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REAL PRODUCT EYE TRACKING

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1. Introduction

It is a common procedure that new products are evaluated before submission to the public market to minimize the chances of designs failing by inviting typical consumers or design experts to evaluate products. This is frequently undertaken by means of reviewing virtual products, due to their lower costs and timesaving implications compared to making true physical prototypes. To evaluate these virtual products one of the most common methods used is the Think Aloud technique. This is used equally by industry and academia [Boren and Ramey 2000]. Think Aloud is seen as a straightforward technique, ready to use with proper handling [Hackos and Redish 1998] by combining it with data gathered by other techniques such as a questionnaire or interview. However this protocol even though it is widely used in human sciences has some negative points due to the unnatural cognitive load it applies to the user whilst undertaking the experiments. This issue is raised by [Branch 2000] who argues that having to verbalise whilst undertaking a task that involves a high cognitive load can be problematic. To overcome these heavy cognitive loads researches have also relatively recently been using eye tracking techniques. Eye tracking data will not reveal by itself what a person is thinking, but can be used with other data gathering techniques such as post review interviews as a way of trying to understand what the user is thinking and feeling and their cognitive thoughts. Current eye tracking systems generally require the user to keep their head relatively still and focus on a flat screen or surface producing an unnatural reviewing situation for evaluating real products. Using a monitor also introduces the central bias effect as described by Tatler [2007] where observers will naturally look at the centre of the screen more frequently. To overcome these issues the aim of this pilot study was to create a more realistic 3D eye tracking methodology allowing users to review a physical product in a more natural way. The data produced could then be compared to traditional 2D eye tracking of virtual products to see if there were consistent or differing results. The results of this study could help to inform researches towards how realistic virtual evaluations are compared to real products or whether certain caveats needed to be applied.

This paper is structured with first a brief explanation of eye tracking, leading on to the description of the new 3D eye tracking methodology. The results from the test are reviewed in the discussion including the lessons learned and the possible ways to improve the test and 3D eye tracking methodology. The paper is concluded with possible future benefits and the means to utilise this research in the future.

2. Eye tracking

Duchowski [2003] describes eye tracking as a tool that collects data on eye position, gaze path; time spent looking at a stimulus or fixations at objects along with numerous other variables. The data collected from eye tracking is used in experiments to determine where the users are looking. This is widely believed to reflect what within the viewing space is being assessed. Eye tracking experiments have been performed for several decades already and on various research fields [Duchowski 2003].

Eye trackers work by capturing a user's focus whilst looking at a display. This is accomplished through special hardware and software which gathers X and Y locations by tracking the user's pupil once a calibration session have been undertaken. Fast movements of the eyes (saccades) are recorded along with fixations gaze points which are then combined into scan-paths. Most eye tracking systems come with some form of analysis software which helps to abridge the data gathered into meaningful statistics or visual results. The most described result in eye tracking does not in fact relate to movement, but to fixation points. Fixation points are when the eye remains stationary for a specific amount of time, i.e. when an eye stops temporarily to read a word. This time period could be from a few milliseconds through to a few seconds. It is generally considered that when the eye tracking system measures a fixation it is also measuring attention to that position. The rapid movement of the eye from one fixation point to another, such as reading one word then the next is called a saccade. Saccades are very fast typically taking between 30 and 80ms so it is widely believed that the person is effectively blind during the saccade movement.

3. Real product eye tracking

It is impossible to tell from eye-tracking data alone what people think, but it can be used to look for patterns. The main goal of the research was to compare how the attention of the user is drawn to product details when viewing a real 3D object compared to a virtual model.

To allow for a more natural hand held product review to be undertaken a number of issues needed to be addressed. Firstly through ethnographic study it was shown that users do not keep their heads still when reviewing an object. Even though the users are free to manipulate the object with their hands, they will often pre-empt the products movement by tilting their head in the appropriate direction. They also will move their head backwards or forwards either keeping the part of the object they are viewing at a comfortable distance or bringing it nearer for closer examination. Therefore some sort of tracking system to record the relative position of the head is required. This is also true for the object they are reviewing which is naturally rotated whilst being viewed. Even if an object has only one obvious interface side (such as a tablet computer) when first presented to the user they will turn it over to examine the back.

A number of tracking options are available; firstly an electromagnetic positional tracker such as the Polhemus Patriot system could be applied as used by [Lukander 2003] in their experiment of eye tracking a mobile phone screen. This uses a single sensor that contains electromagnetic coils that emit magnetic fields. These fields are detected by the aforementioned sensor. The sensor is connected to an electronic control unit via a cable, the sensor's position and orientation can then be measured as it is moved. As the sensor is tethered to the control unit, the use of these sensors is limited.

There are also head mounted eye tracking systems that have a more restricted version of the electromagnetic positional tracker, these use a small camera mounted on the head gear, with four LEDs that are placed at the corners of the viewed object (normally a screen). The position of the head is then calculated by the relative position of these corner LEDs in the camera image. This only works whilst the plane is perpendicular to the head, any tilting of the head and the relative positions are distorted corrupting the data.

To avoid tethering and fixed corner LEDs, another option is to use optical motion capture. The two most common forms are either Passive or Active. Both systems apply markers to a user and then use special video cameras to track the marker's position. Reflective (Passive) optical motion capture systems use infra-red LED's mounted around the camera lens, along with an infra-red pass filter placed over the camera lens. The light emitted from the camera mounted LED's are reflected off the markers which are then captured by the cameras. The advantage of this system is that the markers do not need to be powered, but the system can suffer from unwanted noise or loss of marker positions, resulting in the need for extra post-production time to clean up the data. Optical motion capture systems based on pulsed-LED's measure the Infra-red light emitted by the LED's rather than light reflected from markers. These systems have the advantage that the LED's are generally smaller than the reflectors but each LED needs its own power supply. The optical systems are generally more accurate with less noise and related cleaning up issues.

The chosen route used in the experiment was to use an active system, with the pulsed LED's markers being attached to the head of the user and to one of their hands (fig.1.). Through the associated biomechanical software it was then possible to extrapolate the participants head and hand movements. Markers were also originally placed on the actual product but the participants eyes were drawn repeatedly to the markers rather than the product itself. To overcome this issue new virtual markers were created based on the participant's finger markers positions. These were used to produce a new virtual 'bone' that represented the real product's position and orientation in space. This only worked whilst the user held the product in a given manner, when they moved their hand the virtual marker positions and resultant virtual bone was lost.

Figure 1. Active markers on fingers & head

Once the relative 6-axis positions and rotations of the viewer and the object are recorded the next stage is to plot the eye tracking data onto the object. Lukander [2003] used a polyhemus system linked to a users head to track the head position and then directed the gaze points on to a mobile phone face using a computer software. This only required the relative head position to be calculated and accounted for as the phone was held in a fixed position on the users lap. In the new system both head and product were moving so not only did the eye tracking position of the head need to be accounted for but also the relative position and orientation of the model needed to be calculated.

The relative positional co-ordinates were exported from the biomechanical software in to a new bespoke software package developed in the Design School, RePETS (Real Product Eye Tracking Software). The new software created an avatar head using the participants eye distance parameters and placed the virtual CAD model (in this particular case, it was a domestic iron) of the product in its correct relative position in space. The appropriate motion patterns from the biomechanical software were then imported, these were applied to the head and product so they moved accordingly.

The eye tracking data taken in to RePETS was parsed to select individual gaze fixation points and their increment number. The gaze fixation points in relative XY coordinates to the head were projected on a trajectory to intersect with the virtual product's surfaces. Where these projected points intersected with the surfaces an intersection point was created in the shape of an euclidean sphere. The alpha setting of the material applied to the intersection spheres was set at 50%. The more spheres the darker the area became, so creating a basic 3D attention map showing 'entries' or how many times the area was looked at, which could be used for comparison with the 2D attention maps.

To gauge the accuracy of the system a number of set markers were applied to the product and the users were asked to look specifically at one and then look at the next. The eye tracking data was then put through RePETS. To begin with this produced a number of tracking issues as the participant would bring the product closer to their face for increased scrutinisation. To help reduce this effect, the participants were asked to keep their elbows on a table and asked to keep the product at a comfortable distance. Reviewing the results through RePETS it showed that the gaze position data applied was on average accurate to within 1 degree of the fixation of actual target. This meant that areas of interest could be easily identified, but specific details on the product may have been difficult to identify with the RePETS system by itself. To overcome this, a post review interview was conducted where the recorded eye tracking video was replayed with the participant talking though what they had been looking at.

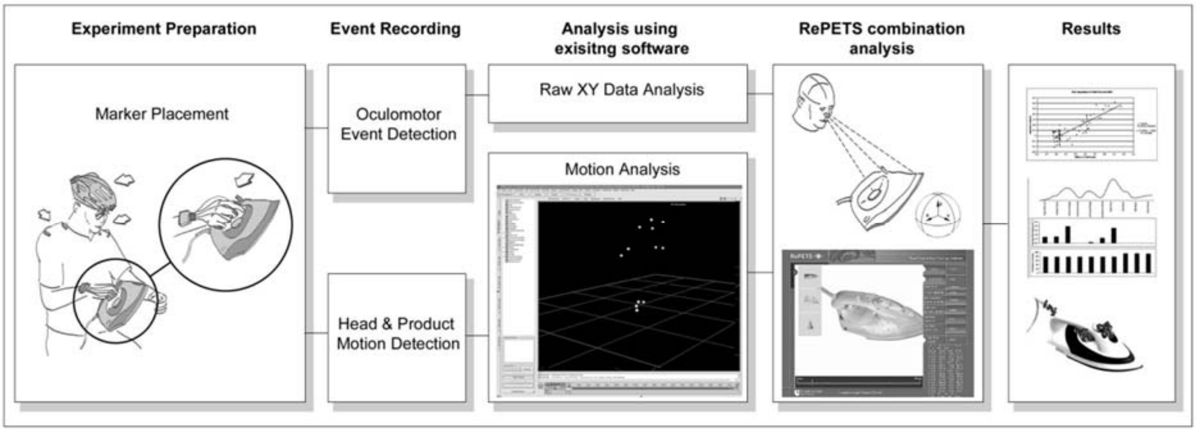

Figure 2. Real product eye tracking methodology

3.1 Participants

Five participants used the 3D eye tracking system. Two of them were disregarded due to bad eye tracking data. The remaining three included 2 male and 1 female. Average age of the participants was 26. For both sets of experiments a standard domestic iron was used. This was chosen as it is a recognizable product that all the users would be familiar with so helping to minimalise additional cognitive load.

In tandem to the 3D eye tracking that took place another 2 males and 1 female participant were recruited who all produced good eye tracking data and had an average age of 23. These participants reviewed the same product using traditional 2D screens with the virtual 3D product model that mirrored the real products rotational characteristics. The virtual model was displayed on screens that were large enough to represent the product at a true 1:1 scale. The 2D screen analysis used the same head mounted eye tracking system.

Rather than just asking the participants to look at the product, two statements were presented to them. "Is the product easy to understand and use?" and "To what degree did you appreciate this product?"

The reason two statements were presented is due to research having shown that viewing behavior of participants changes as the task changes. [Duchowski 2003]. This is backed up by Rayner [1995] who states that, "The triggers to move the eyes are different according to the specificity of the task ". Therefore having two distinct purposes would act as guides in directing the users.

After the test each participant filled in a questionnaire regarding their backgrounds including, profession, age, gender, education and possible problems with eyesight and how frequently they ironed.

3.2 Analysis

The software which comes with eye tracking systems produces a number of parameters that can be useful for statistical analysis. The parameters used in the pilot study were based on algorithms that detected the location and duration of gaze fixations. Gaze fixation points are created when the participant's eyes are relatively still and focused on a specific target. There are several definitions of fixations and their duration. The common fixation duration is between 200 and 300ms. Different systems use different algorithms to calculate them. Within the RePETS system minimum fixation duration was set to 200ms which has become the de facto standard in clinical studies, which was originally derived from a 1962 study of eye movements in reading. The same analysis software (SMI's BeGaze) algorithms and settings were also used with the 2D screen review. The eye tracking headset used were not capable of picking up on saccades but general gaze paths could be extrapolated measuring one fixation point to the next.

Jacob and Karn [2003] reviewed 24 eye tracking usability research studies and listed six of the most commonly used parameters: overall fixation count, percentage of the total time spent on each area of interest, average fixation duration, fixation count on each area of interest, average dwell time on each area of interest, and overall fixation rate. Within this pilot study the following were used:
Average fixation duration on each area of interest, fixation count on each area of interest and finally transition fixation points between different areas of interest to see how the participants looked between areas of interest.

4. Results

4.1 Areas of interest

Before the tests began it was assumed, as stated by Hammer & Lengyel, [Hammer and Lengyel 1991], that areas of interest (AOI) which caught the viewers' attention could easily be located by the help of eye-tracking. On the iron a number of AOIs were set up, these included the buttons groups at the top of the iron, the temperature control knob under the handle, the wire and sole plate spray points. Within the RePETS system these AOIs were created as 3D bounding boxes around the specific AOIs. These invisible bounding boxes could then register when a fixation point was plotted within that specific area. The new RePETS system could track where a participant looked within 1 degree when a product was held at arm's length and participant were asked to fixate on a specific target. Through the analysis of the post review interview and visual analysis of the tracking data it was interesting to note that participants often fixated on blemishes or marks on the real product, such as scratches or where the tampo printing had smudges. This was not replicated in the virtual CAD model which had perfect surfaces. Taking these anomalies out of the equation the average fixation durations on each AOI were shorter for the virtual model, 200-300ms compared with 350-450ms for the real product. Findings show that a longer fixations duration is often associated with a deeper and more effortful cognitive processing so indicating higher interest in the object.

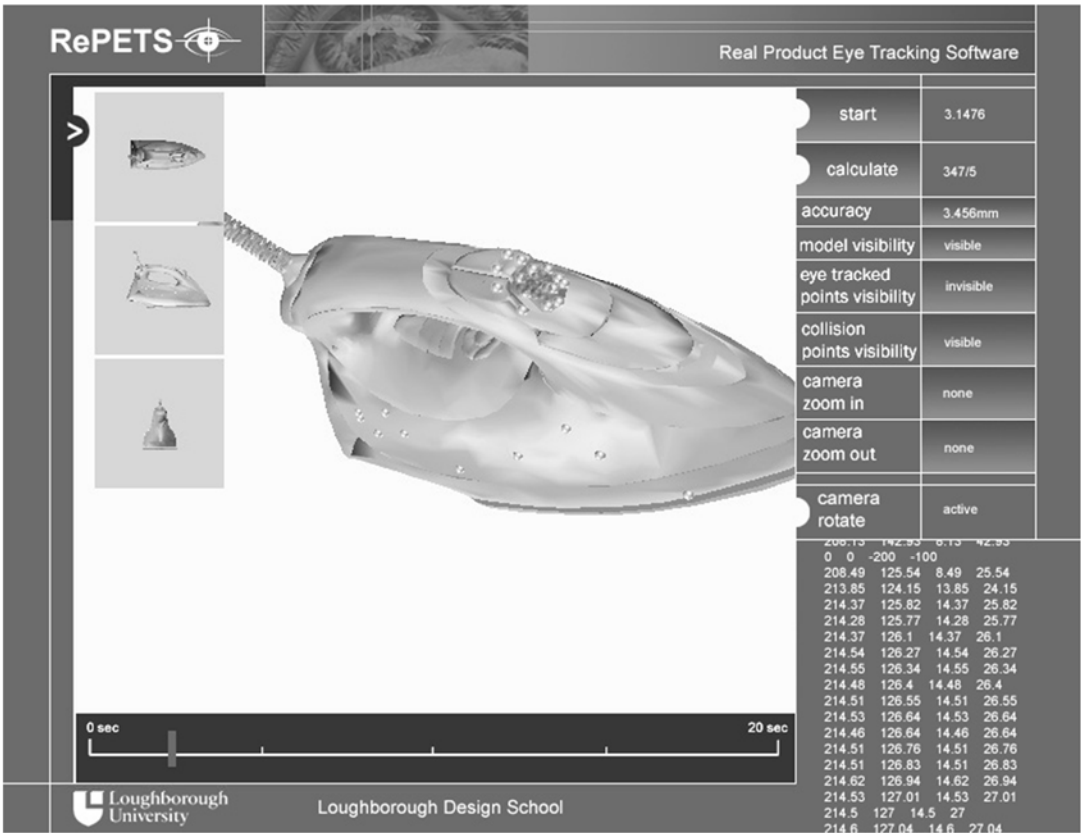

Figure 3. RePETS

On the virtual model a very time consuming manual implementation of AOIs was undertaken due to the virtual model inheriting the actual model's rotational characteristics which were not constant or in a uniform direction. The cloning of the real model's rotational characteristics was to allow for AOI and attention map comparisons between the virtual and real product. The results showed that there were shorter gaze fixation times on the virtual model. The number of fixation gaze points were also less on the virtual model compared to the real model. The transitional paths between fixation points were frequently different as well.This may be accounted for due to the virtual model being spun in a certain way by the original participant and the 2D participant not knowing what they were originally looking at. The cloned rotational characteristics may also explain why there were less fixation points on the virtual model with participant 'scanning' to find an area of interest. This was particularly apparent when the participants were asked how easy the product was to use. When asked about the appreciation of the product, the position of the fixation gaze points for both the real product and virtual product were more widely spread around. Both however, still had their differing fixation durations with the fixation times averaging 200-300ms for the virtual models compared to 350-450ms for the real product.

To eliminate the inherited orientation issue, a short experiment using traditional 2D eye tracking was also undertaken using a virtual model that could be spun in any orientation by the viewer. Counting the fixation gaze points revealed that this virtual model again had fewer points than the real product. However, it was not possible to compare attention maps due to the differences in orientation. The two virtual model experiments revealed indications of the central bias effect as described by Tatler [2007]. Central bias effect is common on monitor based eye tracking experiments where participants are more likely to look more at the centre than towards the edges. They are also more likely to make more horizontal than vertical saccades, and very few oblique ones. Tatler attributes this observation to one of three possibilities: Firstly, that of the centre of the screen is the optimal position for early information processing. Secondly, that the centre of the screen may be a convenient location to start oculomotor exploration. Or third, it may be that the central bias reflects a tendency to re-centre the eye during its orbit. With the real product the RePETS system did not show any noticeable central biasing.

4.2 Attention maps

Attention maps or heat maps is another form of representation of eye tracking data. Although they do not represent attention per se they do represent the spatial distribution of eye movement data. The beauty of heat maps is that they provide quick and intuitive visual representations of eye tracking data which researchers can easily determine a meaning from. This is also their major disadvantage due to their simplicity; it is easy to draw conclusions from them that often should not be drawn. It could be that these regions are interesting to the viewer, but it could also be due to the region having markings such as scratches or blemishes and the viewer needs to look twice or longer. Nethertheless heat maps are an important compliment to quantitive data of AOIs. Within the experiments attention maps were used for comparison to see if similar AOIs attracted people's gazes. They were compared visually which showed that the real model had tighter clusters of gaze fixation points compared to the virtual product.

5. Conclusions

The study is rather small and all the participants were staff and students available at Loughborough University at the time of the study. This group of participants are however to be felt suitable for this research as it is a comparison study between traditional 2D viewing and the new 3D methodology.

The natural movement of the participants were restricted by asking them to keep their elbows on the table and to keep the product at a constant distance to reduce tracking issues. As the RePETS system produces relative coordinates within space it would be possible in the future to introduce minimum and maximum 'head to product' variables to eliminate wayward tracking points. The participants were also asked to keep a hand fixed on the product. When asked to reflect on the experiment, none of the participants felt that either constraint had been a big hindrance in examining the product. This may have been due to the chosen product being an iron, as the handle is an obvious and comfortable place to hold. However, from observation when the participants were first handed the product a number of them did move their hands when examining the object. This could have been adjusted for within the biomechanical software but recalibration would have been required at each stage. This is also a problem with many existing eye tracking systems where [Goldberg and Wichansky 2003], suggest "recalibration every few minutes".

The virtual model viewed on the 2D screen was limited as the photorealism was reduced to allow for quicker rendering of the animation. The observation time was also restricted to 20 seconds for each question to help reduce the post processing time. The photorealism was reduced even more with the virtual model that could be spun in any orientation as it required real time rendering. Creating more photorealistic virtual models including blemishes may enhance the realism of viewing a virtual product. Future research in to the emotional responses of handling a real 3D object would also be of interest.

Even though there are a number of restrictions the findings from the research did show that the RePETS system can be used with real products. This allows for a more natural evaluation to be undertaken compared to viewing virtual models. It also appears to illuminate the central bias issues of requiring the use of a monitor to view a virtual model. The use of attention maps cannot be used to draw conclusions of why people looked at specific areas, but they can be used to point out regions that attracted people's attention and how clustered the fixation points are within those regions. Using a 3D model allows the heat maps to vary when viewing a product at different angles which could be used for example within engineering design to improve the aesthetics or the clarity of information be it either printed or semantic of a product when it is used in certain ways. This would have an advantage over designing it purely from the direction that the designer perceives it will be used.

The use of AOIs allows for a more statistical analysis to be performed allowing for total dwell times along with number of fixations within the AOI to be measured. The results of the experiment showed that when reviewing the real product, longer fixation times and larger fixation numbers with the AOIs were produced indicating more interest in the AIOs. Using 3D AOIs allows for a more informative summary of how a product is evaluated rather than a static image. This in turn could help improve the product's features, for example a popular AOI could have better quality materials assigned to it then less popular areas, such as in the design of a car instrument panel.

There is a large amount of measurements and analysis that can be performed with eye tracking data (eye tracking as a research tool can provide its users with over one hundred different measures), so the ability to accurately plot eye tracking data on to a 3D model may prove useful in developing real product analysis in the future. It is also possible that the findings may help or adjust virtual product analysis to reflect how a real product is actually reviewed.

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