Using Gaze Interaction to Improve the Way People View Art

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Submitted by: Felix Crocker

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Abstract

Art museums have seen a general trend in recent years of falling attendance numbers. Studies indicates that this number is particularly high amongst a younger demographic.

Common explanations for this point towards the inability of the traditional gallery to provide viewers with information relating to the exhibition, in a way that engages viewers.

Art museums have been embracing the use of technology, and the development of novel interactive systems,in an effort to connect with visitors, and provide a more engaging experience.

We propose gaze interaction as an ideal solution for the creation of an system to provide visitors with information relating to the exhibits, in a way is interactive and enjoyable experience. We investigate the inherent challenges of designing for gaze, and the requirements for a fully gaze controlled, public-space system.

We identify a novel application of a technique called *Subtle Gaze Direction* (SGD). The technique utilises gaze interaction to guide a user's eyes gaze around an image. It is designed to be unnoticeable to the user, as such it has potentially interesting applications in guiding a novice viewer over artworks.

The culmination of the study is the design and implementation of a novel system for browsing a digital art galleries. The system incorporates the features of gaze interaction, subtle gaze direction and contextual auditory information.

We carry out an empirical study assessing the usability of the system. As well as the effects of audio and SGD on a viewers enjoyment, interest and understanding. The study reveals a strong correlation between the presentation of audio and user's level understanding, as well as insight into the effects of SGD and audio on users gaze patterns. Furthermore, it was found that the gaze interactive system was very well received by users in terms of enjoyment and usability.

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Acknowledgements

I would like to extend my gratitude to Dr Christof Lutteroth, for his guidance throughout the project. His advice and support have been truly invaluable.

I would also like to thank my family for their support and encouragement, during this project, and the rest of my time at university.

Chapter 1

Introduction

In this section we will outline the problem that this project aims to address. We will then present our system as a proposed solution. We highlight some research problems involved with the project, and define our research goals, providing a general outline of the work involved.

1.1 Problem Description

Recent studies have shown a significant decline in attendance to art museums and galleries, with the Tate group reporting a 15.9% drop in attendance last year (Ellis-Peterson, 2017). Whilst there are a wide variety of motivations for visiting art museums, and potential reasons for falling attendance numbers, this project aim to focus on the specific area of novice visitors, and the requirement for systems to provide information.

A study into the motivations of visitors to art museums identified that 40% of visitors are driven by intellectual reasons. Specific example being: self-improvement, academic interest, and a sense of cultural identity (McIntyre, 2007). It would seem, in this case, there is a strong need for the galleries to curate and information relating to art, particularly when concerning visitors less well versed in the subject.

Art galleries and museums typically present information through static text or audio displays. Such means of display seem insufficient to present a significant amount of information about the subject, in a way that remains engaging to the viewer. Particularly so, when concerning a digital generation used to obtaining information in an instantaneous and interactive manner. This rationale is supported by a study a study that found young people (aged 16-26), tend to visit art galleries far less than the population as a whole (Mason and McCarthy, 2006).

Another growing tend amongst art museums is the embracing of technology, as a means of engaging visitors. Such exhibits often attempt to make novel use ways, to provide exciting, interactive experiences. The focus of this project is to use such technology to address the aforementioned problems of presenting information, and appealing to a wider demographic of visitors, including novices.

1.2 Proposed Solution

The intended outcome of this project, is an interactive system designed to sit inside a gallery or museum exhibition space, with goal of allowing visitors to access more in depth information relating to the artworks.

The proposed system will make use of eye tracking technology, and will feature an entirely gaze controlled interface. Eye gaze interaction is a growing area of interest, with eye trackers becoming commercially available at a lower cost, and with improved accuracy. As well as being a novel and exciting means of interaction, eye gaze has many inherit benefits to a system for use in a public space. These include hygiene, and the lack of peripherals to maintain.

The system will aim to provide users with contextualising audio information as they view artworks. Taking advantage of the user's eye gaze input to present the audio information in a way is interactive, and allows the viewer to remain immersed in the art viewing.

A recent study presented a novel application of eye-tracking technology called *subtle gaze direction* (SGD). This technique applies subtle image-space modulations to direct a viewer's gaze around digital images. SGD exploits differences in our periphery and foveal vision, to direct the viewer's gaze without them noticing any changes to the image. Real-time analysis of the viewer's gaze pattern provides a means to add further subtlety to the technique (Bailey et al., 2009).

Subtle gaze direction would be an ideal means guiding a viewer around a painting, in a way that is non-intrusive, and does not distract from the viewing experience, as normal overlayed user interface elements would. Through the combination of this technique, audio, and gaze interaction, we aim to create an truly novel way for people to view art.

1.3 Research Problem

One of the main challenges for the project simply arises from the novelty of eye gaze interaction. Designing a gaze interactive interface presents unique challenges, and there exist no concrete design standards.

Similarly, the novelty of subtle gaze direction means the technique is relatively undocumented. Implementations have been lab tested, however the way the technique behaves when applied in different scenarios is fairly untested. The application of SGD proposed in this project presents particular challenges, due to the complex nature of visual art, meaning there are more distractions from the intended gaze point. Furthermore, the SGD system will need to be both accurate and reliable enough to guide the user around all the points of interest on the image.

1.4 Research goals

- We will conduct research into the influence of external factors, such as information, on ones emotional responses when appraising art. We will assess whether contextual audio information provided to a user when viewing a painting is beneficial to their overall experience. Evaluating emotional responses such as understanding and enjoyment.
- We will assess the usability and enjoyment of a fully gaze controlled system, designed to be used in the context of a museum or gallery space, that allows users to view a library of artworks. This will include research and experimentation with some of the current methodologies for creating gaze based interfaces.
- We will conduct research into existing implementations of subtle gaze direction, and their level of success. We will assess whether we can use SGD to influence a user's viewing pattern, in a way that is not detrimental to the viewing experience.
- Study assess whether subtle gaze direction can be applied to guide a user's gaze when viewing a painting is beneficial to their overall experience. Including interest, ability to understand, and aesthetic appreciation.

1.5 Outline

We will begin by conducting a review of existing literature. This will include a review of the psychology, and other external factors, that influence ones enjoyment of art. We will then look at some novel uses of technology in art museums. We will review the current state of eye-gaze interaction, assessing some relevant design considerations. Finally, we will review studies on the topic of subtle gaze direction, examining implementations and applications.

The literature review will be used to inform requirements for the final system, as it is intended to be used in the gallery space. Requirements will be broken down into Hardware, software, user interface.

Following on from the development of the requirements list, and the information from our literature review, we will cover design of the system. This will include the intended hardware configuration, a high level look at the user experience design, a more detailed review of specific user interface design elements, and finally a high level review of software design choices.

We will then cover the details of implementing the system. With a particular focus on the implementation of Subtle Gaze Direction, and challenges of implementing a gaze interactive system.

Having created a prototype implementation, we will use this as the basis of a user study. Formulating hypotheses based upon our research goals. we initially discuss the decisions behind the design and methodology of the experiment. Next we will analyse the empirical data obtained by the study, and assess the usability of the system based on the results of user testing.

Finally we will conclude by summarising the contributions of the project, a discussion of potential future work relating to research or development, and a brief reflection on the project itself.

Chapter 2

Literature Survey

In this section we will review some existing literature, that will inform the design of our system. We begin by looking at the psychology, and other external factors, that influence ones enjoyment of art. We will then look at some novel uses of technology in art museums. We will review the current state of eye-gaze interaction, assessing some relevant design considerations. Finally, we will review studies on the topic of subtle gaze direction, examining implementations and applications.

2.1 Psychology of the Appreciation of Artworks

2.1.1 Aesthetic Appreciation of Art

Philosophers consider aesthetic appreciation to be the appreciation of beauty and excellence. Defined in Peterson and Seligman's *Character Strengths and Virtues* as "the ability to find, recognize, and take pleasure in goodness in the physical and social worlds" (2004).

It is important to understand the factors relating to aesthetic appreciation, when designing a system to improve the enjoyment of art.

Leder, Belke, Oeberst and Augustin (2004) proposed a theoretical five-stage information processing model describing aesthetic experiences: perception, explicit classification, implicit classification, cognitive mastering and evaluation. The model describes what cognitive processes may take place, when an individual is exposed to some artwork, until they form a judgement.

The model highlights factors that might influence an individual's evaluation of an aesthetic experience, such as: a pre classification of the object, previous experiences, domain specific expertise, and personal tastes.

The result of the processing model is comprised of two distinct outputs. The first being Aesthetic judgement, a result of higher order cognitive evaluation. The second being aesthetic Emotion.

Leder et al. (2004) state that whether this aesthetic judgement is positive or negative, is dependant on whether or not the interpretation was successful or unsuccessful.

It is worth noting the implication of this, that aesthetic appreciation, as it relates to a user viewing a piece of art, is not as such a 'gut reaction'. Rather a result of a complex processing model.

Reber, Schwarz and Winkielman proposes aesthetic pleasure is a function of the perceivers processing dynamics, this is similar to the complex model proposed by Leder et al. (2004).

Leder et al.'s view that positive aesthetic judgement is based on understanding, is supported by Reber et al.: "The more fluently perceivers can process an object, the more positive their aesthetic response" (2004).

Reber et al. consider the level of processing fluency to be a product of the type of images being viewed, and their traditional values of beauty.

In contrast to this Belke, Leder, Tilo and Carbon (2010), considers augmenting the level of cognitive fluency of an art piece by manipulating supplemental information. The effect of this is investigated by changing the titles of artworks.

In an empirical study, Belke et al. found that related titles produced highest appreciation followed by no titles and unrelated titles.

Belke et al. conclude that "the phenomenal experience of cognitive-fluency is an intrinsic source for the hedonic value of art". Whilst this concurs with the views of Leder et al. and Reber et al., the more important conclusion, as it relates to our study, is that the addition of supplemental information relating to an artwork, can improve the level of cognitive fluency.

2.1.2 Aesthetic Appreciation and Context

Previously mentioned studies indicated that a high cognitive fluency when viewing an art piece, results in a positive aesthetic experience. Furthermore, the addition or removal of relevant contextual information correlates to increases or decreases in cognitive fluency. We will further explore the effect context, in the form of prior or supplied information, has on an aesthetic judgement.

A study by Silvia (2013), researches the effect domain expertise has on cognitive fluency of an art piece. The results were assessed in terms of two knowledge emotions, interest and confusion.

Expertise was measured on the aesthetic fluency scale (F. Smith and Smith, 2006). This is a numeric value based upon an individuals knowledge relating to ten concepts or art pieces. It has featured in many studies in the field. 174 individuals took part in the empirical studies. They were first assessed on their level of art expertise, and then asked to complete a 7 point semantic-differential questionnaire for 11 art pieces. The questionnaire assessed different emotional responses, including comprehensibility.

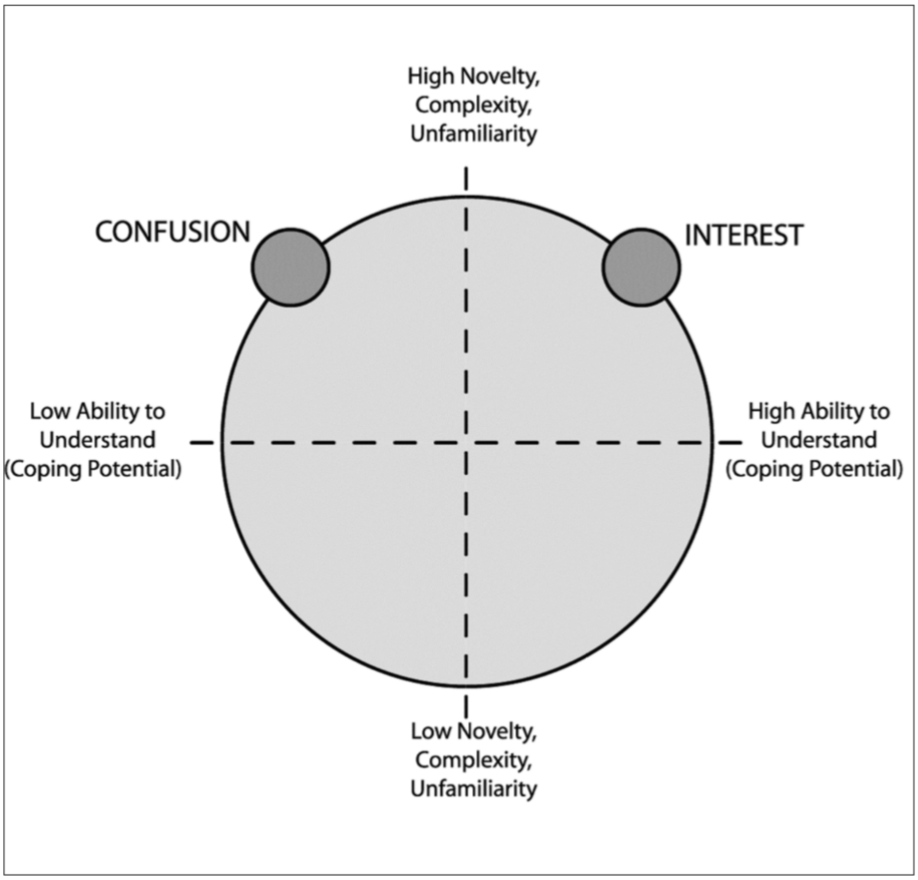

Figure 2.1: The two knowledge emotions (Silvia, 2013)

One of the principle findings of the studies was that individuals with higher art expertise scores found the images more interesting and less confusing. These results concurred with previous studies in the area.

These findings are expected, and implied by the general fact that experts derive more enjoyment from art galleries than novices do.

This demonstrates the effect of prior contextual information. Though the aim of our project is not necessarily to turn a novice into an expert, rather to increase the aesthetic appreciation of a novice when viewing a particular art piece. This will be done by presenting contextual information as done by Belke, Leder, Tilo and Carbon (2010).

This concept is in an empirical study explored further by Swami (2013). In an empirical study, participants were presented 12 paintings from Max Ernst's *Forest* series. They were divided into four groups, and also provided an amount of contextualising information: *Control group - no information, Titular information, Broad genre information, Content-specific information.* Participants were then interviewed on their level of understanding, and aesthetic appreciation.

The results of the study showed that elaborate content specific information (titular,descriptive) had the greatest impact on both understanding and aesthetic appreciation.

Further empirical studies by Swami (2013) were conducted, it was found that this also held true for abstract paintings by Picasso. Representational paintings by Picasso, however, did not result in an improved understanding or aesthetic appreciation.

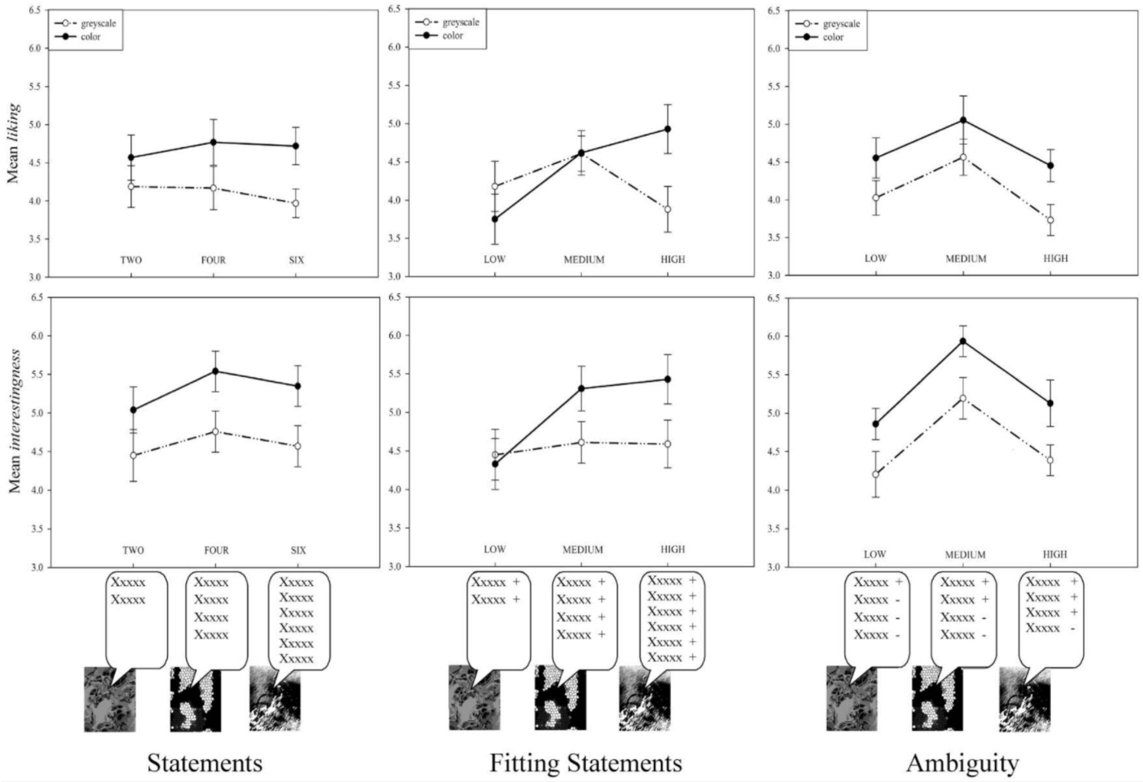

Figure 2.2: Results of different levels of information on liking and interestedness (Jakesch and Leder, 2009)

A study by Jakesch and Leder (2009) offers a contrasting view, that a certain level of ambiguity is, in fact, conducive to aesthetic appreciation. The empirical study selected 36 participants, none with a background in art, and presented each 18 paintings alongside auditory statements.

Hypothesis examined, assessed not only the effect of the quantity of statements provided. But also the effect of the level of dissonance between the statements provided. That is, to increase the level of ambiguity of a painting through the addition of non-matching statements.

Participants were then assessed on their level of liking and interest. The results can be seen in Figure 2.2.

The results indicated that the quality of presented statements had a far greater impact on aesthetic appreciation than the quantity of statements. Furthermore, ambiguity is an important determinant of aesthetic appreciation, and that a certain level of ambiguity is appreciable.

It's clear the type of information presented will be a determinant of the success of our system. A study by Temme (1992) examined the amount and kind of information related to art, in the context of a museum, and the effect on aesthetic appreciation.Empirical studies were conducted both in a laboratory, and in the field at Stedelijk museum, Amsterdam.

Visitors were presented paintings, with information sheets of four different lengths, systematically varied. Results showed that visitor's general enjoyment increased with the more information presented, for both Abstract and Traditional paintings. However, there was a negative correlation between aesthetic appreciation and the volume of information presented.

Temme proposes a potential reason for this being that visitors spent more time reading than looking at the painting. This is something the novel design of information presenting our system would look to address.

A further interesting conclusion by Elbert is that nearly half of all museum visitors found the traditional art gallery labels to be insufficient.

2.2 Use of technology and interactivity in Art Galleries

Recent media sources have reported drops in gallery attendance, we will explore the reasons behind this, and examine some of the case studies of galleries utilising technology to address this.

Evidence suggests this is particularly true concerning a younger demographic A survey by Mason and McCarthy (2006), conducted at New Zealand's Auckland Art Gallery showed that young people visit art galleries less often than the population as a whole. Mason and McCarthy concluded that young people felt disconnected with the way art galleries collect and display art.

Mason and McCarthy proposes potential solutions to appeal to a wider visitor base, instead of the 'cultural elite'. Suggestions included a greater variety of art styles, and different types of exhibitions.

The feeling of exclusion amongst younger demographics could be attributed to the fact that the means of presenting information feels outdated in this digital age. This coincides with opinions that the inclusion of technology would help galleries appeal to a wider visitor base, including those less well-versed in art.

Fei, the Jewish Museum of New Yorks director of digital, argued that the embracing of technology, and directing the technological development of galleries, is critical in helping them reclaim their role as curators (2016).

In recent years, Art galleries have begun attempting to address these issues through the introduction of novel technology based exhibits.

The UK Government recently published the *Culture is Digital* Report. The commitments listed included a 2 million investment by the Arts Council England and the Heritage Lottery Fund to build the digital capacity of their sectors, and the creation of an Innovation Lab in the National Gallery to explore applications of immersive media.

The Dali Museum, St. Petersburg, added the *Dreams of Dali* Virtual Reality experience. The experience takes users through an immersive walk through Dali's *Archaeological Reminiscence of Millets 'Angelus'*. Garnering visitor, as well as critical acclaim, the experience won numerous awards such as the 'Cannes Cyber Lion GOLD'.

Figure 2.3: ArtLens Wall, Cleveland Museum of Art

The Cleveland Museum of Art, Ohio, has been quick to embrace novel uses of technology with the 'Artlens Gallery', a collection of technology-based exhibits. Included are touch-screen free digital elements, giving users the opportunity to create digital art, and interactive with the existing collection. Furthermore, the Museum's 'ArtLens' App, gives users access to images and information about every painting in the gallery. The ArtLens Wall is a 40 foot, tiled multitouch wall that displays digital renderings of all the art from the museum's permanent collection. Visitors are able to browse art and view collections.

The NYC Metropolitan Museum of Art recently digitised it's entire collection of public-domain artworks. Making a library of 380,000 images, available for free and unrestricted use.

It seems that there is a large push towards technology becoming supplementary to the art gallery experience. The popularity of Cleveland's ArtLens galley is particularly relevant to our project.

In addition to this, there seems to be a second approach of utilising technology to allow visitors to browse artworks and connect to museum exhibits whilst at home in order to further educate themselves.

2.3 Gaze Interaction

Whilst the concept of gaze-based computer interaction is relatively novel, research into the Study of gaze patterns goes back over a century.

As reported by Huey (1908), one of the earliest studies was in 1879 in Paris. Louis mile Javal observed that reading does not involve a smooth sweeping of the eyes along the text, as previously assumed, rather a series of short stops (called fixations) separated by quick saccades. Huey then proceeded to construct an early eye tracker out of a contact lens with an aluminium pointer (1908).

The concepts of saccades and fixations provided the basis of many further studies. With research being conducted into patterns of fixations and saccades on countless areas, outside of the reading of text.

A natural topic for the target of eye tracking studies is the perception of art, and the psychology behind it. With the intent to study this area Buswell (1935) furthered Huey's initial eye tracking prototype and devised more complex apparatus to track eye movements in 3 Dimensions, in order to asses eye tracking in 2 Dimensions over a painting.

With the advent of digital eye trackers, there has been continuous analysis and study of our viewing patterns when looking at artworks.

2.3.1 Evaluation of Gaze Interaction

The accuracy of eye tracking technology has increased over the years, with the release of eye trackers available to consumers such as the Tobii 4C and the Eye Tribe. These are often intended be used alongside traditional input methods. Fully gaze controlled user interfaces are still a fairly novel area of research.

Our project will need to be controlled entirely by gaze interaction in place of a mouse or touch screen input. We will examine prior studies, looking at the feasibility of eye-gaze as a full replacement of traditional input methods.

A study by Sibert and Jacob (2000), compared the use of eye gaze and a mouse for user input. It was found that for simple object selection, the eye gaze interaction was faster than selection using a mouse. Sibert and Jacob implemented an algorithm to extract useful information from jittery input data, this was presumably necessary due to the relative immaturity of eye tracking technology at the time.

A study by Gowases, Bednarik and Tukiainen (2008), advanced beyond the basic object selection featured in the study by Sibert. The empirical study required participants to attempt to solve two problem solving puzzle games, Sudoko and the Tile Slide puzzle.

The between-subject study compared the use of eye gaze interaction, and mouse input. The findings showed that gaze interaction provided more subjective immersion, and was interesting to participants. The mouse however was the preferred method of interaction, allowing participants to solve the problems faster. Furthermore, gaze selection was more erroneous than the mouse.

It seems there is a certain threshold, related to the complexity of the required interaction, at which point gaze interaction ceases to be on par with a mouse input in terms of ease of use. However, the advances in the accuracy and availability of eye trackers have bought about studies into more complex interfaces, as well as design practices, relating to gaze interaction.

Figure 2.4: ActiGaze method of small target disambiguation (Lutteroth et al., 2015)

A recent study by Lutteroth et al. (2015) investigated whether a purely gaze interactive interface would be sufficient to replace a mouse or touch screen in the context of a web browser. The study culminated in the implementation of the *ActiGaze* web browser, and the evaluation of several alternative gaze selection methods for cases in which the target is too small to be a simple dwell selection target. The alternative selection methods included the combination of gaze and keyboard input, and the use of additional on screen buttons (2.4, as a means of disambiguating between targets. The results of the empirical study showed that whilst participants were able to successfully carry out the web browsing task, all the gaze alternative approaches were significantly slower and less accurate than a mouse input.

It is clear that there are limits to the capability of gaze selection. If our system is to be easy to use, and feel as natural as using a mouse, the simplicity of the interface will be a key design factor.

2.3.2 Designing for Gaze Interaction

As mentioned, the inherent inaccuracy of gaze interaction results has many implications to the design of a gaze based system. We will explore some prior studies in this area.

One obvious design consideration, already mentioned, is the minimum size objects must be if they are to be gaze selectable, due to the eye tracker accuracy limitations. Whilst Lutteroth et al. considered novel ways of dealing with this (Figure 2.4), they involve either an additional hardware input or an additional confirmation buttons on screen.

It would of course by more beneficial if users could select objects in a single action, as such arguments could be made for avoiding small interactive objects altogether.

As argued by Penkar, Lutteroth and Weber (2012), who claim that the 'dwell' is most natural means of selecting objects using gaze interaction. A dwell selection consists of a user selecting object by simply gazing at it for a short time. (Penkar, Lutteroth and Weber, 2012) conducted a study aiming to find optimal design parameters for this means of interaction. The study compared the key parameters for a gaze selectable button: dwell time, button size, and placement of content.

Penkar et al. conclude that these parameters should be varied depending on the type of content in the button. Most interestingly, however, several unique problems were identified when designing gaze-interactive buttons:

The 'Midas Touch' problem occurs when a buttons content (a text description for example) is placed inside the button, as is common. The user's act of reading the button can result in the button being selected. Potential solutions identified for this issue are either placing button content outside of the button, or using a longer dwell time (more than 1 second).

The 'Gaze Hold' problem occurs when a user is unable to hold their gaze on a button, long enough for it to register a click. This could occur due to eye tracker noise or the user's inability to maintain their focus on the particular area of the display. Proposed solutions to prevent this are to ensure buttons are larger than 150 pixels, and use a shorter dwell time of around 0.2 seconds.

Whilst there are definitely challenges to gaze interaction, it is seen as necessary to our project. Gaze interaction provides technological novelty, and a natural way of interactive way of interacting that contributes to our system's focus on a hedonic experience. There are also implicit benefits of using gaze interaction for public exhibits, such as hygiene, and the lack of a need to clean peripherals.

Realising a fully gaze interactive interface that is as easy to use as a mouse is certainly possible, however care will have to be taken to make the interface as simple as possible. Furthermore, the previously discussed design suggestions must be followed.

2.4 Subtle Gaze Direction

Subtle Gaze Direction (SGD) is a novel technique, first proposed by Bailey et al. (2009) to direct a viewer's gaze around an image. The technique applies brief, subtle image-space modulations to areas of an image with the intention of causing the viewer's gaze to saccade to the modulated regions. The technique is designed to not have an noticeable effect on the appearance of the image. Implementations takes advantage of the fact that our peripheral vision has poor acuity compared to our foveal vision.

Subtle Gaze Direction has potential applications in our project in that it could be used to direct a viewer's gaze around important areas of an artwork, whilst negating the need for user interface elements that would detract from the viewing experience.

2.4.1 Implementations of Subtle Gaze Direction

Bailey et al. produced the first technical implementation of this technique in their (2009) study. The implementation used modulations, appearing as alternating interpolations of pixels in the selected regions. Experimentation showed that an optimal frequency for modulations was 10Hz. The study experimented with modulations of both warm-cool, and luminescence of the regions. A Small pilot study to establish thresholds for each type of these modulations. The study also found modulated regions selected with a diameter of 1cm, (0.76 degrees of the visual field) to be optimal.

Bailey et al.'s implementation also study also took advantage of eye tracking technology; the modulations to the regions were terminated before the viewer's eyes had a chance fixate on them. This further added to the subtlety of the technique.

This technique, is demonstrated in Figure 2.5. The method makes use of the user's velocity vector (V), the vector (W) from fixated region (F) to the modulated region (A), calculating the angle between v and w, θ. When this angle is less than 10 degrees, the modulation to the region is immediately terminated.

Furthermore, Bailey et al. notes that during the period of a saccade a phenomena called 'saccadic masking' occurs; a momentary lapse in the viewer's perception prior to fixating. The implementation keeps track of when the viewer's gaze is the state of a saccade or fixation (Figure 2.5 Inset). Modulations are then only terminated during a saccade, as to not be noticeable to the viewer.

Clearly for this implementation it is necessary to determine whether the user's gaze is currently in a state of saccade or fixation. Bailey et al. used a research paper by Salvucci and Goldberg, which collated and classified algorithms for detecting saccades and fixations (2000).

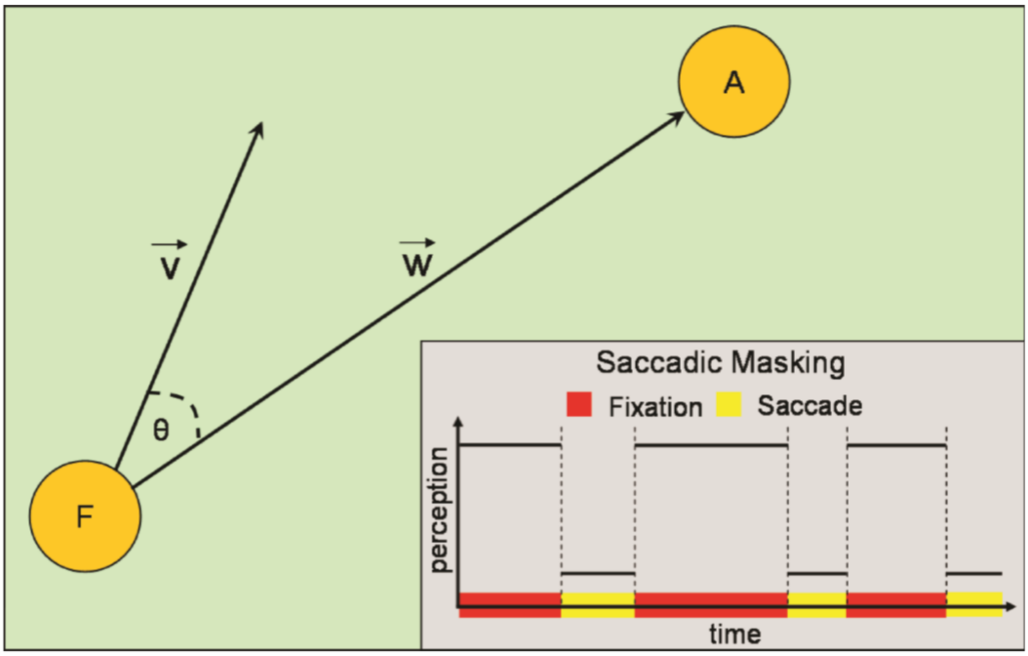

Figure 2.5: Subtle Gaze Direction and Saccadic Masking (Bailey et al., 2009)

Bailey et al. conducted an empirical study, with ten participants, divided equally into a control group, and modulated group. Participants were shown a randomised collection of 40 images. The modulated group had either luminescance or warm-cool modulations to points on the image (points were deliberately selected to not be points of interest). The overall viewing pattern was assessed, as well as the viewer's perceived quality of the image. An heatmap of one of the images, with and without SGD, is shown in Figure 2.6.

The results found that overall, approximately 75% of the target regions were found within 0.5 seconds, and 90% within 1 second. Modulations consistently drew viewer's viewer's gaze, however the viewer's gaze did not always reach the modulated area due to the modulations being terminated.

Participants did not report any concious observations of the modulated regions, however, there was a statistically significant drop in the average overall perception of the quality of the images, when SGD was applied (7.07 vs 6.17).

Bailey et al. attributed this to the fact that the SGD points were selected not to be areas of interest, thus the drop in perceived quality was a result of the disturbing of the natural viewing pattern of the image.

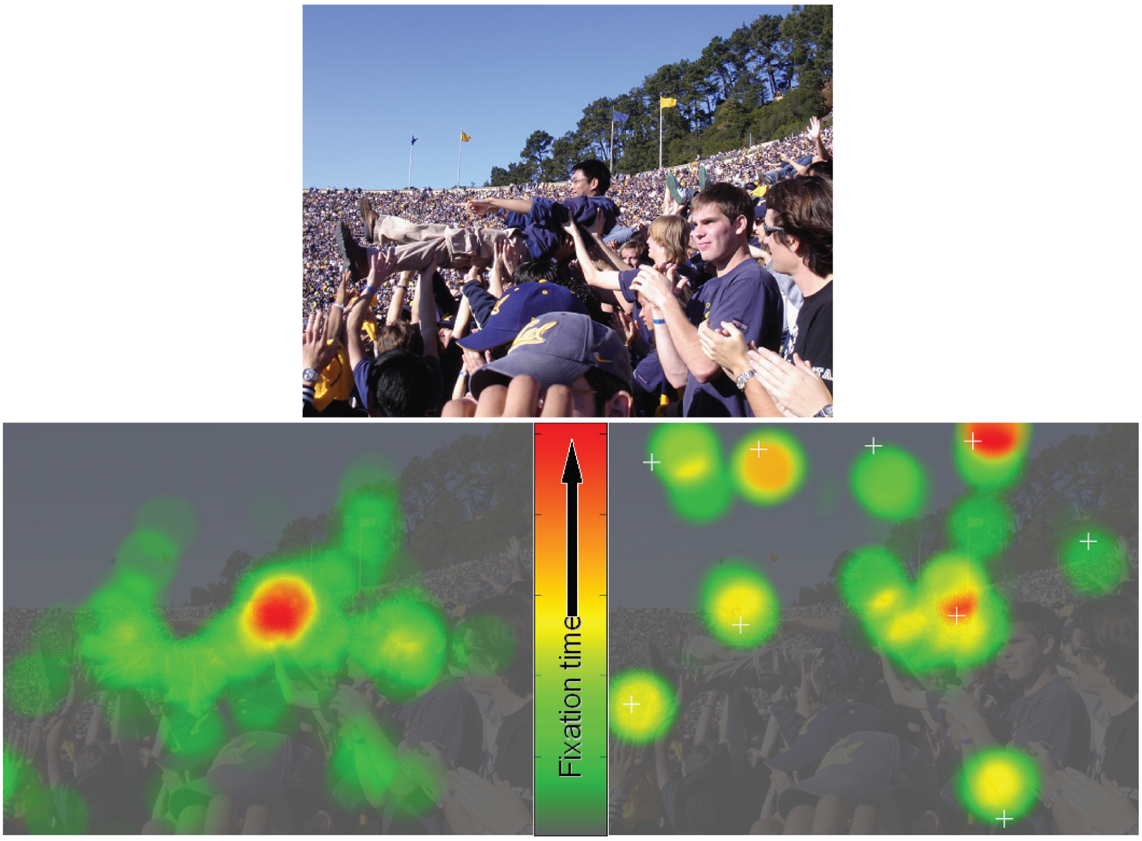

Figure 2.6: Viewing heatmap without (Left) and with (Right) Subtle Gaze Direction (Bailey et al., 2009)

Conclude drop in image quality may not be a problem as we are using SGD to direct a user towards points of interest anyway. Modulations not bringing viewer's gaze exactly to point also not a problem.

A more recent, alternative implementation of SGD originates in a study by Ben-Joseph and Greenstein (2015). Similarly to Bailey et al.'s implementation, this implementation takes advantage of the differences in our eye's perception in the fovea and the periphery.

The implementation by Ben-Joseph and Greenstein differs however, in that eye tracking is not used. This means the modulated regions cannot be terminated as the viewer's gaze moves towards it.

Instead Ben-Joseph and Greenstein use differences in the flicker fusion rate between the fovea and periphery, finding an optimal frequency for modulations, such that they are only visible in the viewer's peripheral vision. For the design, a frequency of 30Hz was chosen as was theorized to be optimal given the flicker fusion rates. Their implementation made use of modulations to the luminescence of regions, as this was found to be most effective.

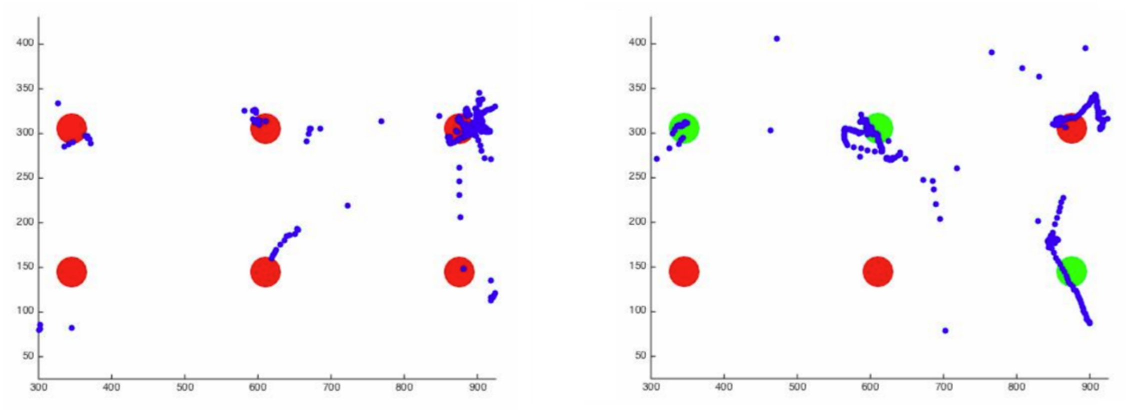

Figure 2.7: Fixation map without (Left) and with (Right) Subtle Gaze Direction (Ben-Joseph and Greenstein, 2015)

An empirical study was conducted by Ben-Joseph and Greenstein with five participants, using a within participant design. Participants were first shown a render of six identical teapots, on a black background. They were then shown the same teapots but with SGD applied to three of them. Their gaze pattern was tracked, Figure 2.7 shows the resultant eye tracking data from one participant.

Analysis of test verses control ratios showed that the modulated teapots drew at least twice as much of the viewer's gaze time.

A second part of the study aimed to find the ideal level of luminescance modulation. It was found that a difference in luminescence between the modulated and unmodulated areas of 30% to be optimal, values above this were noticeable to participants.

We have reviewed to implementation options for the novel technique of Subtle Gaze Direction. Ben-Joseph and Greenstein's implementation did provide reasonable results using a far simpler method, and without the need for an eye tracker.

Bailey et al.'s implementation, however, directed viewers to gaze points with a greater level of reliability, through the addition of an eye tracker. This is because the use of saccadic masking allows for slower and more intense modulations, whilst maintaining subtlety. For our system the reliability of the implementation will be of high importance, as we aim to direct user's gaze around artworks.

2.4.2 Applications of Subtle Gaze Direction

Prior implementations have proven the effectiveness of subtle gaze direction in the context of a lab study, when looking at controlled images. However, the technique may not be as effective when looking at artworks which by their nature feature a large number of distracting features.

A study by Sridharan, Bailey, McNamara and Grimm (2012) examined a novel application of subtle gaze direction (SGD), using the technique to guide novices in finding abnormalities in mammograms. SGD was used to guide novices along a scanpath, previously recorded from an expert radiologist viewing the same image. Sridharan, Bailey, McNamara and Grimm hypothesised this would improve the likelihood of the novice being able to correctly identify abnormalities.

It was found that after following the expert's gaze, the novices performed consistently better. Furthermore, a post-training lingering effect occurred in which the novices retained their ability once SGD was disabled.

The study also examined was the differences in performance when guiding novices along the scanpath recorded by the expert, and guiding users over the key points selected by the expert. There was no discernible advantages between these found.

A study by McNamara et al. (2012) researched the application of SGD into the viewing of narrative art. (Narrative art tends to have several regions contained in the same frame, that have an optimal viewing order to tell a story). The study applies a similar technique as Sridharan, Bailey, McNamara and Grimm, having an intended visual scan path, and guiding a novice over it using SGD.

McNamara et al. implemented SGD using the method defined in Bailey et al.'s (2009) paper. Luminescence modulations were used. Participants viewed a series of artworks, each containing three to seven 'panels' intended to be viewed in an episodic fashion.

Thirty six participants were randomly assigned to either a control group, or a group with sequential modulations applied to the panels in the intended order. The participant's gaze patterns were than analysed. Figure 2.8 compares the viewing heatmap of two participants from the control and modulated groups.

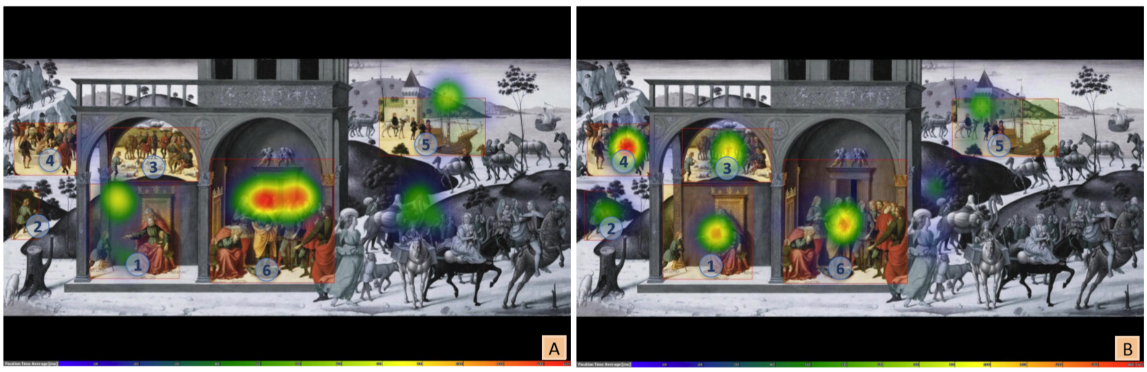

Figure 2.8: Gaze heatmap without (Left) and with (Right) Subtle Gaze Direction. The numbered circles indicate the intended viewing order of the narrative panels (McNamara et al., 2012)

It was found that participants in the SGD group showed statistically significant in performance concerning viewing of the panels in the intended order. Furthermore the viewer's tended to be more focused on the panel areas as shown by the heatmaps in Figure 2.8.

This study is of particular relevance to our project, it proved the use of SGD as an aid to visual navigation on artworks. Furthermore, it shows that SGD continues be effective in guiding the viewer's gaze in the context of artworks with many visual distractions.

Chapter 3

Requirements

This section covers the requirements for the proposed system, as it will be implemented in the context of a public exhibition space. Findings from the literature review section, are realised as functional or non-functional requirements. The requirements are categorised into Hardware, Software, and User Experience.

These requirements will be used to inform the design and implementation of the system. It is worth noting, the scope section is limited to the intended final implementation, it does not relate to the wider research goals of the project, or the user studies.

3.1 Hardware

3.1.1 Must make use of a commercially available eye tracker

Non-Functional Requirement
The system is designed to be available to museums and galleries, and implemented in a way that it could be added to an exhibition space at a fairly low cost. As such the system should make use of an eye tracker that is commercially available, at a reasonable price point.

3.1.2 The eye tracker must be functional after a brief calibration

Functional Requirement
The eye tracking hardware must be capable of providing sufficiently accurate eye tracking input, after a brief calibration. Typically calibration windows consist of several points on screen, that the user must gaze at for a short period of time. As the system will need to be calibrated per user, this calibration sequence shouldn't take more than ten seconds, and should consist of four or less points.

3.1.3 Eye tracker must be usable with and without glasses

Non-Functional Requirement
As the system is designed for use in a public space, it should be as accessible as possible. As such, it is critical that the eye tracking hardware works with users wearing glasses.

3.1.4 Eye tracker must function at a range of viewing angles

Non-Functional Requirement
The system is intended to be set up in a gallery space, where user's can approach the exhibit and use it at their leisure. As we cannot dictate exactly where a user will be standing, the eye tracker must be robust enough to be used at a range of distances; 50cm - 100cm should provide a reasonable range. Furthermore, the eye tracker must have a sufficiently wide operating angle, such that it can be operated by users of a range of heights (130cm-200cm) without the need for readjusting the sensor.

3.2 Software

3.2.1 Must be entirely gaze controlled

Functional Requirement
The benefits of gaze interaction have previously been discussed. Asides from enabling the use of Subtle Gaze Direction, the fully gaze controlled system should provide a more novel and engaging experience. Furthermore, it will eliminate the hygiene risks when having a touch screen set up in a public space.

3.2.2 Must feature a menu to allow a user to navigate a library of paintings

Functional Requirement
User's should be able to browse through a digital library of the artworks that are available on the system. This should be implemented as a fully gaze-controlled menu, that displays thumbnails and basic information about each artwork. Users should be able to scroll through the range of artworks, selecting one to view with their gaze. Include scrolling through library, and the ability to exit

3.2.3 Must provide contextual audio information when a user is viewing a painting

Functional Requirement
Studies of related work have shown that contextual information is a critical contributor to a

positive aesthetic experience, when viewing a piece of art. The system should automatically play contextual audio when a user looks at relevant areas of the artwork. Using the eye tracker in this way aims to provide information, in a way that is novel and interactive, whilst not detracting from the artworks.

3.2.4 Must use Subtle Gaze Direction to guide a user's gaze over artworks

Functional Requirement
The implementation of Subtle Gaze Direction (SGD) through the use of the eye tracker is a critical part of the project. The objective of SGD is to ensure the viewer's gaze is guided over the most important parts of the artwork, and the audio clips are triggered. Furthermore, it will hopefully encourage the viewer to perceive the artwork more fully. The system should follow the SGD implementation by (Bailey et al., 2009), making use of the eye tracking technology.

3.2.5 Subtle Gaze Direction must not be visually noticeable by the user

Non-Functional Requirement
It is critical that there are no noticeable visual distractions when the user is viewing the artwork. As such the implementation of SGD should be carefully balanced as to not be observable by the user. Specific parameters controlling the SGD, such as the level of modulation and frequency, will have to tested to find the optimal values.

3.2.6 Design must automatically scale on a range of monitors

Non-Functional Requirement
It is not possible to dictate the space constraints when the system is implemented in an exhibition space. As such it must be capable of automatically scaling between monitor sizes. We defined a range of monitor sizes from 20-42 inches that should be supported, at a minimum resolution of 1920x1080.

3.2.7 Software must automatically detect user presence

Functional Requirement
The system is designed to be unaccompanied in a gallery or museum setting. It must automatically return to an introductory screen after a timeout of 30 seconds of inactivity. This way it will be available to the next user.

3.3 User Interface Design

3.3.1 Interface must be intuitive enough to use without training

Non-Functional Requirement
There will be no technical staff or text-based instructions available to users, as the system is designed to be set up on a screen in a gallery space. Aside from some brief introductory text on the default screen, explaining the basics of the system, the rest of the interface must be self-explanatory. It must be designed in a way that is is immediately clear to the user how to operate it, without the need for assistance.

3.3.2 Not render any UI elements over the art

Non-Functional Requirement
As previously discussed, it is critical that we do not distract from the user's viewing experience. Therefore, the system must not render an User Interface elements over the artworks themselves. The UI when viewing artworks should be as minimal as possible.

3.3.3 Buttons must be optimised for Gaze interaction

Non-Functional Requirement
We have previously discussed several challenges that arise when designing interfaces for gaze interaction. Namely, the *midas touch* problem and the *gaze-hold* problem. To negate address these challenges we must make considerations relating to the size of the buttons, the dwell time before activation, and the placement of the button's content. User's should be able to control the final system without difficulty.

3.3.4 Navigation of the system must be optimised for Gaze interaction

Non-Functional Requirement
Prior research suggests that even with optimisation, a gaze select is typically more laborious than a mouse click. It is therefore essential that this is a consideration when designing the system. Steps should be taken to minimise the number of interactions required to navigate the system, wherever possible.

Chapter 4

Design

In this section we will present the design of the system, as informed by the requirements. We will cover both the high level design, using diagrams where necessary, and the specific details relating to interface elements.

4.1 Hardware Design

In this section we will discuss the hardware configuration used on the system during testing and development. We will also briefly discuss the intended final hardware setup of the system deployed in a museum exhibition space.

4.1.1 Computer

The system was designed to use a fairly standard hardware configuration. Intended to run on a Windows PC of low-moderate specifications, such that it could be run on an embedded PC in a gallery space. The system will be tested on a laptop with the following specifications, setting these as a minimum benchmark: (Intel Atom Quad Core 1.83 GHz, 2GB DDR3 RAM, Intel HD Graphics, Windows 10 32 Bit)

4.1.2 Monitor

The will be developed and tested using a 24 Inch LCD monitor, however, it will be designed to run on a monitor sizes and resolutions as per requirement 3.2.6.

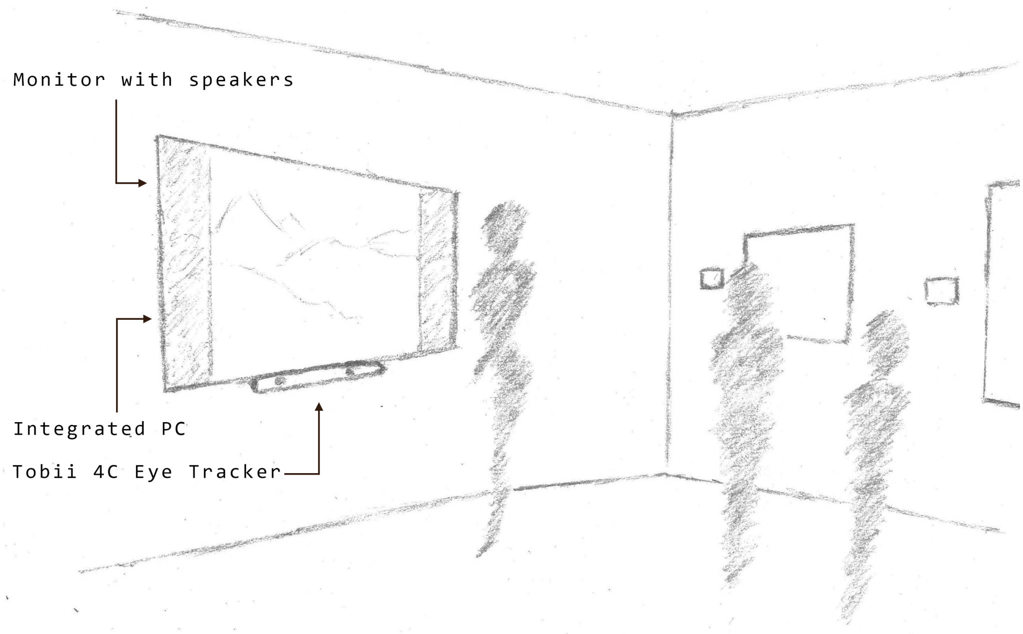

Figure 4.1: Proposed Hardware Set-up of System in a Gallery Space

4.1.3 Eye Tracker

The choice of eye tracker was a Tobii 4C, as it satisfied all the requirements in Section 3.1. Providing accurate, reliable gaze tracking with hardware available to consumers. The eye tracker was connected to the PC via a USB cable.

4.1.4 Gallery Concept

Figure 4.1 shows a concept sketch of the intended set-up and use of the system, in the context of a gallery or exhibition space. In this scenario the system is running on an embedded PC, on a large (42 Inch) monitor, with built in speakers.

4.2 User Experience Design

In this section we will go over a high level overview of the user experience.

4.2.1 User Journey

A high level flowchart for the system is shown in Figure 4.2. It shows the four main screens that make up the system, and the use actions to move between them. We will break down each of the four screens indicated in the flow chart.

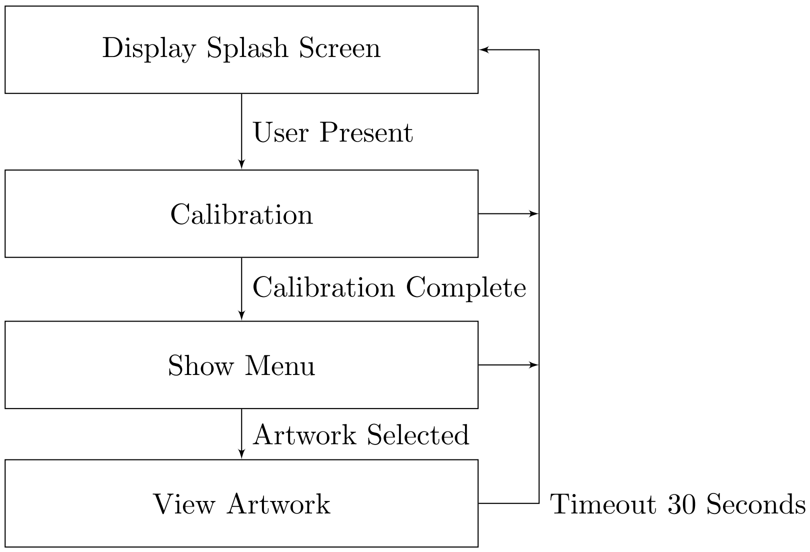

Figure 4.2: High level user journey flow chart

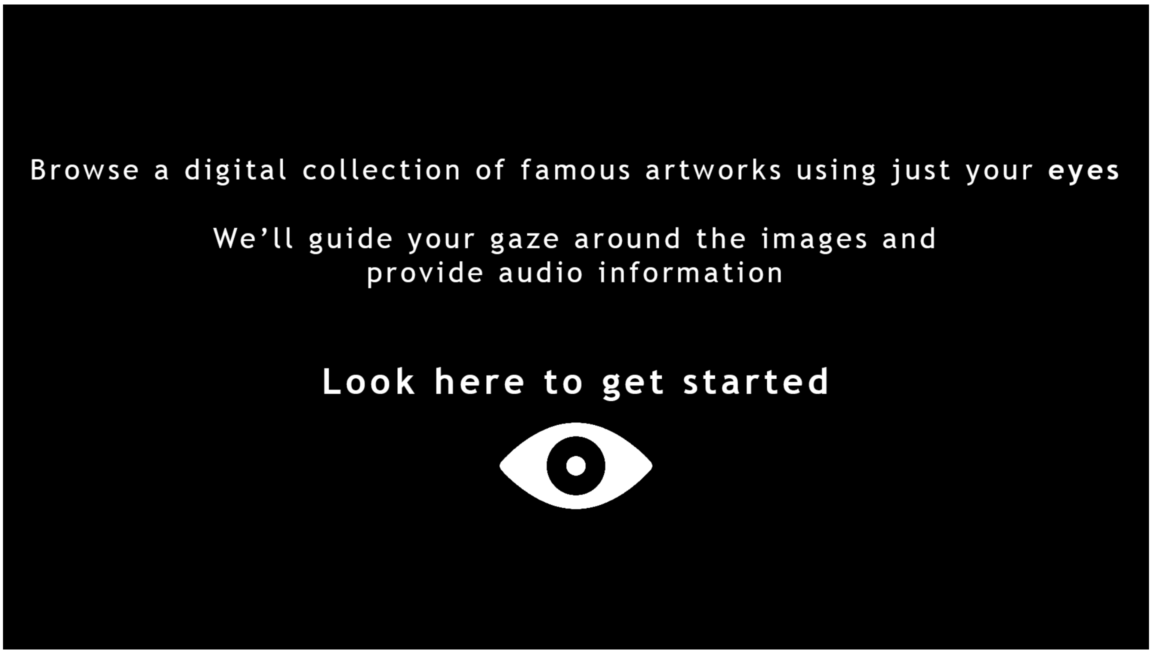

Figure 4.3: Design of the 'Splash Screen'

When users approach the display, they are greeted by the 'splash screen' shown in Figure 4.3. This is serves as the default screen when the system is not in use and should provide users with some basic information about the exhibit. The contents of this screen inform users about the use of Subtle Gaze Direction and Auditory information.

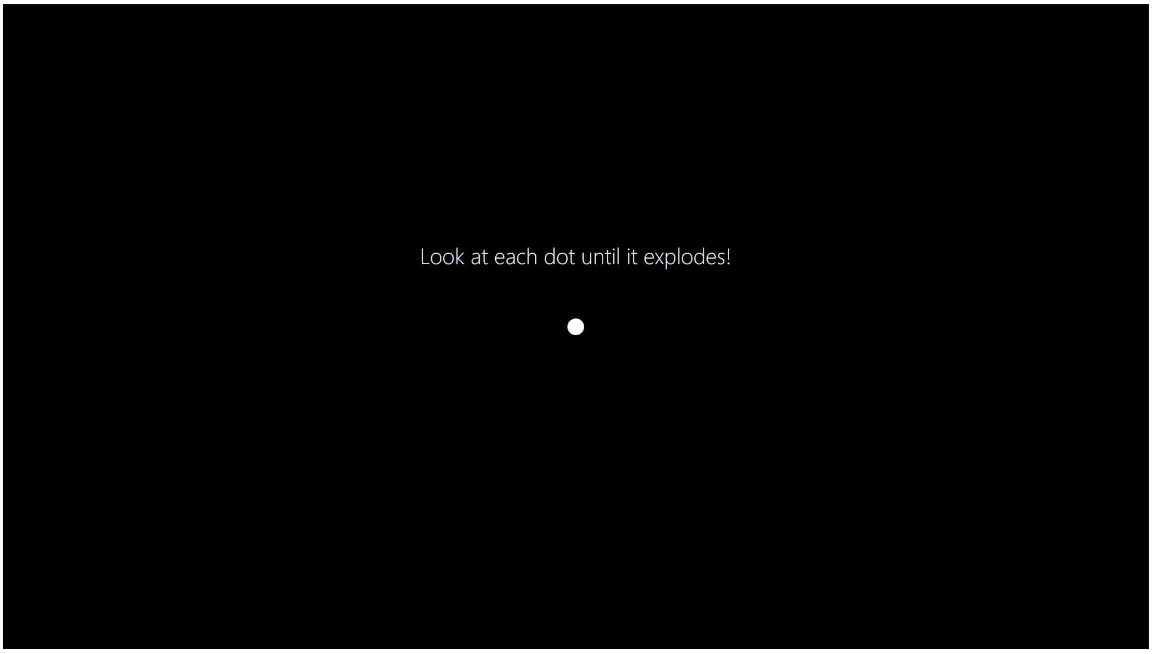

Figure 4.4: Screenshot of Tobii's Calibration Screen

As per requirement 3.2.7, the system will automatically detect if a user is present. It will initiate the Tobii Eye Tracker's 3 Point 'retail' calibration. This calibration method was chosen as per requirement 3.1.2, as it needed to be fast, whilst providing a reasonable level of accuracy. A screenshot this calibration method is shown in Figure 4.4.

Upon completing the calibration, the system will surface the main menu. Shown in Figure 4.5. Here users can browse through the library of artworks, viewing basic information, and then use their gaze to load a selected artwork.

The system will then show the 'view artwork' screen, shown in figure 4.6.

As per requirement 3.2.7, the system will be continually aware of user presence. If a user is not present for 30 seconds, the system will return to the Splash Screen.

4.2.2 Viewing Artworks

The 'View artwork' screen (Figure 4.6) presents the artworks rendered on screen, with minimal User Interface elements.

This screen is where the auditory information will be presented to users. When the user's gaze fixates on selected areas of the image, audio information will play providing context

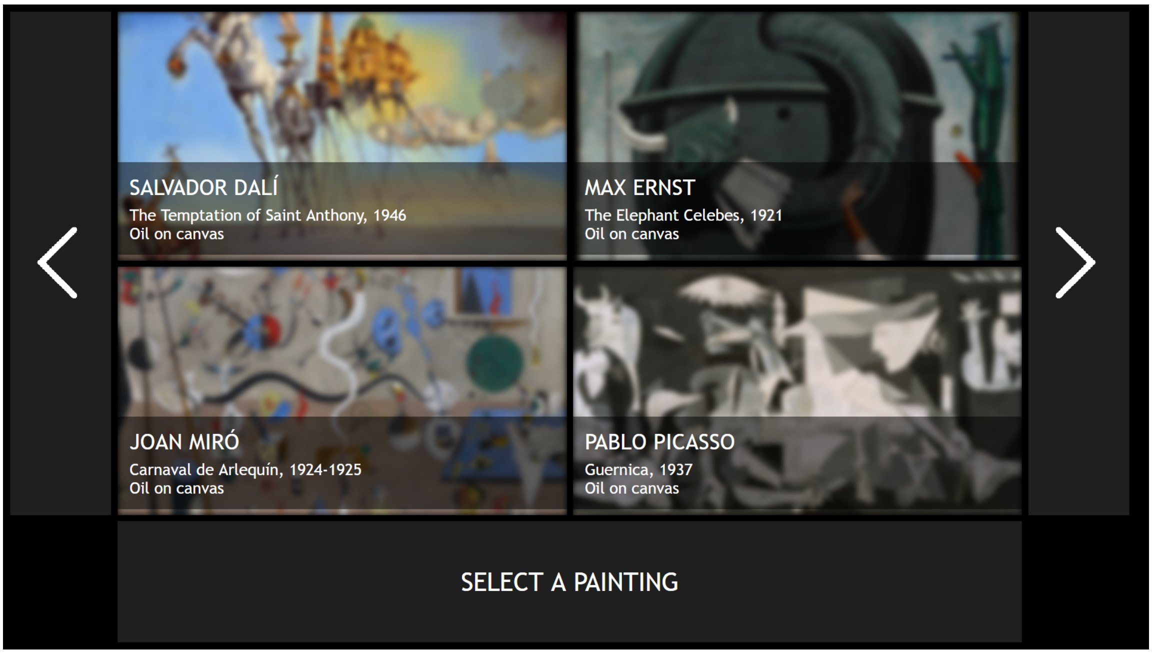

Figure 4.5: Design of the Menu Screen

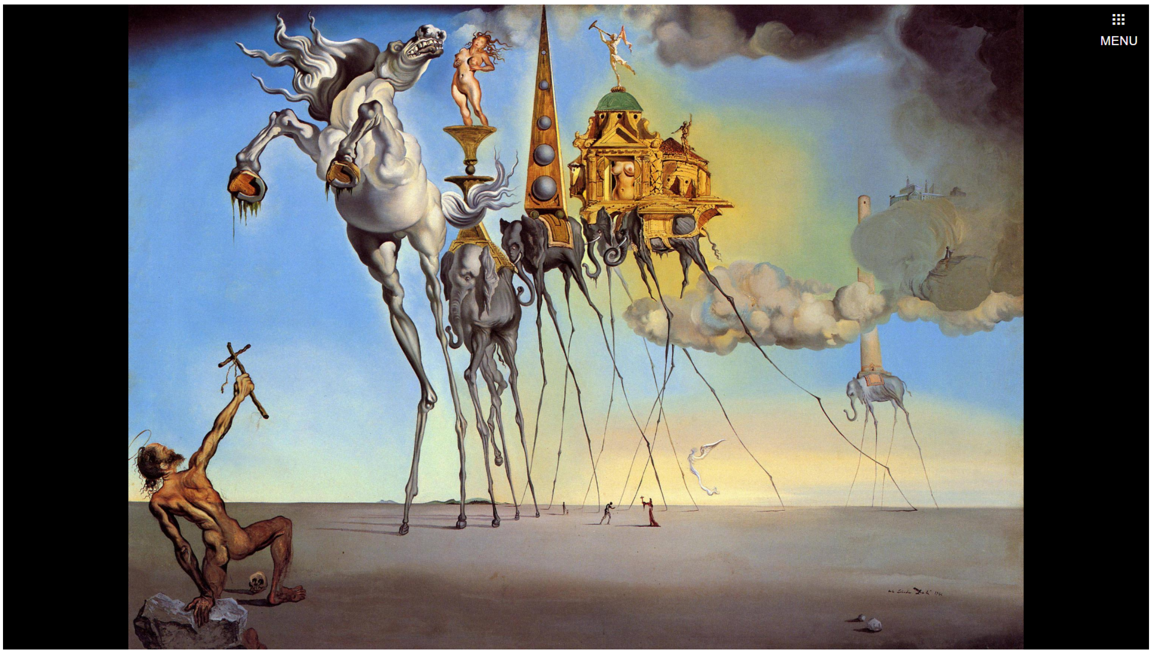

Figure 4.6: Design of the 'View Artwork' Screen

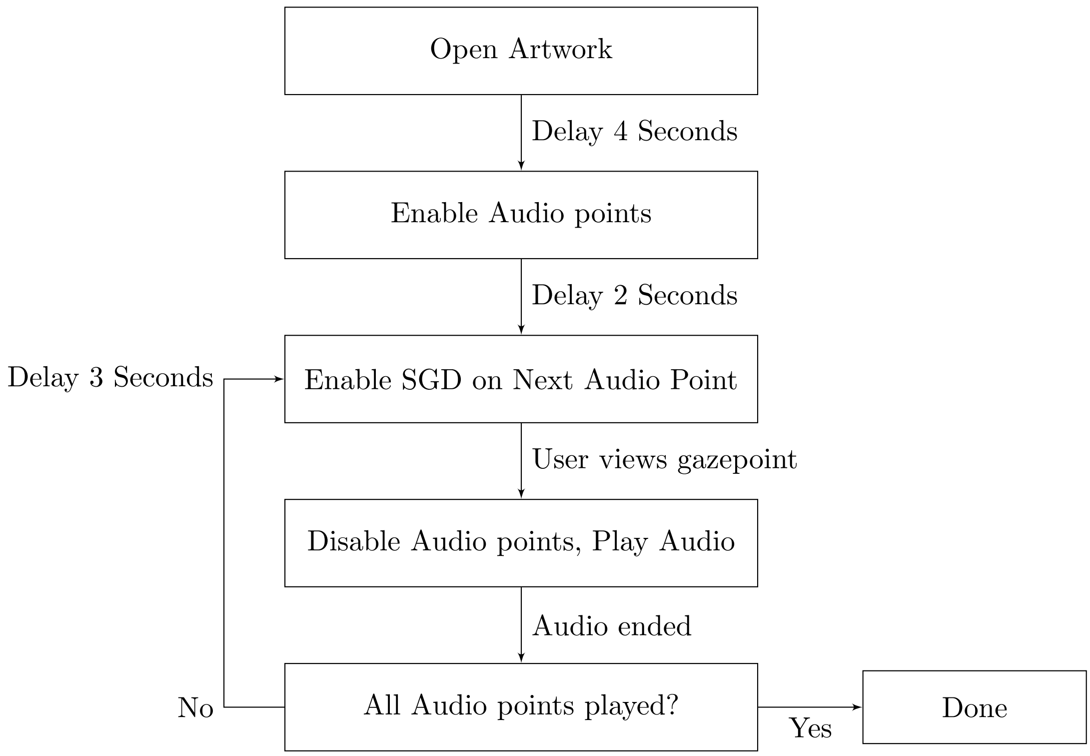

Figure 4.7: The sequence and timings for presentation of audio points

or insight relevant to that particular area of the artwork. The audio points are all enabled concurrently, so can be activated by the user in any order. Once an audio point has been viewed, and the audio has played, that particular point will be permanently terminated.

In addition the artwork screen would apply Subtle Gaze Direction (SGD) to guide the user's gaze to these audio points. The objective of this is to ensure the user views all the important areas of the image, and also to attempt to guide the user over the audio points in a particular order. The flickering modulations (SGD points) would be presented to the user one at a time. Again terminating once the user has viewed the point, and moving on to the next SGD point. If an audio point had been previously previously activated by a user, out of the intended order, it will not be rendered as an SGD point.

Figure 4.7 shows a flowchart overview for the presentation and timings of audio points and SGD points. The decisions on the timings and presentation of the final system were made by the testing of initial prototypes, both by the author and with participants.

4.3 User Interface Design

In this section we will look at the design of the user interface more closely. Focusing on particular design elements and exploring the methods of designing optimal interfaces for

Gaze Interaction.

4.3.1 Splash Screen and Calibration

As the design of the calibration screen was not able to be altered, the splash screen (Figure 4.3) was designed to match Tobii's interface for calibration (Figure 4.4 with the aim of providing a cohesive user experience. The simple motif of white text on a black background was used, furthermore a large font size and icon were selected. This was so system could easily be identified at a distance.

4.3.2 Menu Screen

Figure 4.8: Traditional Gallery label (left) compared to menu item (right)

The menu thumbnails shown in Figure 4.5 have been designed to mimic traditional exhibition labels. Providing basic information in a way that will be familiar to gallery users. A comparison is shown in Figure 4.8.

Figure 4.9: Menu item, showing gaze transition effects.

The system was designed with many considerations, to enhance the usability of gaze interaction. Selectable items, such as the thumbnails, confirmation and scroll button, were all made to be as large as possible to allow a bigger target.

Furthermore, for gaze selectable elements, a progress bar was implemented. When the user gazes over the object, it provides an animated indicator of for how long the user should hold their gaze on an object in order to select it. This was done as a solution to the 'gaze hold' problem. In addition to this, a blur effect was added to the menu thumbnails, which was removed when a user gazes at a thumbnail. This makes it immediately clear to the user, where their gaze currently is. The design of the menu thumbnails is shown in Figure 4.9.

Figure 4.10: Menu confirmation button. (Top) No painting selected, (Center) user not gazing, (Bottom) user gazing

A confirmation button was added to the menu (Figure 4.5). A two stage process was used; users select an artwork, and then select the confirmation button to open it. This allowed for content to be placed on buttons, whilst negating the 'Midas Touch problem'. The button is initialised with text instructing the user, and updated once a user has selected an artwork. The two states of the confirmation button, as well as the progress bar, are shown in 4.10.

4.3.3 View Artwork Screen

The UI in view art screen (Figure 4.6) was deliberately very minimal. As per Requirement 3.3.2, no interface elements should be rendered on top of the artworks. The interface consists of just a 'Return to Menu' button in the top right corner.

This button had to be a fairly small target, to not distract from the artworks. As such, to avoid the gaze-hold problem, it had a larger invisible gaze area that also extended off the screen. The progress bar was also used here, as well as a change of background colour when gazing. This can be seen in Figure 4.11. To address the Midas touch problem resulting from having content placed inside the button, and avoid accidental activation of the button, a longer dwell activation time was used.

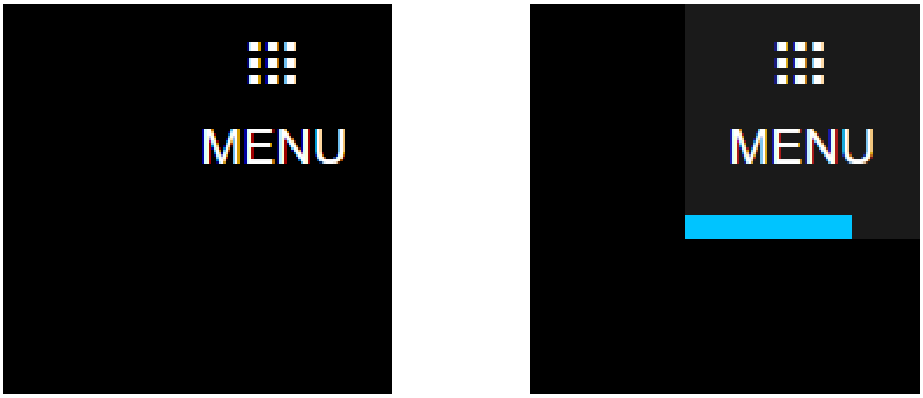

Figure 4.11: 'Return to Menu' button. User not gazing (Left), user gazing (Right)

4.4 Software Design

In this section we will discuss the decisions relating to the choice of software. We will also go over the software design at a high level.

A decision was made to be build the system using HTML/CSS and Javascript. The reasons for being this decision are as follows:

- The requirements of the project fit the use of the HTML Canvas. Rendering artworks on screen is naturally analogous to the canvas element. This allowed for easy manipulation of the images, and animations, necessary for Subtle Gaze Direction.
- Javascript is an ideal language for rapid prototyping, as it is dynamic and weakly typed. Furthermore, the fact that it's an interpreted language means the code can be edited on the fly without the need to recompile.
- Using CSS to fine-tune the buttons and UI design to ensure it's optimal for gaze interaction

To enable the usage of system I/O functionality, the Javascript program uses Node.js. The program was then packaged as an electron application, for one-click running (Electron applications run in a self-contained instance of the Chromium web browser). Electron applications are comprised of two processes: a 'main' process for control, and a 'render' process for rendering pages. The processes communicate via Inter-Process Communication (IPC). Figure 4.12 shows a high level overview of this structure.

As Tobii only provide SDK's for Unity and C#, it was necessary to create a launcher using C# that would interface with the eye tracker via the C# SDK. The launcher is responsible for initiating the calibration sequence, launching the Javascript program, and passing the eye gaze data on to the Javascript program. This behaviour is shown in the sequence diagram in Figure 4.12.

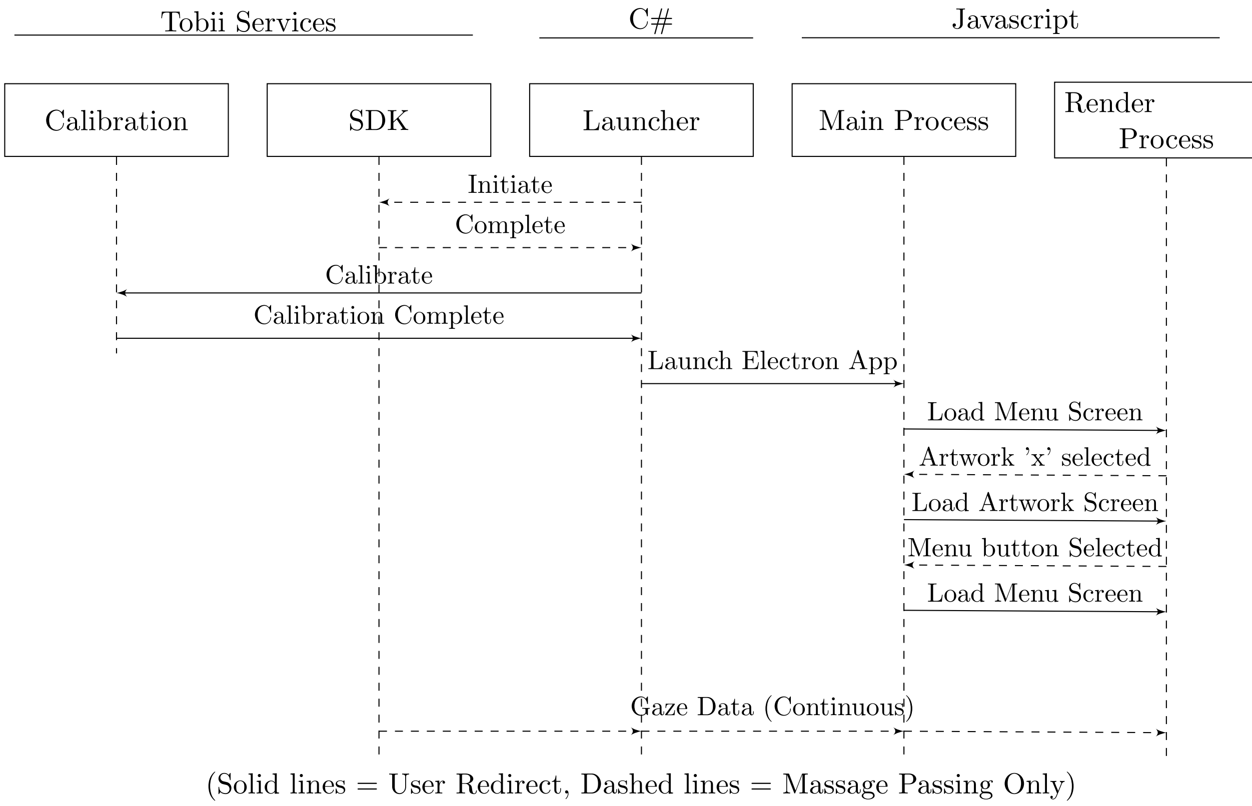

Figure 4.12: Sequence Diagram showing interaction between program components

Chapter 5

Implementation

In this chapter we will go over the specific implementation details, covering the features outlined in the design section.

5.1 Launcher and Gaze Data Stream

As discussed in the design section, it was necessary to have create a launcher to initiate the Tobii eye tracker calibration agent, and pass the eye tracker information to the main program.

A solution was devised that treated the launcher as the server, and the main program as the client. gaze information was transmitted over the local network socket using UDP. UDP was chosen over TCP as a low latency was required, and confirmation of packet delivery was not necessary.

Testing revealed this additional step of passing the gaze data over the network port resulted in almost negligible increases in latency.

5.1.1 C#

Here we will cover the entirety code written in C#, for the launcher program. The launcher, was designed to be as lightweight a as possible. As it was only responsible for initialising the connection to the eye tracker, launching the Tobii calibration window, then launching the main electron application. At which point it redirects the user, and begins transmitting gaze data.

The main code for the launcher program is shown in Listing 5.1.

The main code calls the function shown in Listing 5.2, as it arrives from the eye gaze tracker, to send the data to the client. The data is transmitted as timestamped coordinates, formatted as a JSON string.

Listing 5.1: C# Launcher

```
//Get current Directory
var env = System.Environment.CurrentDirectory;
env = Path.GetFullPath(Path.Combine(env, @'..\'));

// Initialise Tobii Host
var host = new Host();

//Launch Calibration
System.Threading.Thread.Sleep(1000);
host.Context.LaunchConfigurationTool(ConfigurationTool.
        RetailCalibration, (data) => { });
System.Threading.Thread.Sleep(10000);
//Minimise our current window
ShowWindow(p, 2);
//Open Electron.exe
Process.Start(Path.Combine(env, @"electron\electron.exe"));

//Setup Server
UdpClient udpClient = new UdpClient();
udpClient.Connect("127.0.0.1", 33333);

//Initialise data stream from Tobii
var gazePointDataStream =
   host.Streams.CreateGazePointDataStream();

// Get the gaze data, send to input
gazePointDataStream.GazePoint((x, y, ts) =>
   SendInput(udpClient,x, y, ts));


// Read from Tobii host
Console.ReadKey();

//Disable Tobii Host before exit
host.DisableConnection();
```

Listing 5.2: C# Server

```
//Send the gaze data to the client over UDP
 static void SendInput(UdpClient client, double x, double y,
    double ts){
   String sendString = @"{""id"":""gaze_data"", ""x"":" + x +
      @", ""y"": " + y + @", ""timestamp"":" + ts + @"}";
   Byte[] senddata = Encoding.ASCII.GetBytes(sendString);
   client.Send(senddata, senddata.Length);
}
```

5.1.2 Javascript

The code for setting up the client in the main program is shown in Listing 5.3. This is located in the Main Javascript process, so that it is always running. The Main process is then required to forward the gaze data packets on to the Render process if any windows are open. This is done using electron's Inter Process Communication.

The Render process uses the code in Listing 5.4 to receive the stream of gaze data via IPC, as packets are forwarded from the Main process.

Listing 5.3: Javascript Client Main Process

```
//Client set up
var PORT = 33333;
var HOST = '127.0.0.1';
var dgram = require('dgram');
var server = dgram.createSocket('udp4');
var previousTimestamp = 0;

server.on('listening', function () {
    var address = server.address();
});

server.on('message', function (message, remote) {
    parseMessage(message);
});

//Forward gaze data to open windows
function parseMessage(message){
  var messageObj = JSON.parse(message);
  //Drop packets recieved out of order
  if(messageObj.timestamp>previousTimestamp){
    if(mainWindow !== undefined){
      //Send gaze via IPC
      mainWindow.webContents.send('gaze-pos', messageObj);
    }
    previousTimestamp = messageObj.timestamp;
  }
}

server.bind(PORT, HOST);
```

Listing 5.4: Javascript Client Render Process

```
ipc.on('gaze-pos', (event, arg) => {
        if(arg.timestamp){
                gazePosition.x = arg.x;
                gazePosition.y = arg.y;
        }
});
var gazePosition = {x : 0, y: 0};
```

Listing 5.5: Gazeaware HTML Elements Process

```
<div class="item gazeIndicator"
   gazeOverClass="gazeIndicatorGazing" gazeAction =
   "openPainting()" gazeAware>
</div>
```

5.2 Gaze-Aware HTML Elements

Having implemented a means of enabling access to the stream of Gaze data within the electron app, it was also necessary to add a general means of detecting gaze on HTML elements. This provide a means of creating gaze selectable user interface elements.

5.2.1 Declaring Gaze-Aware Elements

The custom HTML attribute *gazeaware* was declared. This was a means of identifying elements that should be enabled for gaze interaction. Also declared was the custom attribute *gazeOverClass* which would contain the name of class or classes, to be added when the user is gazing over the element. Lastly the *gazeAction* attribute holds a reference to the function that should be triggered, once the user has dwell selected the element.

Listing 5.5 shows an example of declaring a gaze aware HTML element using this new syntax. In this element the *gazeIndicator* and *gazeIndicatorGazing* classes refer to the implementation of the progress bar animation for gazing discussed in the design section.

5.2.2 Progress Bar Effect

Listing 5.6 shows the CSS used to implement the progress bar animation.It makes use of the 'after' CSS psuedo-element. Initially, the progress bar is defined with a width of 0px. This is then overwritten by the *gazeIndicatorGazing* class. CSS transitions are used to create the animation, with the animation time matching up to the dwell time for the element.

As this was a pure CSS implementation, it was very lightweight. Furthermore, it resulted in two classes which could arbitrarily be assigned to any gaze-aware elements, in addition to any other classes specific to those elements.

5.2.3 Initialising Gaze-Aware Elements

Upon loading the page, gaze-aware elements are then initialised into a global object. This was done to improve efficiency, as it means our function for checking gaze (called on a 10ms loop) doesn't read from the DOM, which is a fairly slow operation.

The elements are loaded into the array, alongside a boolean to be used to determine if the

Listing 5.6: CSS Implementation of the progress bar

```
.gazeIndicator:after{
      position:absolute;
      bottom:0;
      left:0%;
      width:0;
      height:10px;
      background:rgba(0,196,255,1);
      display:block;
      content:'';
      transition: width 2s ease-in-out;
    }

    .gazeIndicatorGazing:after{
      width:100%;
    }
```

element is currently being gazed upon, and an object to store the Timeout variable for controlling when to trigger the dwell action. This set up is shown function is shown in Listing 5.7.

5.2.4 Checking for Gaze on Elements

The *updateGaze()* function is called every 10ms. Shown in Listing 5.8, it is responsible for comparing the user's current gaze position with gaze-aware elements on the page. It will update classes, and trigger dwell actions where necessary. To determine if the user is gazing at a particular element, coordinates of the element's bounding rectangle of are compared with the current gaze coordinates.

As outlined in this section, we developed a framework for the enabling of gaze-aware HTML elements. As a solution, this turned out to be lightweight, and very robust. The initial development of this framework, made it very easy to put together the rest of the interface. Writing the remaining HTML code for the interface was very similar to the creation of any other HTML project.

5.3 Storing Artworks

Careful consideration had to go into the method of storing artworks that were to be used by the system. It was necessary that artworks could easily be added, or edited. Furthermore, it was a important this could be done without any specialist knowledge. The decision was made to use the JSON structure shown in Listing 5.9. All artworks that had a JSON file

Listing 5.7: Initialising Gazeaware elements

```
function setupGaze(){
      //Get all elements on page
      var arr_elms = [];
      arr_elms = document.body.getElementsByTagName("*");
      var elms_len = arr_elms.length;

      //Add all gazeaware elements to global object
      for (var i = 0; i < elms_len; i++) {
        if(arr_elms[i].getAttribute("gazeAware") != null){
         gazeAwareElements.push({'element': arr_elms[i],
            'dwell':false, 'dwellTimeout': null});
        }
      }
    }
```

present would be loaded into the system.

Gaze points were simply stored as coordinates and a radius, relative to the original image's pixel size. The image file and audio files are referenced by a relative path, and stored in the sibling folders shown in Figure 5.1.

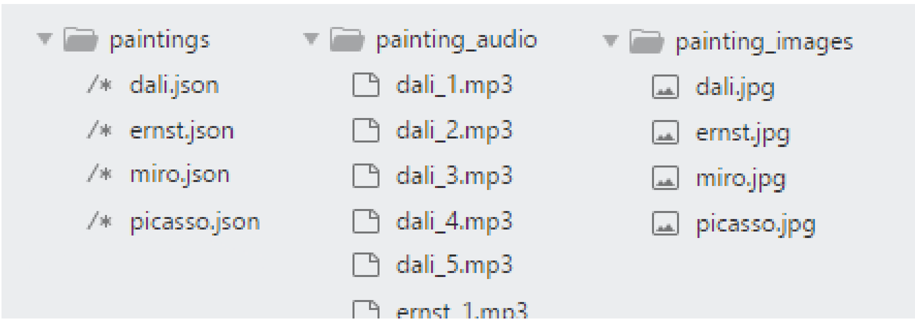

Figure 5.1: Folder Structure for the system

Listing 5.8: Checking for Gaze

```
function updateGaze() {
      for (var i = 0; i < gazeAwareElements.length; i++) {
        var el = gazeAwareElements[i].element;
        var elRect = el.getBoundingClientRect();
        var gazeClass = el.getAttribute("gazeOverClass");
        var actionFunction = el.getAttribute("gazeAction");

        if(gazePosition.x > elRect.left
          && gazePosition.x < elRect.left + elRect.width
          && gazePosition.y > elRect.top
          && gazePosition.y < elRect.top + elRect.height){
          //Gazing
          if(gazeAwareElements[i].dwell){
            //Already gazing, no change
          } else{
            gazeAwareElements[i].dwell=true;
            el.className += " " + gazeClass;
            gazeAwareElements[i].dwellTimeout =
               setTimeout(actionFunction , 2000);
          }
        } else {
          //Not Gazing
          if(gazeAwareElements[i].dwell){
            gazeAwareElements[i].dwell=false;
            el.classList.remove(gazeClass);
             clearTimeout(gazeAwareElements[i].dwellTimeout);
          }
        }
      }
    }
```

Listing 5.9: JSON for storing artworks


```
{
"title":         "The Temptation of Saint Anthony",
"artist":        "Salvador Dali",
"year":          "1946",
"medium":        "Oil on canvas",
"image":         "painting_images/dali.jpg",
"width":         2400,
"height":        1728,
"gazePoints" :   [
   {"x": 180, "y": 1300, "r" :100, "audio": "dali_1.mp3"},
   {"x": 640, "y": 280, "r": 100,  "audio": "dali_2.mp3"},
   {"x": 900, "y": 260, "r": 100, "audio": "dali_3.mp3"},
   {"x": 1320, "y": 440, "r": 100, "audio": "dali_4.mp3"},
   {"x": 2160, "y": 500, "r": 100, "audio": "dali_5.mp3"}
  ]
}
```


5.4 Viewing Artworks

5.4.1 Rendering the HTML Canvas

An HTML canvas element was used to display the artworks. The canvas had to support artwork images of differing aspect ratios, whilst always rendering the art as large as possible. Listing 5.10 shows the method for calculating the canvas size based of the image dimensions.

The artwork image was set as the background of the canvas element. Modulations could then be rendered over the top as needed. This method greatly improved the efficiency of the system.

5.4.2 Rendering Audio Points

The coordinates and radius of the 'gaze points' (areas on the image which should trigger audio) were loaded from artwork's JSON file. It was necessary to check whether a user was looking at a gaze point, so that the system could trigger the relevant audio clip, and terminate the gaze point.

The code in Listing 5.11 was used to calculate if a user's gaze was currently within a point. It uses the radius to define a circle around that point, additionally using a margin parameter, such that the global minimum distance required to trigger a point could be configured.

This code was called as part of the canvas' render loop, meaning it would be executed as

Listing 5.10: Configuring HTML Canvas Size

```
if(viewport.aspectratio<paintingInfo.aspectratio){
  //Fit width
  canvas.width = viewport.width;
  canvas.height = paintingInfo.height *
     (canvas.width/paintingInfo.width);
  renderedScaleFactor = canvas.width/paintingInfo.width;
} else {
  //Fit Height
  canvas.height = viewport.height;
  canvas.width = paintingInfo.width *
     (canvas.height/paintingInfo.height);
  renderedScaleFactor = canvas.height/paintingInfo.height;
}
```

Listing 5.11: Checking for user gaze on audio points

```
//Return true/false for if gazing at point
function gazingAtPoint(x, y, r){
  //Check if point in circle, use margin
  var margin = 100; //Margin around point
  return (Math.pow((gazePosition.x - x - canvasMargin),2) +
     Math.pow((gazePosition.y - y),2) < Math.pow(r+margin,2));
}
```

fast as the system hardware would allow. This was necessary as a this particular function had to checked in real time, however care had to be taken to only keep essential code in the render function to avoid the system slowing down.

Listing 5.12: Modulating the Image Data

```
for (var i = 0; i < numPixels; i++) {
  pixelsModulated[i*4] = pixelsDefault[i*4]     * 1.05;//Red
  pixelsModulated[i*4+1] = pixelsDefault[i*4+1] * 1.05;//Green
  pixelsModulated[i*4+2] = pixelsDefault[i*4+2] * 1.05;//Blue
}
```

5.5 Subtle Gaze Direction

5.5.1 Modulating The Images

A decision was made to apply a global modulation to the image when the page was initialised, rather than modulating the image dynamically as part of the canvas' render loop. This philosophy of trying to do all the heavy lifting on page load was crucial in producing a system that ran well, as any drops in framerate would impact the effectiveness of subtle gaze direction.

Upon page load a second, temporary canvas was created and the image data was loaded into it using *putImageData()*. Image data was then pulled into the array *pixelsDefault* using *getImageData()*. Adjustments could then be made on a per pixel level, adjusting the RGB channels of the image, as shown in Listing 5.12. This made it very easy to experiment with an arbitrary list of modulation types, such as temperature.

A choice was made to use a luminosity modulation of +5%, which proved to be the ideal threshold during initial testing.

5.5.2 Rendering Modulated Images

Having obtained an array containing the image data of the modulated regions, it was then necessary to use this data to create each of the modulated regions. The decision was made to create a separate canvas element for each modulated region, creating these at initialising, such that they could simply by written to the main canvas as needed during the render loop. Again, this was for efficiency reasons, to ensure a stable framerate.

The modulated image data was written to a canvas, then clipped around the appropriate region for each gaze point. A blur filter was used, when clipping the canvas. This was based on the gaussian falloff function by Bailey et al.(2009), however designed to be a more lightweight approach. The *cliparc* function in Listing 5.13 shows the method of creating the modulated regions, and the application of the blur filter.

Having done all the setup upon loading the page, and obtained a canvas element for each modulated region, (stored in the array these could simply be written to the main canvas when needed at runtime as needed. This was an incredibly efficient approach.

Listing 5.13: Guassian clipping of modulated regions

```
//Clips canvas into a fearthered blur around region
function clipArc(context, x, y, r) {
    context.globalCompositeOperation = 'destination-in';
    context.filter = "blur(10px)";  // "feather"
    context.beginPath();
    context.arc(x, y, r, 0, 2 * Math.PI);
    context.fill();

    //reset comp. mode and filter
    context.globalCompositeOperation = 'source-over';
    context.filter = "none";
}
```

The result of this setup was the array *gazePointsCanvas*[] containing the canvas elements for each of the modulated regions, ready for use by the render loop.

During the render loop, a gaze point that was enabled would be shown at a frequency of 10Hz, as defined by Bailey et al.(2009).

Two global boolean variables *renderPoints* and *renderPointsVisual* were used to globally control whether the system should be enabling the audio callout points, and the subtle gaze direction points, respectively.

5.5.3 Saccading Masking

First it was necessary to detect whether a user's gaze was currently in a saccade or a fixation. For this we used an algorithm called Velocity-Threshold Identification (I-VT). As an algorithm it is simple, and a fairly robust means of distinguishing between saccades and fixations. It functions by calculating the velocity between past two gaze positions, if the velocity is less than a given threshold then this indicates a fixation (Salvucci and Goldberg, 2000).

The threshold for the velocity was optimised to achieve the average number of fixations per minute that normally occur when viewing an image, based on prior studies.

Although prior studies had applied smoothing operations to remove noise before applying this algorithm, I found this step was not necessary to to the high accuracy of the Tobii 4C.

The implementation for this algorithm is shown in the *checkFixation()* function in Listing 5.14.

We then proceeded to follow the implementation for Saccadic Masking, as defined by Bailey et al.(2009). We begin by calculating two vectors:

Listing 5.14: I-VT Algorithm Implementation

```
//Checks whether we're in a fixation or a saccade
function checkFixation(){
  var threshold=25;
  var vX = gazePosition.x-lastGazePosition.x;
  var vY = gazePosition.y-lastGazePosition.y;
  var velocity = v_Magnitude(vX, vY);
  if(velocity<threshold){
    //Fixated
    if(!fixated){
      fixated = true;
      fixation.x = gazePosition.x;
      fixation.y = gazePosition.y;

      if(renderPoints){
        updateVectorW();
      }

    }
  } else{
    //Saccading
    if(fixated){
      fixated = false; //Ended Fixation
    }
  }
}
```

- **V**: The vector of from the last fixation point (f), to the last gaze position (g). This represents our current saccade.
$$\mathbf{V} = g - f$$

- **W**: The vector from our current fixation (f) to the point of interest (p).
$$\mathbf{W} = p - f$$

Then we calculate the angle θ between **V** and **W**. This is shown in Figure 2.5.

$$\theta = \arccos\left(\frac{\mathbf{V}.\mathbf{W}}{|\mathbf{V}| * |\mathbf{W}|}\right)$$

Figure 5.2 shows our system with the debug overlay, the vectors V and W are shown, along with the fixation points.

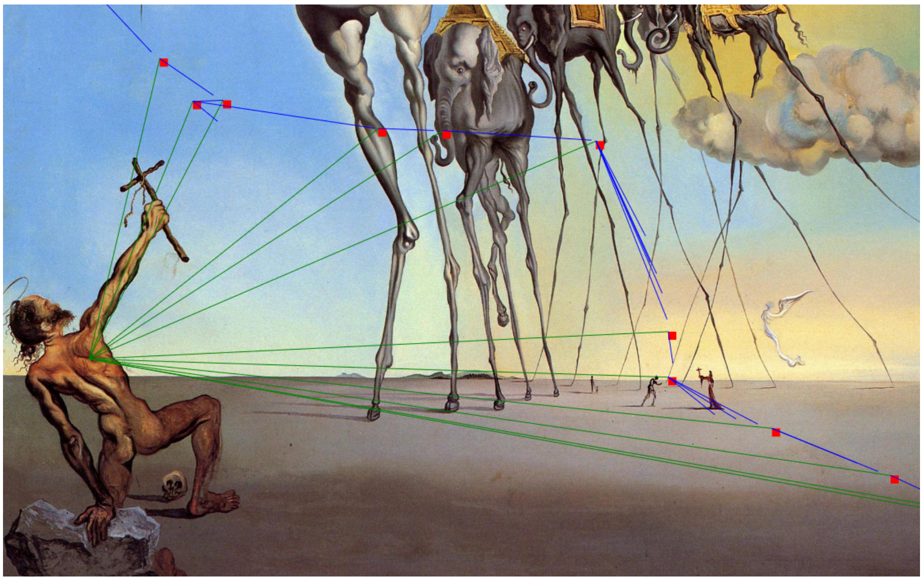

Figure 5.2: Rendering of Fixations (Red) Vector V (Blue) and Vector W (Green)

We define a threshold (0.17 Radians), if θ is within this threshold, then the viewer is saccading towards the gaze point. The gaze point would then be immediately terminated. Out implementation of this is shown in the *saccadicMasking()* function in Listing 5.15.

Bailey et al.'s (2009) implementation would permanently terminate the gaze point upon detecting a saccade towards it. For our system, the choice was made to terminate the point for three seconds. Only Permanently terminating the gazepoint once the user had actually viewed the point for four seconds, and activated the relevant audio cue. Again, this was a decision made based on testing of early prototypes.

Listing 5.15: Saccadic Masking Implementation

```
function saccadicMasking(){
  if(renderPoints&!fixated){
    updateVectorV();
    var thetaThreshold = 0.17;     //radians
    var theta = Math.acos( (V.x*W.x + V.y*W.y) /
       (v_Magnitude(V.x,V.y) * v_Magnitude(W.x,W.y)) );
       //radians

    if(theta < thetaThreshold){
      //Saccading, towards POI
      if(renderPointsVisual){
        printDebug("Saccade towards Gaze Point. Hiding");
        renderPointsVisual = false; //Hide Gazepoints for 3
           seconds
        setTimeout(function() { renderPointsVisual = true; },
           3000);
      }
    } else {
      //Saccading, not towards POI
    }
  } else {
    //Fixated
  }
}
```

Chapter 6

Evaluation

In this chapter we will review the evaluation of the system. We begin by detailing the design and methodology of the experiment, defining the hypotheses we aim to test. We then proceed to review and analyse the results of the experiment.

6.1 Methodology

The goal of the empirical study is to assess the effect of the addition of Subtle Gaze Direction and Auditory information, on the following factors when a participant views an artwork:

- *Aesthetic Appreciation*,
- *Interest*
- *Ability to Understand*

These factors will be assessed using a questionnaire. We will also assess the effect of the conditions on the gaze pattern of the viewer, by recording the viewer's fixations.

Lastly, the study looks to evaluate the usability and suitability, of the system in general, assessing the design decisions that have been made.

6.1.1 Experimental Design

In order to assess the two variables, SGD and Audio, we created four designs, each representing one of our conditions. These designs are shown in Table 6.1.

The main design (D4) features both SGD and contextual audio callouts. This is considered the feature-complete design, as per the Requirements in Chapter 3.

Subtle Gaze Direction	Audio Information	Design	User Experience
No	No	D1	E1
Yes	No	D2	E1
No	Yes	D3	E2
Yes	Yes	D4	E2

Table 6.1: Designs Conditions

	A1	A2	A3	A4
P1	D1	D2	D3	D4
P2	D2	D1	D3	D4
P3	D1	D2	D4	D3
P4	D2	D1	D4	D3
P5	D3	D4	D1	D2
P6	D4	D3	D1	D2
P7	D3	D4	D2	D1
P8	D4	D3	D2	D1

Table 6.2: Participants (P), Artworks (A), Designs (D)

We would used a within-participant design for the study. A critical part of the study was not informing the participants of the presence of SGD as this knowledge would likely influence their viewing pattern.

As such, participants were be told they would be evaluating two different user experiences; one user experience where they are simply viewing art, the second in which art will be presented alongside auditory information. Table 6.1 shows the four designs, as they relate to the two user experiences.

It was of course necessary to permutate the order in which participants view the design to avoid any training or fatigue bias. However, in order to maintain a clear distinction between the two user experiences, a decision was made to keep designs D1 and D2 (no audio), and designs D3 and D4 (audio), together sequentially. As such we arrived at the permutation Table 6.2.

The table uses a Latin square structure to ensure that half the participants, test Experience 1 first, and half the participants test Experience 2 first. Furthermore, the four conditions were equally permutated over four different artworks.

In order to evaluate the design of the system as a whole, participants would test the four designs as part of the same cohesive run. The system was configured such that four artworks would be available, and each one would be loaded in with a different design, as indicated by Table 6.2.

Participants would begin by completing the calibration (Figure 4.4), at which point they would arrive at the menu screen (Figure 4.5). They were instructed to select the first artwork, and view it for as long as they desired (at least 90 seconds), as if they were viewing it in the gallery. The participant was then instructed to navigate back to the menu, and then fill out a questionnaire assessing their opinion of the artwork. They would then repeat this process for the remaining three artworks.

6.1.2 What are we measuring

We recorded the coordinates and timestamps of the participant's fixations as they viewed the artworks. This enables us to assess the effect of our four conditions on their viewing pattern.

Another focus of the study is see how the four conditions effect the viewing of artworks, in terms of the participant's opinion. The three factors we identified for this being:

- *Aesthetic Appreciation*,
- *Interest*
- *Ability to Understand*

These factors were assessed through the use of seven, seven point semantic differential questions that were answered after the participant viewed each of the artworks. The questionnaire was formed using questions from prior studies, that similarly assessed these three factors. The following relates to part 1 of the questionnaire in Appendix A.

For assessing aesthetic appreciation we use the two questions from the study by (Swami, 2013). This is a well cited method of assessing aesthetic appreciation. These questions are numbered 1 and 2 in Appendix A.

For the assessment of interest we will used the questions numbered 2 and 3 (Appendix A). These were taken from the semantic scale in the study by (Silvia, 2013).

Finally, the assessment of a user's ability to understand used questions 4,5,6, and 7 (Appendix A). These were taken from the (2013) study by Swami.

In addition to the questionnaire assessing each artwork, a secondary questionnaire (Appendix A Part 2) was completed by the participants at the end of the study. The goal of this was to assess the overall usability and enjoyment of the system. The questionnaire consisted of six, five point semantic differential questions. The questions were taken, or adapted from, which were adapted from the System Usability Scale (SUS). Whilst usually the entire SUS would be used, it was necessary to to drop some questions as they were not relevant to the system.

Part 2 of the questionnaire, also included a question to ascertain whether the user was aware of the presence of Subtle Gaze Direction. We used the question '*Did you notice anything unusual about any of the artworks?*", with the term 'unusual' left deliberately undefined.

This was the method used by Bailey et al. (2009) to assess whether the participant was aware of SGD.

In addition to the quantitative data, some qualitative data was collected. The Questionnaire Part 2 included a section for participant comments. The study coordinator was also making observations relating to any difficulties that participants encountered when using the system.

6.1.3 Participant Demographic

A total of 16 participants took part in the study. All of whom were undergraduates or research students, from the University of Bath.

Specific statistics on the participants were not recorded as it was not relevant to the study, merely that the participants were a fairly accurate representation of the general populus. The participant group consisted of both males and females, and a range of ethnicities and ages. participants among the group did have visual impairments, however it was required for the study that they be wearing corrective glasses or contacts where necessary.

Participants were recruited simply on the basis that they considered themselves 'art novices'. This was sufficient for this study, however a more in depth investigation into how one's art expertise effects their use of the system could make use of the Aesthetic Fluency Scale (F. Smith and Smith, 2006) for appraising participant's art expertise..

6.1.4 Choice of Stimuli

The four artworks selected for the study were:

- *The Temptation of Saint Anthony*, Salvador Dali
- *The Elephant Celebes*, Max Ernst
- *Carnaval de Arlequn*, Joan Miro
- *Guernica*, Pablo Picasso

The decision was made to use four artworks from the Surrealist movement. The decision was based on previous studies that suggested Abstract paintings were perceived better than Representational when presented alongside contextual information (Swami, 2013).

Furthermore, the paintings were chosen because of the high levels of visual symbolism. It was thought that these paintings would be most suitable when playing audio related to specific points on the painting.

The auditory statements were adapted from *Surrealism*, (Caws, 2004) and *Surrealism*, (Schneede, 1973), supplemented by information from the Met and Tate's websites. Information included accepted interpretations from art historians, historical contextual information, and statements on representation by the artists themselves.

6.1.5 Hypothesis

The empirical study would look to test four Hypothesis:

- **H1** - The addition of Subtle Gaze Direction will result in increased overall aesthetic appreciation, interest and understanding.

  This will be assessed by comparing the results from Questionnaire Part 1, for designs D1 and D3 (no SGD) and designs D2 and D4 (SGD). It will be necessary to perform a significance test for each of the factors.

- **H2** - The addition of auditory information will result in increased overall aesthetic appreciation, interest and understanding

  This will be assessed by comparing the results from Questionnaire Part 1, for designs D1 and D2 (no audio) and designs D3 and D4 (audio). It will be necessary to perform a significance test for each of the factors. The effects of audio designs D3 and D4, will be measured by Questionnaire Part 1.

- **H3** - The addition of Subtle Gaze Direction will cause users to focus more on high level features of the artworks

  Using Subtle Gaze Direction to assist a participant in navigating over an artwork, we expect the viewer to focus on more high level features. This will result in longer fixations, less overall fixations, and lower proportion of time spent in saccade. These are all features of how an expert views artwork, compared to a novice (Pihko, Virtanen, Saarinen, Pannasch, Hirvenkari, Tossavainen, Haapala and Hari, 2011).

  This will be assessed by comparing the average gaze data, for designs D1 and D3 (no SGD) and designs D2 and D4 (SGD).

- **H4** - The addition of auditory information will cause users to explore more of the paintings.

  The presence of audio statements are intended, as well as providing information, may have a positive side effect; viewers may be encouraged to explore more of the artwork in an effort to find all the audio trigger points. This will be assessed by examining the coverage of the participant's gaze data.

6.2 Results

In this section we will evaluate the results of the experiment, analysing the data where necessary to identify any areas of support for the hypothesis

6.2.1 Aesthetic Appreciation, Understanding, Interest

	A1			A2			A3			A4		
	AA	I	AU	AA	I	AU	AA	I	AU	AA	I	AU
D1	5.50	5.13	4.31	3.75	3.50	3.19	4.88	4.88	3.19	5.25	5.25	3.81
D2	5.00	4.63	3.56	3.75	3.50	2.94	5.63	5.75	3.25	4.50	5.00	4.06
D3	6.00	5.63	5.06	5.88	4.75	5.25	5.13	4.75	4.38	4.88	4.75	5.00
D4	5.88	5.63	4.50	4.50	4.00	3.75	4.75	4.13	4.50	5.25	4.88	4.88

Table 6.3: Mean Aesthetic Appreciation (AA) Interest (I) Ability to Understand (AU) Across Designs (D) and Artworks (A)

From the results of the semantic differential questions in Part 1 of the questionnaire, the appraised scores for the factors of aesthetic appreciation, interest, and ability to understand were obtained. These mean average of these values was then taken for each condition and artwork as shown in Table 6.6.

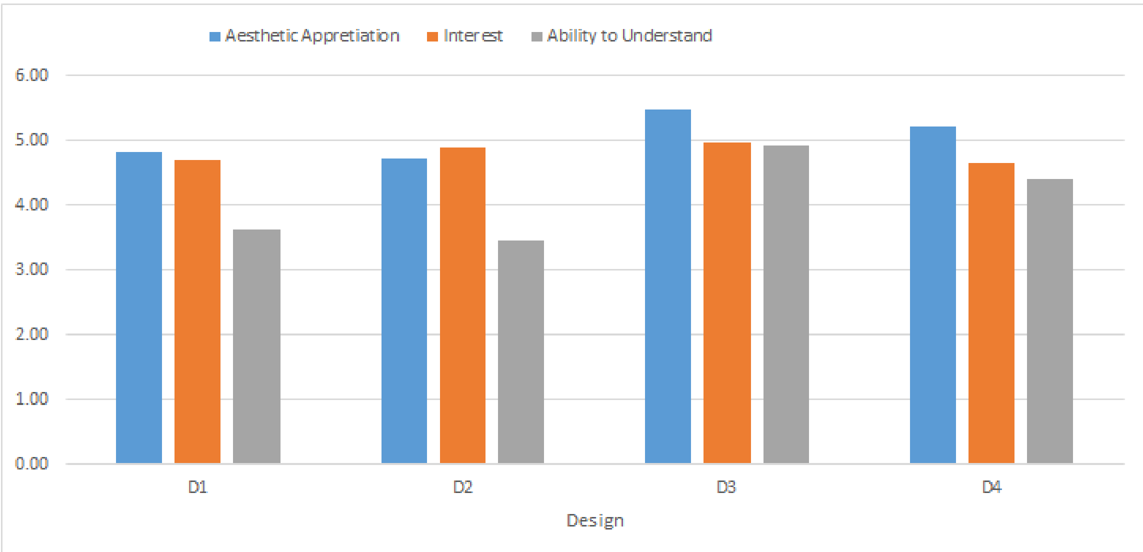

Figure 6.1: Average Aesthetic Appreciation, Interest, and Ability to Understand across 4 Designs (D)

The values for the four artworks, across the four conditions, were then averaged. The resulting appraised scores for each condition are graphed in Figure 6.1. The graph shows in increase in both aesthetic appreciation and ability to understand, for designs with audio, suggesting support for Hypothesis H2. However it was necessary to test the statistical significance of these results, as they relate to Hypotheses H1 and H2.

For each condition we had a set of sixteen data points (the appraised scores), for each of the three factors. These data was used for the significance test. A two-way analysis of variance (ANOVA), was used as it provides a test of significance when measuring the effect of two independent variables (Audio and SGD), on one continuous variable (the appraised score). The analysis was carried out six times in total, comparing two independent variables, across three factors.

The results of the significance tests are shown below:

No Audio vs Audio

- Aesthetic Appreciation: $p = 0.1051$
- Interest: $p = 0.7258$
- Ability to Understand: $p = 0.0003$

No SGD vs SGD

- Aesthetic Appreciation: $p = 0.6346$
- Interest: $p = 0.6522$
- Ability to Understand: $p = 0.2446$

We used a value of 0.05 as a threshold for for statistical significance. The results prove that the increase in Ability to Understand with the addition of audio, was not a coincidence ($p = 0.0003$). This provides strong evidence, partly supporting Hypothesis H2. The data showed no evidence, however, in support of Hypothesis H2 relating to the factors of Interest and Aesthetic Appreciation.

The data did not reveal any evidence in support of Hypothesis H1. The p-values suggests that the addition of SGD does not have a statistically significant effect on the levels or aesthetic appreciation, interest, or ability to understand.

6.2.2 Eye Gaze Data

As participants viewed the artworks, timestamped coordinate data of each of their fixations was recorded. A heat map was created of the combined fixation data for the participant viewings of artwork A1 (Dali). Figure 6.2 shows the gaze data for viewings without audio,

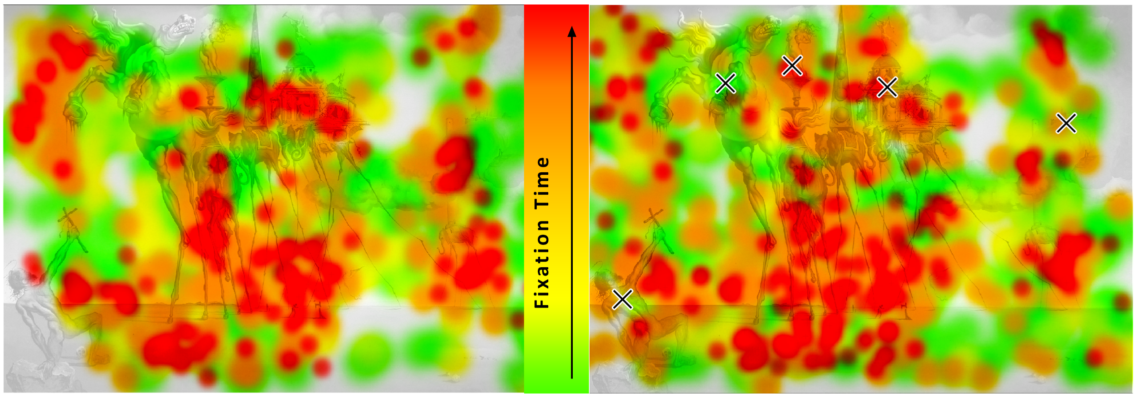

Figure 6.2: Heat Maps for Design D1 (Left) Design D2 (Right)

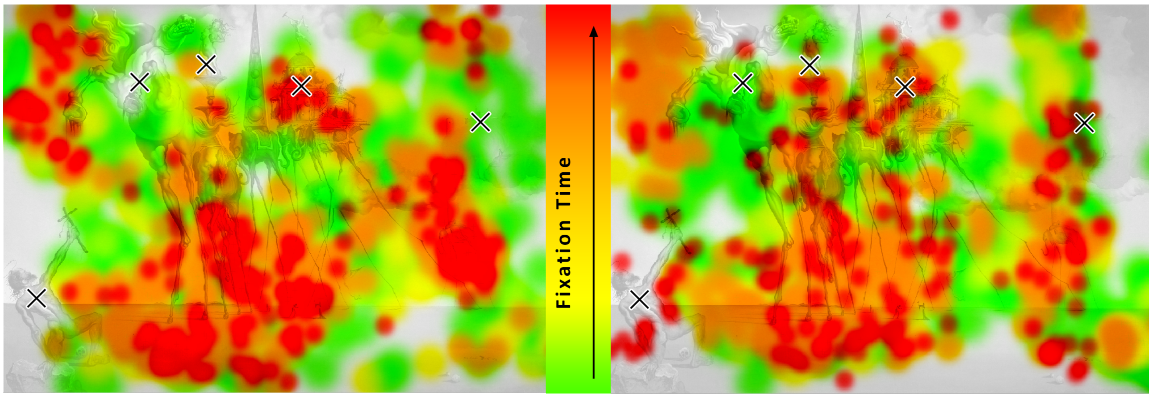

Figure 6.3: Heat Maps for Design D3 (Left) Design D4 (Right)

and Figure 6.3 shows viewings with audio. The SGD or audio trigger points are marked as crosses on the relevant images.

Whilst the heat maps provide a good means of visualising the data, they are not sufficient to provide evidence in support, or against Hypothesis H4. To ascertain whether the addition of SGD increases the coverage of the viewer's gaze pattern, it is necessary to carry out some more complex analysis.

An appropriate means of assessing the coverage of a gaze map was proposed by (Wooding, 2002). However, Wooding's process for obtaining this metric is very involved, requiring a map of fixation points be represented as a 3D Gaussians. Due to the sheer scale of the data that was collected, and the time requirements to obtain this metric, it was deemed out of scope for this project.

Furthermore, traditional, more simple measures of deviation in 2 dimensions were deemed to not be appropriate for this context, as the metric we are interested in is visual coverage,

	Mean Average	Variance
Design D1	270.64	6907.3
Design D2	303.11	9957.13
Design D3	281.05	3558.56
Design D4	308.57	9278.85

Table 6.4: Fixation Lengths

	Mean Average	Variance
D1	0.9154	0.00086
D2	0.9167	0.0007
D3	0.8903	0.00657
D4	0.9180	0.00111

Table 6.5: Fixation Ratio

not the distance of fixations from a particular centroid. As such, it was not possible to obtain any statistical data in support, or against Hypothesis H4.

In order to determine the validity of Hypothesis H3, further data analysis was required. Two factors were chosen, to determine how conditions effect the viewer's tendency to focus on more high level features of the artwork:

- Average fixation length
- Proportion of time spent fixating.

The average fixation length was calculating for each of the data sets, relating to individual viewings of artworks:

$$averageFixationLength = \frac{\sum_{n=1}^{n}(fixationEnd - fixationStart)}{n}$$

Where n represents the total number of fixations in the individual dataset. The proportion of time spent fixating was then calculated:

$$fixationProportion = \frac{averageFixationLength * n}{totalViewTime}$$

These values were then averaged for each Design, resulting in datasets consisting of 16 points for each condition, for the factors of both Average fixation times, and average saccade length.

The mean and variance for the fixation lengths and fixation ratio, are shown in Table 6.4 and Table 6.5, respectively. The table does show an increase in fixation length for the Conditions with SGD (D2 and D3).

As before, a 2 way-ANOVA was the carried out to ascertain whether there was any statistically significance to the data as it relates to Hypothesis H3.

Results of the ANOVA significance test are below:

No Audio vs Audio

- Average fixation length $p = 0.7134$
- Average fixation proportion: $p = 0.3259$

No SGD vs SGD

- Average fixation length $p = 0.1689$
- Average fixation proportion: $p = 0.2320$

We used a value of 0.05 as a threshold for for statistical significance. Examining the p values for the comparison between SGD and No SGD, it is clear the data does not suggest any support for Hypothesis H3.

6.2.3 User Experience Evaluation

To investigate the effectiveness, ease of use, and enjoyment of the system as a whole, participants were asked to fill out Part 2 of the questionnaire. Table 6.6 shows the average results of the five-point semantic differential questions.

I found this system enjoyable to use	4.63
I found this system easy to use	4.50
I would use this system if it was available in an art gallery I was visiting	4.31
*I think I would need the support of a technical person to use this system**	1.81
*I found the system cumbersome to use**	1.94
I felt very confident using the system	4.25
Final calculated score (out of 30)	23.94

**Reverse scored*

Table 6.6: Mean Scores for Usability Questionnaire

The system achieved an overall rating of **79.8%**. This can be compared to a usability rating, from the System Usability Scale, upon which it was based. It is generally considered that a usability scale of greater than 68% is above average. In this regard the system was very successful, as the creation of a fully gaze interactive system that maintains ease of use similar to a traditional input, was one of the major challenges of the project.

Participants rated the enjoyability of the system particularly high, this was a particularly important metric, as the system is designed to provide a novel and enjoyable experience.

A relatively high proportion of users found the system cumbersome, and felt that they may need technical assistance. It was expected that users would face some level of difficulty when using a gaze interactive system. Furthermore, the scores in these categories are still fairly positive.

6.3 Discussion

6.3.1 Hypothesis

This section is a summary of the extent to which we have managed to prove, or disprove, each of our Hypotheses.

- **H1** - The addition of Subtle Gaze Direction will result in increased overall aesthetic appreciation, interest and understanding.
  The result of statistical analysis was not in support of any aspect of this hypothesis. It is worth noting, however that the addition of SGD did not have any negative effects on the user's perception of the artworks.
- **H2** - The addition of auditory information will result in increased overall aesthetic appreciation, interest and understanding.
  Data did not support an increased level of interest. Data did show a marginal increase in Aesthetic appreciation, however this was shown to be statistically insignificant. Regarding the participants ability to understand, however, the data we gathered was definitely in support of this hypothesis.
- **H3** - The addition of Subtle Gaze Direction will cause users to focus more on high level features of the artworks.
  Did see a minor increase in fixation length for artworks viewing with Subtle Gaze Direction. However statistical analysis proved this to not be of significance.
- **H4** - The addition of auditory information will cause users to explore more of the paintings.
  We were unfortunately not able to carry out sufficient analysis of the eye tracking data, to provide any evidence for or against this hypothesis.

6.3.2 Participant Comments

Included in Part 2 of the questionnaire (Appendix A) was a space for participants to note any additional comments they had, here we will discuss the feedback.

To establish whether participants were aware of the presence of Subtle Gaze Direction, they were asked whether they noticed anything unusual about any of the artworks. 4 out of 16 participants said yes. However, the first participant attributed their answer to a minor bug in the software with the audio statements:

- *Looked at 2 different places in 4th painting and got two different audios playing simultaneously.*

The remaining three clearly did notice the presence of SGD:

- *Certainly in the 2nd and 3rd works there was a 'bobbing effect' where a small portion of the picture would seem to protrude slightly outwards, grabbing my attention*
- *Occasional flashing lights on screen*
- *Slight fuzziness when part of the artwork was going to be talked about*

Overall a minority group of **18.75%** did notice SGD. This is a fairly low amount, and reflective of the fine tuning of the various control parameters that went into the implementation. Further experimentation could reduce this number, getting closer to the ideal threshold for these control parameters.

One participant provided feedback on the audio subjects themselves.

- *Felt with audio you could interpret it many ways. While audio provided context it wasn't always interesting*

This is reasonable statement. The success of the system hinges greatly on the quality of the content in the audio. However, the statements were adapted from respected sources. Generally the audio statements were viewed very favourably by participants with **93.75%** stating they preferred the user experience with audio. Furthermore, when asked which of the four artworks they preferred most **81.25%** answered with one of the two, that were presented with audio.

Further comments received were:

- *After an initial small learning period, I found the system very easy and intuitive to use*
- *Could include ways of showing where audio cues get triggered*

6.3.3 Observations

Reviewing some of the observations made by the study coordinator, relating to the general usability of the system.

Generally participants could use the system with ease. The design considerations meant the interface functioned as intended, as illustrated by the high ratings. One noted point of friction amongst participants was the confirmation button on the menu screen. Whilst it was clear that they should select a painting using their gaze, it took some time to figure out that they would not notice the change of text on the confirmation button. Proposed fix would be a flash or other animation to act as a call to action.

6.3.4 Limitations of the Study

The main limitation of the study was the fact that users tested the system in a lab, rather than a scenario better set up to mimic the intended setting of the system. Users were sat in a chair, looking at a regular monitor, on a desk. Whereas, the system is intended to be set up in a public gallery, on a large wall mounted display, with users standing.

It is likely that the majority of our results are generalisable to the system set up in the intended scenario, and would not change; efforts were made to use a representational sample, to ensure external validity. However, a field test would be necessary to evaluate the usability of the system, as this is likely to differ.

Order bias, training and fatigue effects were mitigated through permutating the conditions over different artworks. Efforts were made to eliminate other threats to validity wherever possible. However, one possible threat to the validity of the study is the 'Social Desirability Bias'. It was necessary to have the study coordinator present to make observations during the experiment. As the study took place at the university, participants were naturally aware that this was part of an academic project. It is possible that this could of put a bias on participant's questionnaire responses, as they try to provide answers they deem helpful.

Chapter 7

Conclusions

In this chapter we will discuss the main contributions of the project. We will then discuss potential future work, relating to both potential areas of research and possible extensions to the system we produced. Finally we will reflect on the process of the project in general, and the success of the outcome.

7.1 Contributions

7.1.1 Creation of a novel system for viewing artworks

Overall we have successfully implemented a system, that meets the initial goals of the project. The system combines gaze interaction, subtle gaze direction, and audio information, to create an entirely novel way for users to view artworks. User studies with the system have shown it was received very well, with users particularly enjoying the presentation of the audio statements.

7.1.2 Evaluation of how contextual auditory information and SGD effects a viewer's perception of art

We identified three key variables to evaluate, based on prior research: Aesthetic appreciation, interest, and ability to understand. Formulating a list of seven semantic differential questions to assess this, again based on prior studies. We conducted an empirical study assessing the effects on these three factors on the viewing of Surrealist artworks, when varying our design conditions (SGD and audio information). Statistically significant correlations were identified relating to audio information and one's ability to understand artworks.

7.1.3 Research into subtle gaze direction applied to the viewing of art

We conducted a review of literature and implementations of subtle gaze direction, as well as the areas of application. We implemented SGD into the system, which was successful in that it was not visibly noticeable by the majority of users. We then carried out some analysis of how SGD effects the viewing pattern of users, when looking at artworks. A further contribution in this regard is the implementation of SGD using the HTML canvas, modifying the implementation by Bailey et al. (2009) to take advantage of the canvas to improve efficiency.

7.1.4 Research and development of a fully gaze interactive interface

After a comprehensive literature review into the current state of eye gaze interaction, and some existing design practices we created a fully gaze interactive user interface. Applying these design methodologies, and detailing the challenges faced when building such a system. We evaluated the usability of this gaze interactive system, which proved to be very positively received by users, in terms of both enjoyment and usability.

Another contribution relating to the implementation was the development of the client/server to enable data from the Tobii eye tracker to be used for developing with Javascript. Also providing a framework for gaze interactive HTML elements. This will be be published as open source, as it will be potentially valuable to other developers, opening up the possibility of developing electron based desktop applications that utilise gaze interaction.

7.2 Future Work

Whilst the evaluation of the user study was sufficiently comprehensive to cover the research goals of the project, there's is much potential for further analysis to be done. A vast amount of data relating to the user's fixation points when viewing the artworks was collected. One area in particular, previously mentioned, is the analysis of the total coverage of the viewer's gaze, and how our experimental conditions effect this. Another example for potential further analysis would be the visualisation and comparison of the participant's visual scanpath.

Participants responded positively to the system during the study, however this was conducted in laboratory conditions. A key area of further work would be to test the system in it's intended context, of a public exhibition space. Repeating the usability questionnaire to see if the results confer, and to assess whether the additional external variables negatively impact the usability of the system.

The user study we carried out was deliberately limited to artworks from the surrealist movement, for reasons previously discussed. An interesting area of further research would be to test the system using artworks from varying styles and movements. It is possible that different types of art would present the need to present audio information. For example, artworks with less direct symbolic representations may require audio statements to be played that are not linked to a particular area of the painting, narrative artworks may require a specific order of audio statements to be enforced. The system would have to be updated to accommodate these changing requirements.

The system itself provides a great deal of potential for future work in the form of additional features. In addition to input of the user's gaze position, the Tobii 4C can also provide head position. This could be used to further enhance the design, for example adding a dynamic zoom when the user moves towards the screen to enable them to view rendered artworks at a higher resolution. This could be coupled with a method of panning over the artworks by gazing at the edge of the screen.

Other extensions to the system exist in the methods by which it is implemented in the exhibition space. One possible method that could be explored would be modifying the system such that it can be used with physical artworks is well. Similarly using the eye tracker, but using a projector or spotlight in place of subtle gaze direction.

7.3 Reflection

Overall I feel proud with the outcome of the project. I am very proud of the final system that was implemented, and believe that I have created a way of viewing art that is truly novel, staying true to the initial goal of creating a system to provide accessible information to novice art viewers.

Designing for eye gaze interaction proved to be an exciting challenge, furthermore the breadth of topics covered in the literature review were highly interesting. The combination of research into the bleeding edge technology of gaze interaction, and the equally novel technique of subtle gaze direction resulted in a project that was extremely enjoyable to work on. Even more so when developing a system that has potential real world applications for art galleries.

Whilst I felt most of the design, implementation and subsequent evaluation went well, it is possible the scope of the project was spread somewhat thin. Sufficient analysis was done on the emotional responses to the conditions of the experiment however there was not sufficient time to do a comprehensive evaluation of the recorded viewing patterns. The topic of research into viewing patterns was also something somewhat neglected in literature review. However, the topic of gaze pattern analysis is a very in depth one, and could be the basis of another research project in and of itself.

It is my opinion that the viewing of art is an excellent candidate for the use eye tracking technology, for both research and interaction. I will be excited to see future projects that combine these fields. I will also be continuing work on the prototype, and hope for an opportunity to test it in a public exhibition space.

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Appendix A

Questionnaire

Eye Gaze Interactive Art User Study

Questionnaire part one

Please complete this section, by ticking the relevant boxes, to provide your opinion on each artwork you view.

Artwork 1: *The Temptation of Saint Anthony*, Salvador Dali

1) I like this painting

Strongly Disagree								Strongly Agree

2) I find this painting interesting

Strongly Disagree								Strongly Agree

3) I find this painting exciting

Strongly Disagree								Strongly Agree

4) I felt able to understand the painting

Strongly Disagree								Strongly Agree

5) This painting was easy to understand

Strongly Disagree								Strongly Agree

6) I could get a sense of what the artist wanted to express

Strongly Disagree								Strongly Agree

7) This painting was basically meaningless

Strongly Disagree								Strongly Agree

Artwork 2: *The Elephant Celebes*, Max Ernst

1) I like this painting

Strongly Disagree								Strongly Agree

2) I find this painting interesting

Strongly Disagree								Strongly Agree

3) I find this painting exciting

Strongly Disagree								Strongly Agree

4) I felt able to understand the painting

Strongly Disagree								Strongly Agree

5) This painting was easy to understand

Strongly Disagree								Strongly Agree

6) I could get a sense of what the artist wanted to express

Strongly Disagree								Strongly Agree

7) This painting was basically meaningless

Strongly Disagree								Strongly Agree

Eye Gaze Interactive Art User Study

Artwork 3: *Carnaval de Arlequín*, Joan Miró

1) I like this painting

Strongly Disagree								Strongly Agree

2) I find this painting interesting

Strongly Disagree								Strongly Agree

3) I find this painting exciting

Strongly Disagree								Strongly Agree

4) I felt able to understand the painting

Strongly Disagree								Strongly Agree

5) This painting was easy to understand

Strongly Disagree								Strongly Agree

6) I could get a sense of what the artist wanted to express

Strongly Disagree								Strongly Agree

7) This painting was basically meaningless

Strongly Disagree								Strongly Agree

Artwork 4: *Guernica*, Pablo Picasso

1) I like this painting

Strongly Disagree								Strongly Agree

2) I find this painting interesting

Strongly Disagree								Strongly Agree

3) I find this painting exciting

Strongly Disagree								Strongly Agree

4) I felt able to understand the painting

Strongly Disagree								Strongly Agree

5) This painting was easy to understand

Strongly Disagree								Strongly Agree

6) I could get a sense of what the artist wanted to express

Strongly Disagree								Strongly Agree

7) This painting was basically meaningless

Strongly Disagree								Strongly Agree

Eye Gaze Interactive Art User Study

Questionnaire Part 2

Please complete this section of the questionnaire to assess your overall experience of using the system.

Of the two user experiences did you prefer, artworks presented with audio, or artworks presented without audio?

☐ With Audio ☐ Without Audio

Of the four artworks you viewed, which did you most prefer?

☐ 1 – *The Temptation of Saint Anthony,* Dali
☐ 2 – *The Elephant Celebes,* Ernst
☐ 3 – *Carnaval de Arlequín,* Miró
☐ 4 – *Guernica,* Picasso

Please tick a box to indicate the extent to which you agree with the following statements:

I found this system enjoyable to use.

Strongly Disagree						Strongly Agree

I found this system easy to use.

Strongly Disagree						Strongly Agree

I would use this system if it was available in an art gallery I was visiting.

Strongly Disagree						Strongly Agree

I think I would need the support of a technical person to use this system.

Strongly Disagree						Strongly Agree

I found the system cumbersome to use.

Strongly Disagree						Strongly Agree

I felt very confident using the system.

Strongly Disagree						Strongly Agree

Did you notice anything unusual about any of the artworks?

☐ No

☐ Yes Comment: ____________________

Please turn over if you have any other comments that you wish to share.
Otherwise, hand in your completed questionnaire.

Eye Gaze Interactive Art User Study

Do you have any other general comments about the use of the system?

Comment:

Appendix B

Participant Instruction Sheet

Eye Gaze Interactive Art User Study

Participant Instructions

You will be testing a system to view a digital library of artworks. The system is controlled entirely through gaze interaction, using an eye tracker. The system is designed to be placed in an art gallery, or museum. The artworks you are viewing are selected works by various artists from the *Surrealist* movement.

Upon beginning the study, a quick calibration of the eye tracker will take place.
You will then arrive at the Menu Screen.

You will view four artworks in total, these art works should be selected from menu **in the order** indicated in the table below:

Artwork 1	Artwork 2
Artwork 3	Artwork 4

You may view each of these artworks as long as you wish, but please try to spend at least 90 seconds viewing each image. The study co-ordinator will signal to you after 90 seconds is up.

When you are finished viewing an artwork, you should navigate back to the Menu Screen using the virtual button in the top right of the screen.

At this point, please fill out the relevant section of the questionnaire, providing your assessment of the art you have just viewed. Then proceed to select the next artwork, and continue with the study.

For this study, you will be assessing two slightly different user experiences:

- Artworks 1 & 2 will be presented on screen **with/without** contextual audio information.
- Artworks 3 & 4 will be presented on screen **with/without** contextual audio information.

After all four artworks have been viewed, I will ask you to fill out a short second part of the questionnaire reviewing your overall experience.

Appendix C

Participant Consent Form

Eye Gaze Interactive Art User Study

Participant Consent

- ☐ I have read, and understand the Participant Instructions.
- ☐ I am taking part in this study voluntarily.
- ☐ I consent to the recording and storing of eye tracking data, by the eye tracking software. (Data will be stored as numeric coordinates of gaze points).
- ☐ I agree to complete and return the provided questionnaire, as part of the study.
- ☐ I understand my data will be stored anonymously, and in accordance with the Data Protection Act 1998.
- ☐ I understand that I have the right to withdraw from the study at any time.
- ☐ I consent to my data being processed and analysed for use in the study.
- ☐ The study features flickering images. I confirm I do not suffer from epilepsy or any other condition sensitive to flashing lights.
- ☐ I understand I should withdraw from the study immediately, if I experience any visual or other, discomfort.
- ☐ If am visually impaired, I confirm that I am wearing appropriate corrective lenses.

Participant

Print Name:

Signature: **Date:**

Study Coordinator

Signature: **Date:**

Appendix D

Ethics Checklist

13-POINT ETHICS CHECKLIST

Have you prepared a briefing script for volunteers?

A briefing script has been prepared detailing the study. This will be read to the participant, and included on the participant consent form, which will be signed by the participant prior to the study beginning.

Will the participants be using any non-standard hardware?

The study will use a Tobii 4C Eye Tracker for control of the system. Aside from the brief four point calibration, no training period will be featured as the system is designed to be used in a context of a public gallery.

Is there any intentional deception of the participants?

The users will be informed they are assessing two different software designs, using them to view digital artworks. They are not, however, informed that some of the artworks are being modulated by *Subtle Gaze Direction*. This will be revealed to them in the debriefing.

How will participants voluntarily give consent?

Participants will be provided with a consent form. This details the experiment, how their data will be used, and any relevant medical questions. This will be signed by the participant.

Will the participants be exposed to any risks greater than those encountered in their normal work life?

The study includes flickering image, participants will be made aware of this and instructed not to participate if they suffer from epilepsy.

Are you offering any incentive to the participants?

No incentive is offered.

Are any of your participants under the age of 16?

No, all participants will be university students or staff.

Do any of your participants have an impairment that will limit their understanding or communication?

No.

Are you in a position of authority or influence over any of your participants?

No, after the instruction script participants will be left to complete the study independently.

Will the participants be informed that they could withdraw at any time?

The health screening and consent form informs the participants that they are free to withdraw at any time. They are also instructed to withdraw if they feel any visual, or other, discomfort.

Will the participants be informed of your contact details?

Contact emails for myself, and the project supervisor, Christof Lutteroth will be provided alongside the printed debrief sheet.

Will participants be debriefed?

A debrief page has been provided. This includes details on the research goals of the study, including use of Subtle Gaze Direction. It also details how the participant's information will be stored and used. Additionally, participants will be given a chance to field any questions during debrief.

Will the data collected from the participants be stored in an anonymous form?

Data will be fully anonymised, with participants being assigned number ID's.