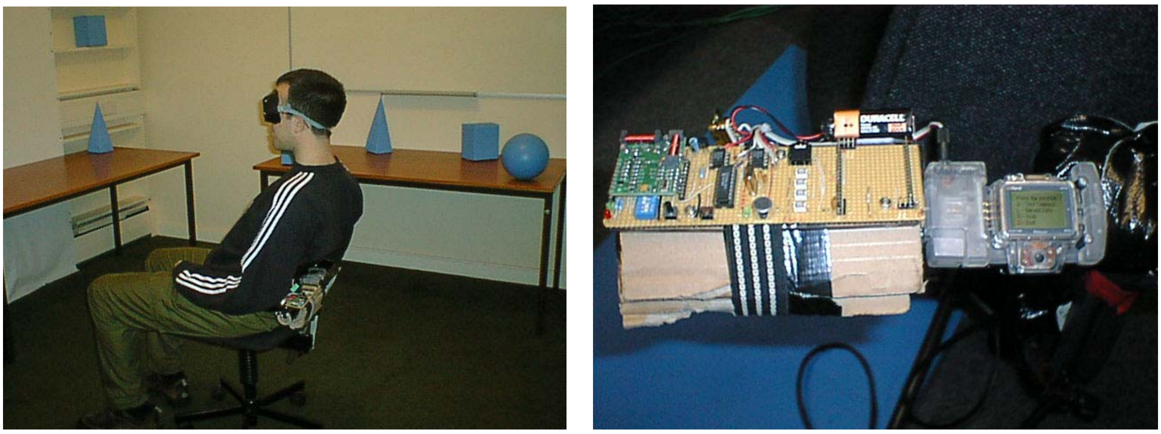

Figure 1: The real world condition (left). The Digital compass on the chair monitoring navigation/idle time of movement for the real world and head tracked conditions (right).

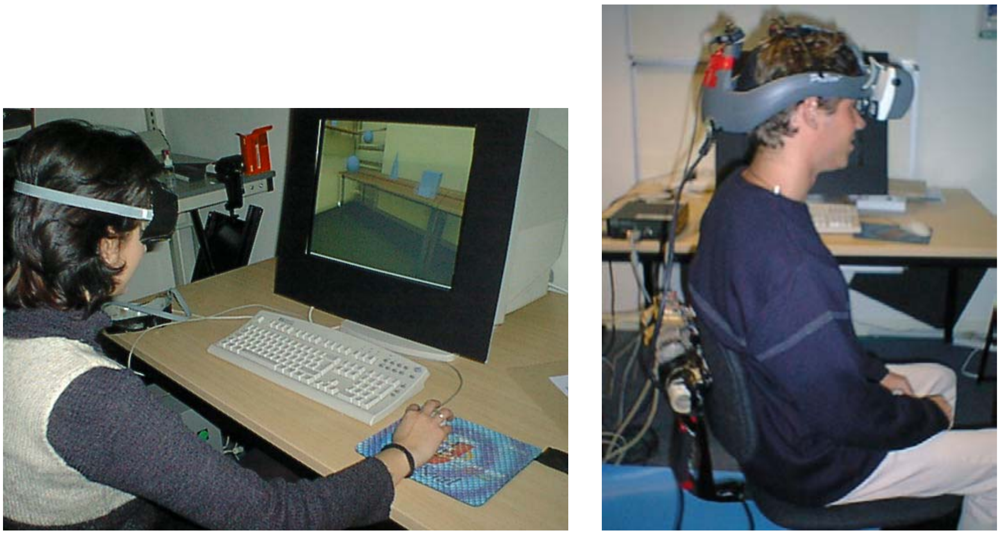

Figure 2: The desktop (left) and the Head Mounted Display conditions (right).

Generally, all the above principles are quite complex issues related to colour vision and how the brain deals with perceptual constancies and are not fully understood. In this study, the illuminant in the real room as measured with a white sheet of paper was taken into account in the conversions of the CIE(x,y) co-ordinates to RGB for all the materials measured in the real experimental room. The colour of the illuminant in RGB values was set as (1,1,1) for the radiosity rendering, e.g. white. All the displays were gamma corrected.

4. Digital Monitoring of Navigation Results

Participants across conditions were monitored in terms of their navigation patterns while horizontally rotating around their viewpoint, placed in the centre of the experimental room. In particular, participants in the real-world, HMD mono head tracked and HMD stereo head tracked conditions were monitored by means of a digital compass, firmly attached to the back of the swivel chair they were sitting on. This was a wireless device and two angle positions were acquired for each second from 0 to 360. More specifically, direction readings were obtained with the 2-axis electronic compass utilising magnetoinductive technology. This was connected to a wristop PC via a PIC microcontroller interface enabling readings to be recorded at a rate of 1Hz. (Figure 1). If the participants were not moving, the same (or largely similar) angle position number was stored indicating idle time. The participants in the desktop and HMD mono mouse condition were monitored by means of software following mouse movements. The participants in these conditions were not rotating the swivel chair they were sitting on but navigated the scene with a common mouse. One angle value from 0 to 360 was acquired per frame.

The statistical analysis of this data was based on the amount of idle time. Idle time could provide a means of understanding participants' navigational behaviour during exposure. Idle time could also offer assessments regarding the level of ease of use of the interface and an indirect measure of overall 'movement' or amount of interactions for each participant. The less idle time participants utilised, the more they navigated around the experimental space (real or computer graphics).

Idle time data were analysed using a comparison of means before carrying out an **AN**alysis **O**f **VA**riance (ANOVA) across conditions [2]. ANOVA is a powerful set of procedures used for testing significance where two or more conditions are used. Once a significant difference is determined among means, post-hoc range tests and pairwise multiple comparisons can determine which means differ indicating significantly different group means at an alpha level of 0.05. The significance level of the Scheffé test is designed to allow all possible linear combinations of group means to be tested. A significant overall main effect was revealed for idle time for the real-world and HMD head tracked conditions (mono and stereo), $F(2, 53)= 5.502$, $p<0.01$. Post-hoc Scheffé tests showed that the amount of idle time for the participants in the HMD stereo head tracked condition was significantly higher than those in the real-world ($p<0.01$) condition. No significant effect was revealed for the desktop compared with the HMD mono mouse conditions, $F(1,41)=2.206$, $p>0.05$. Figure 3 shows the mean idle time in seconds for each condition. It has to be noted that comparisons of idle time between the real-world condition or HMD head tracked conditions and the desktop and HMD mono mouse condition are presented here with some caution. There was a substantial difference between these two groups of navigation that should be accounted for. Participants in the conditions with proprioception cues available could navigate the scene by movement of the head even without any movement of the chair.

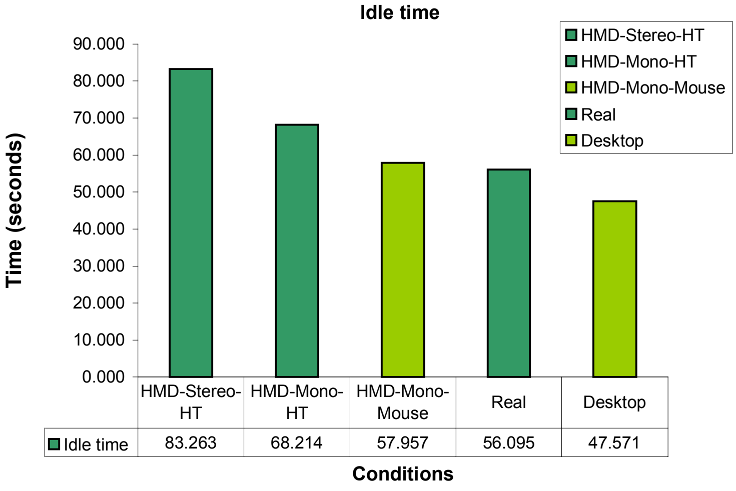

Figure 3: Mean idle time across conditions (secs).

This particular action could result in idle time readings. The participants in the conditions without any proprioception cues such as the mouse-related conditions had to change their viewpoint to achieve the same pattern of navigation and this was accounted for as navigation time. It would be, therefore, valid to compare idle time in two separate groups: The real-world and the HMD head tracked conditions (mono and stereo) in one group and the desktop and HMD mono mouse condition in the second group as shown in Figure . Figures 4-6 show examples of data stored in the digital compass across the real world and the two head tracked conditions for participants with average idle times. Figures 7-8 show examples of the navigation data related to tracking mouse movements by means of software for the HMD mono mouse and desktop conditions for participants with an average amount of idle time for each condition.

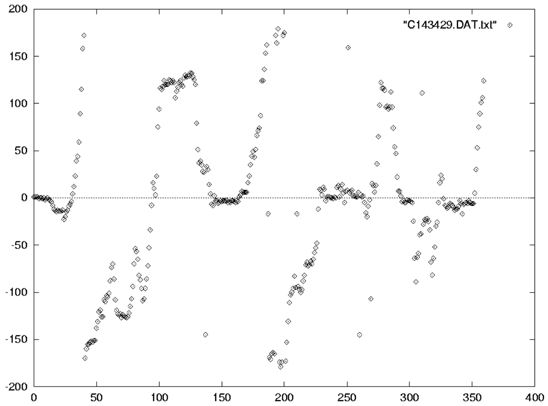

Figure 4: Sample graphs for navigation data for the real-world condition with average idle times (x axis is time in half seconds, y axis is angle value in degrees).

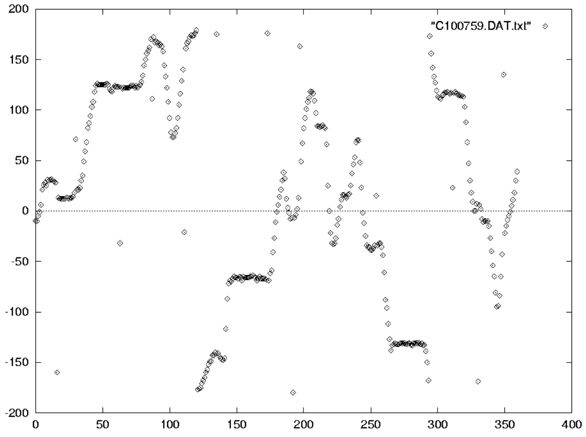

Figure 5: Sample graphs for navigation data for the HMD mono head tracked condition with average idle times (x axis is time in half seconds, y axis is angle value in degrees).

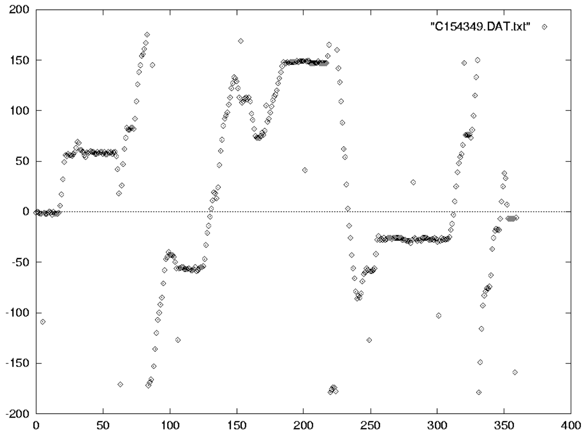

Figure 6: Sample graphs for navigation data for the HMD stereo head tracked condition with average idle times (x axis is time in half seconds, y axis is angle value in degrees).

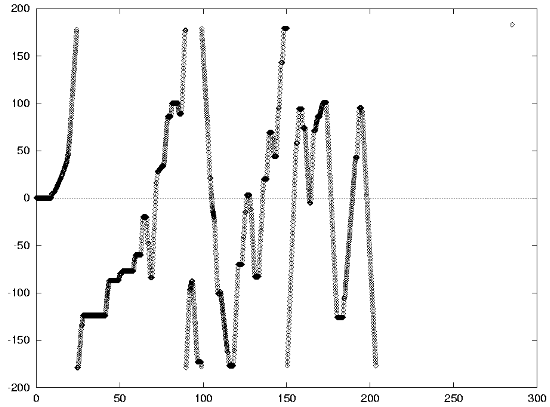

Figure 7: Sample graphs for navigation data for the HMD mono mouse condition with average idle times (x axis is time in seconds, y axis is angle value in degrees).

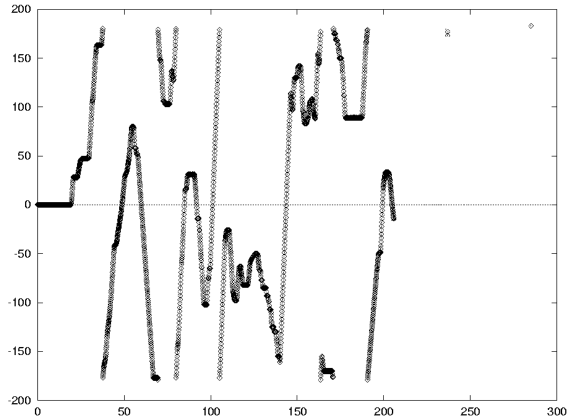

Figure 8: Sample graphs for navigation data for the desktop condition with average idle times (x axis is time in seconds, y axis is angle value in degrees).

For the real-world, the HMD mono head tracked and the HMD stereo head tracked conditions no significant correlations were revealed between the amount of idle time and task performance (accurate memory recall of elements of the space). For the HMD mono mouse condition, a significant positive correlation was revealed between idle time and accurate memory recall of participants ($r=0.42$, Pearson's correlation, $p<0.05$). For the desktop condition, a significant correlation was revealed between idle time and accurate memory recall ($r=0.52$, Pearson's correlation, $p<0.05$), confidence ($r=0.42$, Pearson's correlation, $p<0.05$). Interestingly, the above correlations were revealed in the conditions with a mouse interface. A positive correlation indicates that the higher the amount of idle time, the more accurate recollections participants had. This might mean that in the desktop condition, a higher amount of idle time indicated a higher amount of non-visually induced recollections as opposed to visual mental imagery. This result appears only in that condition and therefore can not be generalised.

5. Conclusions

Generally, participants in the head tracked conditions utilised a higher amount of idle time viewing the scene during exposure. Idle time indicates not only the amount of time that participants spent relatively still, but also, indirectly, it shows the amount of interaction that participants employed to complete the task. Obviously, a high amount of idle time indicates a low amount of interaction or navigation around the scene. The pattern of navigation, therefore, for the real-world condition is not similar to the HMD stereo head tracked condition. The stereo effect might be the reason why participants spent a significantly higher amount of time being idle in comparison to the real-world condition. It could be argued that the higher amount of idle time for the HMD head tracked condition was a result of participants increased focus due to the stereo imagery. However, there is no correlation between idle time and task performance for that condition.

The incorporation of such results offers additional information related to participants' behaviour during exposure. To validate the results mentioned here, a more focused study needs to be conducted including more controls such as, for instance, eye tracking for the real-world condition to account for the movements of the head while idle or head tracking monitoring data.

6. References

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