Creating Observational 3D Sculptures

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Abstract

Technology has been used to assist in communication and concept development by artists, designers/inventors, engineers, clients, manufacturers and others. [1-3] The use of technology to aid artists capture what they see has been used since the Renaissance with the introduction of the camera lucida and the camera obscura.

A modern method to assist in capturing how people see is to use eye tracking technology. The data collected from eye tracking experiments is widely believed to reflect what within the viewing space is being assessed. The analysis of this data can be output in statistical form, or as 2D graphic overlays placed on top of flat images. The innovation described in this paper is the application of a new methodology developed to allow quantitative eye tracking data to be used as a basis to create 3D sculptural forms.

This paper is structured with first a brief explanation of eye tracking, leading to the description of the new 3D eye tracking methodology. The results from the test and the final output are reviewed in the analysis including the lessons learned and the possible areas for improvement.

Keywords

Eye tracking, 3D sculpture, virtual avatars, 3D scanning, rapid prototyping, subsurface etching.

Introduction

Technological developments and artistic works have always been closely related whether as a direct link or in an abstract sense. Developments in technological tools used for analyzing vision have had profound effects on how we see the world. It questions the way we perceive objects, the way we acquire knowledge and how we comprehend the world. Within the realm of art, technological developments have had a distinct impact on artistic representations. One of the most interesting periods for comparison when looking at the introduction of new technology and its affect on the development of art and the perceived differences between vision and representations can be found by examining the attitudes of the Italian Renaissance artists to those of the 17th Century Dutch artists.

Italian representations were based on the conceptual notions of perfect beauty and poesis. Artists selections from nature were chosen with an eye to heightened beauty and mathematical harmony - an ordering of what was seen according to the informed choices and judgment of the artist based on particular issues and concepts rather than as a form of representation where the single most important reference is the natural appearance of things. [4]

In contrast Dutch 17th century Renaissance painting was heavily influenced by the use of technology to assist in the act of seeing. During the century several experiments were carried out to perfect the accuracy in which technology could mechanically assist seeing. New technologies became very popular during this time with a number of different styles of “cameras” and optical lenses being designed to address the popular needs of the artists to help them in their observations of nature. [5] This new technology that could enhance sight through microscopic close ups, reflections and enhancement of distant views was seen as a new way of gaining knowledge and brought insights into how we see.

It is interesting to note that David Hockney’s research into the use of mechanical aids in Renaissance paintings has revealed that the aforementioned Italian artists also used the camera obscura but only as a reference tool for placement accuracy without incorporating any of its effects directly into their landscape paintings. [6]

Each technological tool type influences the nature and structure of artistic conceptualization and production. Each tool type has its own characteristics, as well as its own strengths and weaknesses. For the development of observational 3D sculptures described in this paper the modern day electronic tools of the computer and eye tracker were used.

Computers have been used for the creation of artworks as early as the 1960s. Michael A. Noll, a researcher at Bell Laboratories in New Jersey created some of the earliest computer generated images, among them Gaussian Quadratic in 1963. The works of John Whitney, Charles Csuri and Vera Molnar in the 1960s remain influential today for their investigations of the computer-generated transformations of visuals through mathematical functions. [7] Eye trackers have also been used to create art, however, from the literature review undertaken it appears that they
have only been used to create two dimensional representations. One of the most high profile experiments using an eye tracker and bespoke software to draw images was the Eyewriter project which helps people suffering from ALS (Lou Gehrig’s disease) such as the legendary LA graffiti writer, publisher and activist, named Tony Quan, aka TEMPTONE, who was diagnosed with ALS in 2003, a disease which has left him almost completely physically paralyzed… except for his eyes. [8] The graffiti produced with the technology was projected onto buildings and walls in Los Angeles. Regarding exhibitions of eye tracked art, one of the most recent was at the Riflemaker gallery in London in March 2015 where they exhibited 2D portraits drawn by the artist Graham Fink who uses custom eye-tracking software to transform his gaze into a medium. [9]

Duchowski, 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. [10] 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. [10] However, researchers have emphasized that some common details e.g. scanning path, number of gazes, percentage of participants fixating an area of interest, and time to first fixation on target area of interest were interesting measures for research, but that they have often been overlooked during analysis in many studies. [11-12]

Eye tracking glasses such as the one used in this research, the Tracksys ETG (see figure 1) work by capturing a user’s focus whilst looking at an object. This is accomplished through special hardware including glasses with built in infrared cameras, and specialized 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 scanpaths. Most eye tracking systems come with some form of analysis software that helps to abridge the data gathered into meaningful statistics or visual results.

The uses of eye-tracking methods have made possible the close examination of the conscious and unconscious gaze movement of a respondent in visual systems research. [13-15] The human visual system starts with eye movements, which are linked to perceptual systems; it is the close relation of these movements to attentional mechanisms, saccades, that can provide insight into cognitive processes, e.g. language comprehension, memory, mental imagery and decision making. [9]

Richardson and Spivey cited early empirical findings from Perky, Clark, Stoy, Goldthwait, and that the frequency of eye movements increases during mental imagery.

Figure 1. Tracksys ETG 60Hz binocular tracking glasses.

[16-21] In addition, their recent work suggests that eye movements were related to both memory of specific perceptual experience and cognitive acts of imagination. [16] Levy-Schoen emphasized, ‘to the extent that eye movements are reliable correlates of the sequential centering of attention, we can observe and analyze them in order to understand how thinking goes on.’ [22] The use of eye-tracking for aesthetic-based research by Fischer et al. Russo and Leclerc, Malach et al. and many other works reported in Jacob and Karn were founded on similar grounds; namely the correlation of eye movements and visual perceptual systems. [11],[23-25]

From the literature review undertaken it appears that eye tracking has never been used as a basis to create 3D sculptural work. However, within the field of art, eye trackers have been used to investigate visual exploratory behavior of paintings. [26-33] The areas receiving high densities of fixations have been understood as indicating the observer’s interest in informative elements of the image. [27] The studies of aesthetic judgment driven by neural primitives have mainly focused on the analysis of image composition, i.e. the relation among visual features of an artwork. [28] To begin, the entire visual field is processed in parallel to generate a mental plan that is weighted according to the task. Next, eye movements are performed in order, visiting the strongest or most interesting feature first and proceeding to the weakest or least interesting. From this bottom-up driven process, aesthetic experience appears to be influenced by elements such as balance contrast and symmetry. [29-33] Further work has identified other properties that attract the attention of an observer to specific areas of interest (significant regions of an image). [34] These factors include curves, corners and occlusions as well as edges, lines, color and orientation and contrast of luminance. There is also evidence that a modest degree of complexity increases the aesthetic appeal of visual stimuli. [25-37]

To use eye tracking to create a sculptural shape an object on which the form could be based was required. It was decided that a human face as a 3D form held enough of these areas of interest and complexity to act as the main
source of inspiration. Faces are special objects in human perception. Infants learn about faces faster than other objects. It is as if we are born with visual systems primed to learn to recognize important humans, such as our own mothers. [38-40]

Observing the face would also engage the use of top-down cognitive processes with intentional direction of attention as well as focused attention in terms of eliciting the simulation of emotions and sensations. Several studies have shown that the face is generally the first part of the body that is scanned in portraits activating a constructed visual encoding, instead of the more common analysis of individual features. [42-45] This is thought to be due to the face being constituted of a set of 3D objects which seem to be mentally represented in a holistical way. [44-46] Research has shown that when observing a face the observer can prioritize their gaze towards ‘diagnostic’ features. There is reason to believe that both the familiarity with the human face, and its typical representation can often result in a gaze strategy where the goal is to get as much information as possible. [47-49]

From the research undertaken into eye tracking of faces it appears that the first point of interest of the face is towards the internal region, particularly towards the eyes and bridge of the nose. [50-55] This first point of interest might be anchored onto a position which provides a perceptual span that either covers the whole stimulus or that maximizes the area of the object which is included within the region of high resolution acuity. [50],[58] This extended scanning of the face would be ideal for capturing large amounts of eye tracking data to construct a facsimile in the form of a 3D sculpture.

**Eye tracking 3D objects**

The main goal of the research was to see how it was possible to translate the transitory visual dialogue created by observing a model into a tangible three dimensional object. To capture eye tracked points from an observer viewing a 3D object using 2D eye trackers, and then translate this captured data back into a virtual 3D space, a number of issues that needed to be addressed. The premise was to capture where the observer was looking at the 3D object. Take these points and the relative positions of the observer and the 3D object and place them in a virtual environment. Within this virtual world, re-project the eye tracked points from the observer to the virtual 3D model. Where these points intersected the virtual model, voxels could be created highlighting where the observer had spent time looking. These points in space would then be the basis to create a 3D sculpture (see figure 2).

Firstly through observational studies it was shown that observers do not keep their heads still when reviewing an object. Even if an observer is looking at a relatively small object, small head movements are observed which often pre-empt the movement of the eyes by tilting their head in the appropriate direction. If an object such as a sculpture is observed the user will naturally move around the object and tilt their head to get a better view of the static object. Therefore some sort of tracking system to record the relative position of the head would be required.

A number of options were available; firstly an electromagnetic positional tracker such as the Polhemus Patriot system could be applied. 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 via a thick chord to the control unit, the use of these sensors is limited. Previous research into eye tracking objects by Lukander used a polyhemus system fitted 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. [59]

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**Eyetracking Set Up**  
**Event Recording**  
**Analysis using existing software**  
**PO3TS combination analysis**  
**Output**

Figure 2. Graphical representation of the methodology to produce 3D sculptures from eye tracking data.
To avoid tethering, the second 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 or Active motion capture systems are 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 on the negative side each LED needs its own power supply.

The chosen route used in the experiment was to use the passive system. Similar to Lukander, markers were originally placed on the observer. After some experimentation it was found that the movements of the head of the user whilst observing the model, combined with the eye tracked positional data caused too many inaccuracies with the recorded data. To overcome this issue, more markers were added to the observer, but the system could not be calibrated enough to eradicate the inaccurate readings. The solution was to attach the markers to the model’s head, which only slowly turned (see figure 3). The observer was able to keep their head still by resting their chin on a chin mount. With this arrangement there was the downside that the observer would often look at the markers, rather than just the head, but the accuracy was greatly increased. The markers also had another advantage as acting as calibration markers on the model.

Once the relative 6-axis positions and rotations of the object was recorded the next stage was to import all the data into a 3D CAD system. The relative positional coordinates were exported from the biomechanical software associated with the passive tracker system in to a new bespoke software package developed by the author entitled PO3TS (Positional Observational 3D Tracking Software). The model’s head was scanned using a NextEngine 3D scanner and then also imported in to PO3TS. To this model the appropriate motion patterns were applied so the head became animated.

An avatar head of the observer using their eye distance parameters was modeled and imported into the new software. The eye tracking data was then also taken in to PO3TS and parsed to select individual gaze fixation points along with their increment number and time stamp. The gaze fixation points in relative XY coordinates to the head were applied to a plane at the same distance as the scanned model’s head. These points were then projected using a vector from the observer’s eye, through the point on the plane to intersect with the virtual head’s surfaces. Where these projected points intersected with the surfaces an intersection point was created in the shape of a cube. (see figure 4). The alpha setting of the material applied to the intersection cubes was set at 50%. The more spheres the darker the area became, so creating a basic 3D heat map which could be used for comparison with the 2D heat maps created by the eye tracking software.

To gauge the accuracy of the system the passive markers were used as calibration targets. The observer looked specifically at the center of one and then asked to look at the next. The eye tracking data was then put through PO3TS. Reviewing the results through the software it showed that the gaze position data applied was on average accurate to within +/- 2 degrees of the fixation of actual target. This meant that areas of interest could be easily identified, but specific details on the head may have been difficult to identify with the PO3TS system by itself. In anticipation of any issues regarding accuracy of the plotted points within the PO3TS system a time stamped video showing where the observer had looked at the model through the use of a red laser dot was also recorded.

Figure 3. Model with passive markers.

Figure 4. Processing section of eye tracked points using PO3TS software.
Analysis

The software which comes with eye tracking systems produces a number of parameters that can be useful as outputs for analysis. Jacob and Karn 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. [11] Within the PO3TS system the following were used:

- average fixation duration on each area of interest.
- fixation count on each area of interest.
- transition fixation points between different areas of interest to see how the participants looked between areas of interest.

All three of these parameters are based on the location and duration of saccades and gaze fixations. Saccades are the rapid movements between fixation points during which the brain does not receive visual information. 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 PO3TS system minimum, only fixation duration larger than 250ms were used. Using these three parameters different results could be produced by adjusting the information input into the PO3TS system.

Before the tests began it was assumed, as stated by Hammer & Lengyel, that areas of interest which caught the viewers’ attention could easily be located by the help of eye-tracking. [12] The new PO3TS system could undertake this task within +/-2 degrees of accuracy. Replicating existing research, internal parts of the face; eyes, nose and cheeks, were explicitly focused on more than the rest of the face. This occurred whilst the model’s head was still and also whilst it moved with the same regions being the main areas of interest whilst the head was positioned at different angles (see figure 5). The only difference being that the cheeks had more gaze concentration when the face was oblique to the observer.

The resultant information created a number of cluster areas of interest. The fixations indicated that the visual attention of the observer was predominantly targeted at the center of the face just below the eye sockets in addition to the eyes. However, the other areas of interest around the face were not sufficiently linked together to be able to be output to a 3D rapid prototyping machine without a lot of support material being needed between the regions.

To overcome this linking issue, a sculpture was created using subsurface laser engraving. Sub-surface laser engraving is created by focusing a laser below the surface of a transparent material where it causes small fractures to appear so that the points are seen as being suspended in the material (see figure 6). The materials used for this engraving needs to be of high-grade optical quality to minimize distortion of the beam. This type of process is often seen in ‘crystal’ souvenirs.

This produced an interesting sculptural form, but was restricted by the size of single crystal block available and the inherent cost of this material. To develop a larger sculptural piece the observation of the model’s face required further data to hopefully produce enough data points so that they linked together to be able to form a viable structure for 3D printing. This required the observer to consciously try and look over more of the face of the model. This was a forced experiment and it was interesting to note that the gaze point collections of the first observation were different as the observer was trying to be more systematic. There is evidence that eye movement patterns are affected by the cognitive task based on studies of humans on high-level scene perception as well as from visual aesthetic studies. [27] Zangemeister and colleagues also found that the gaze patterns of the same artworks whether abstract or realistic changed as a observation task was changed. [55-56] During this extended observation there were more wayward points observed then the first sessions. This is also a problem with many existing eye tracking systems where Goldberg and Wichansky suggest ”recalibration every few minutes”. [57]

As the PO3TS system produces relative coordinates within space it was possible to introduce minimum and maximum ‘observer to model’ variables to eliminate some of these wayward tracking points. The parsed data could then be extrapolated from the PO3TS system into Rhino CAD software. Within Rhino some post production cleaning up took place which allowed for the resultant voxels to be output as a water tight 3D object that could be converted into an stereolithography model ready for 3D printing (see figure 7).

Figure 5. Observing the model whilst being motion tracked.
Conclusion

Technology has been used for many years to enable artist’s to produce their work. The PO3TS system is another tool, it does not produce a finished object but facilitates creativity by converting the narrative of vision to the production of unique sculptural forms.

Even though there are a number of restrictions the findings from the research did show that the PO3TS system can be used with 3D models to create sculptural forms that capture the original representation whilst maintain an abstract form. The author is further developing the methodologies and the software to be able to output variations of the forms, both in their complexity and in the nature of the data collected. Possible future outcomes could be from multiple observers viewing the same object to create a collaborative sculptural piece. The methodology could also be used to capture more transient moments such as capturing the movement of a moving object such as dancers.

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**Bibliography**


**Author’s Bibliography**

Kevin S. Badni is the Head of Art and Design, in the College of Architecture, Art and Design at the American University of Sharjah in the United Arab Emirates. His terminal degree is in Multimedia, awarded by De Montfort University in the UK. Before becoming an academic he spent ten years working in the design industry including managing the UK’s first commercial Virtual Reality center. Beyond teaching design and multimedia courses, Kevin’s interests in New Media Art have manifested in a number of related academic journal papers, conference paper presentations and had his art exhibited in galleries in the UK, Australia and the UAE. Kevin’s main area of interest is the personal perceptions of vision, using augmented, virtual reality and eye tracking tools to create engaging art pieces.