

Nudging Spontaneous Public Display Interaction Using Smooth Pursuit

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Abstract—This paper investigates the possibility of using eye-trackers in a public space to create user experiences where the user is not initially aware of the presence of eye-tracking. In all previous works involving eye-trackers in the public space, the participants are aware of the presence of eye-tracking. In particular this paper tries to nudge users to follow moving objects on screen and thereby using Pursuits to compute the correlation between moving objects and the eye movements of the participant. Pursuits is a technique that correlates users eye movements with moving on-screen targets. Results from in-the-wild-experiments show that Pursuits combined with auditory feedback can be used in a public setting, where the user is not aware of the eye-tracker initially and what they are in control of.

I. INTRODUCTION

Displays are getting cheaper and ubiquitous to use in public spaces such as airports [2], shopping centers [3] and train stations [4]. At the same time, sensing technologies such as eye-trackers are becoming more accessible, and with an easy and low cost integration with public displays they are becoming more widespread in use. The use of gaze for public displays has great potential. It is natural to use [9], intuitive [5], usually precedes action and indicates visual attention [7].

A. Eye Movements

There are distinct classes of eye movements that a person can perform. These classes are summarized below, drawing from the work of Rosenbaum [13].

Single point-of-gaze. Though humans have two eyes they typically point together to focus on one location. This produces a single point of gaze, this will be referred to as gaze.

Saccades and fixations. The most typical eye movements are quick saccades which is the action of transferring the point-of-gaze from one location to another, this action is performed in roughly 30 ms. The gaze then typically stays at that new location for a fixation that lasts roughly 100 to 400 ms.

Smooth pursuits. When performing a smooth pursuit the eyeball rotates at a steady rate, this type of movement is typically produced when there is a moving object that the eye can lock onto. This can also be thought of as a moving gaze.

Jitter. While fixating, the eyes do not hold perfectly still but instead makes very small and minute movements on the order of 0.1 degrees of visual angle. The jitter is a movement that prevents the image from fading and prevents the receptor cells from becoming oversaturated.

Blinks. Blinks occur to protect the eye from approaching objects and to moisten the surface of the eye.



Fig. 1. Top: A user controls the volume of different elements of the scene with smooth pursuit controls. Bottom: Shows the scene with the different elements the user can control the volume of.

B. Limitations and Idea

The use of gaze, combined with auditory feedback is still relatively unexplored because of constraints imposed by how and why the eyes move and because of the limits of eye tracking technology. However as the cost of eye trackers continues to drop and as the accuracy of eye trackers continue to rise, it is becoming easier to explore the potential for eye-controlled expression, and more exciting work will certainly be done [1].

The primary core limitation of eye-trackers is however that they usually require calibration, which is a time-consuming and cumbersome task [7]. While using the time for calibration is acceptable for a home setup, the need for immediate usability is required for public displays as interaction times are usually short [8].

To combat the calibration process a popular approach is Pursuits [9]. Pursuits relies on correlating movements of objects on the display with the smooth pursuit eye movement performed when following a moving object. Pursuits has successfully been deployed for multiple public display installations where it was used for both gaze interaction [10], [11] and eye tracker calibration [12]. However, in these scenarios the users was told that an eye-tracker was being used and given instructions as to what they were testing. What would happen if the purpose was to use eye-tracking in a public setting where the user is not told about the eye-tracker? Would the user eventually discover that an eye-tracker is

being used? Would the user come to realize what they are in control of?

Nevertheless, little is known about whether eye-tracking can be used in a public setting where the user is not told that their eye-tracking is being used. This would enable the creation of interactive experiences where the user might eventually find out that their eyes are in control.

In this paper I investigate the use of eye-tracking in a public setting where the user is initially unaware of the use of an eye-tracker. The user will interact with a display showing a landscape rendered using Unity, then by looking at different spheres in the environment the volume of different elements will increase and decrease. The purpose is to investigate if eye-tracking is suited in a setting where spontaneous use is required and whether the user will realize that volume changes are occurring because of what they are looking at.

C. Related Work

In this section related work that this paper builds on is explained. In [1], Hornof argues that the use of Pursuits as an interface for musical expression has not been well explored. His findings show that by moving a composition forward somewhat independently of the eye movements it is possible to accommodate for error in misclassifications. Intuitive Ocu-sonics [14] does this to the greatest extent, using the eye data to just nudge the audio. Likewise, EyeMusic [15] includes audio-visual components that continue independently of the eye movements. However none of these systems use Pursuits and instead use standard calibrated gaze oriented algorithms to indicate what the user is looking at. Even though I am not using my system for musical expression it is possible to imagine a public display spontaneous music instrument of some form using my system but with different sounds and visuals.

Pursuits [9] is a technique that is used for calibration-free gaze interaction. The technique requires moving objects on a screen that can be "pursued" by the eye. Eye movements are then correlated to the movements of the objects. The object whose movement correlates the most with that of the eyes is then assumed to be the one the user is looking at. Since its introduction, Pursuits has been used in a variety of applications including entertainment applications [9], [6], text entry [17] and PIN code entry [18], [19]. Pursuits has also been used for interaction with smart watches [20], [21] and interaction in smart environments [22]. The technique was shown to be intuitive and positively perceived by users [10].

In EyeVote [13], Khamis et al. investigate whether users are willing to spend the time it takes to correct mistakes made using eye-tracking on public displays. They deployed a public gaze-based voting system, EyeVote, that occasionally shows intentionally falsified feedback and prompts users to correct their vote. EyeVote uses Pursuits [9] to correlate the user's eye movements with movements of dynamic stimuli on screen. In a two-days field study they experimented with two methods that allow users to correct cases where the system recognizes a selection other than the one the user intended

on a situated public display. On the first day they deployed a button based correction approach, while on the second day they deployed a gaze-based correction approach. They found that public display users are willing to correct system errors provided that the correction is fast and straightforward. This verifies that usage of public displays needs to be spontaneous and fast or else the user will lose interest.

In TextPursuits [16] Khamis et al. investigate how reading text on a large display can be used to enable gaze interaction in public space. TextPursuits uses Pursuits [9]. Two cases are investigated: (a) Users can spontaneously interact with text-based content without calibration. A sample application could be a survey where answers in the form of text are selected by reading them. (b) An eye tracker can be calibrated implicitly as users read text on the screen. After calibration, fine-grained information on the users gaze point are obtained. Results show that Pursuits [9] with text is feasible and can achieve similar accuracy as non text-based pursuit approaches. Calibration was less accurate, but it allows areas of the display the user is looking at to be identified and integrates smoothly with reading.

In Orbits [24], Esteves et al. introduce a novel gaze interaction technique that enables hands-free input on smart watches. The technique relies on using smooth pursuit movements of the eyes to detect what control the user is looking at. The controls include targets that move in a circular trajectory in the face of the watch. The controls can then be selected by following the desired one for a small amount of time. They conducted two user studies to assess the robustness and recognition of the technique, which demonstrated how Orbits is robust against false positives triggered by natural eye movements and how it presents a hands-free, high accuracy way of interacting with smart watches using off-the-shelf devices. They then present three example interfaces that was built using Orbits, a music player, a notifications face plate and a missed calls menu. These were generally well received by participants in a third and final study.

Gaze interaction using calibrated eye-trackers is already a well established field in several uses [14], [25], [24], [15], and the use of pursuits has been explored for a limited amount of uses [13], [16], [6], [9]. However in all of the works that use Pursuits [9], the participants are aware of what they are in control of and are voluntarily doing what they are told by the test supervisors. What if I could nudge a user into involuntarily using their eyes to control elements of the user experience. This paper tries to build onto the concepts of previous work and investigates whether pursuits is suited for the public space where spontaneous interaction is required. The idea is also to try and nudge the user into these spontaneous interactions by letting them discover on their own that they are in control of auditory feedback.

II. METHOD

To further explore the possibilities of using pursuits for public display settings I want to set up an in-the-wild-experiment using one of the public displays available at AAU Create. On this display a scene with a landscape

will be rendered. There will be trees, rocks, a small lake and a campfire. At each of these elements there will be some spheres performing movements, the movement are distinguishable from each other as one sphere will go in a clock-wise motion, one will go in a counter clock-wise motion and the last two will make horizontal and vertical movement. Then with a mounted Tobii Eye Tracker 4C and the Pursuits [9] algorithm the prototype will determine what sphere the user is looking at. Then, based on what sphere the user is looking at certain sounds will get higher in volume. For example, if the user is looking at the sphere at the small lake, the sound of a small lake will increase in volume, if the user looks at something else, the volume of the lake will go back down. Every sound in the landscape starts with a volume of 0.1, where the maximum is 1.0. Every time the volume of an element is increased, it is increased with 0.2 and vice-versa 0.1 for decreasing. Below is a list of the different sounds that was used for each element, all the sounds are from FreeSound [30].

- Tree: Wind guzzling through trees.
- Rock: Rocks scraping and being dropped.
- Campfire: Campfire burning.
- Small lake: Lake flowing.

And so our problem boils down to the following:

By nudging a user to look at moving spheres involuntarily in an environment, will a user come to realize that they are interacting with an eye-tracker and that they are in control of auditory feedback?

A. Pursuits Implementation

The system uses the Pearsons product-moment coefficient to calculate the correlation between the eyes movements and the movements of spheres. The Pearsons product-moment coefficient is calculated using the formula seen below. It calculated the correlations between two sets x and y .

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} \quad (1)$$

where \bar{x} is the sample mean, and analogously for \bar{y} . r is a value between +1 and -1 where +1 is total linear correlation, 0 is no linear correlation, and -1 is total negative linear correlation. In my case, x is the coordinate of the eye and y is the position of the sphere on the screen. This is calculated for both x and y coordinates and the mean of the two correlations is then the total correlation.

Based on pilot experiments and previous work [13], [16], I chose a threshold for the pearsons correlation of 0.8 and a window size of 2000 ms. The windows size of 2000 ms was chosen also to combat the errors that occurred in preliminary tests. EyeVote [13] and TextPursuits [16] also used a windows size of 2000 ms. This means that every 2 seconds, the system computes Pearsons correlation. I chose the high threshold because I found in preliminary tests that the spheres moving in lines and circles would sometimes be misclassified if they had similar movements. EyeVote [13] and TextPursuits [16] also uses high correlations of 0.8 and 0.9 respectively. The sphere whose movement correlates the

most with the eye movement, is deemed to be the sphere the user is looking at, as long as the correlation is more than 80%. A larger threshold means that the system will not accept an answer until a high correlation is found, which increases accuracy but might result in spending longer time until the system responds. For this system this is very important as you want it to be very precise in terms of what objects it chooses. If you were looking at one object and other objects volume increases then the experiment would have failed.

B. Setup

I set up the test scenario using one of the public displays at AAU create that is usually used to distribute practical information about the building. The display is located close to elevators and there are people passing by regularly. If something other than the general information that people are used to was displayed, it might garner attention. Below is a list of the equipment that I used.

- Tobii Eye Tracker 4C
- M-Audio Fast Track Pro Soundcard
- Large Flat Screen Display
- Dynaudio Acoustics BM6A mkII Loudspeaker

The software was developed using Unity 5.5, in order to use the Tobii 4C I used their SDK [29]. The landscape seen in Fig. 2 was made using free assets from the Unity Asset Store, specifically I used the Nature Starter Kit 2 by Shapes [33] and Campfire by David Stenfors [34]. The spheres are shapes already part of the basic unity installation. The prototype software displayed a landscape with trees, rocks, a small river and a campfire. At each of the different elements of the landscape there are spheres that either rotate or move back and forth.



Fig. 2. A screenshot of the scene used in testing.

In Fig. 2 you can see where the spheres are located and what movements they are performing as indicated by the arrows. If a user looks at one of the spheres the volume of that specific element will increase. So if a user was looking

at the campfire, the volume of the campfire would increase. If the user does not look at anything or looks at one of the other elements, the volumes that has risen will decrease again. So if the user has looked at the campfire and made its volume increase and then looks at the lake, the volume of the campfire will decrease and the volume of the lake will increase. The movement of the spheres would automatically grab a users attention and by grabbing the users attention it should make the eyes perform smooth pursuit movements so that a user would involuntarily activate the Pursuits algorithm and increase the volume of the element they are looking at. The prototype also logs all correlations for each sphere every time the Pursuits algorithm is run.



Fig. 3. The test setup.

In Fig. 3 you can see what the test setup looked like. In order to lure people in I had a text stating "Want to help with a test? Step up to the screen and look around at the spheres on screen". The point was to not let people know that they were in control of the volume of the different elements so I tried to be as vague as possible. This image can be seen in Fig. 4.

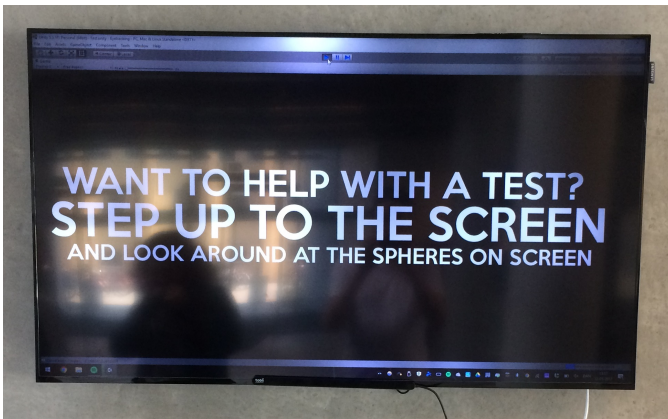


Fig. 4. The image displayed before a user stepped up to the display.

C. Procedure

After the user spent a couple of minutes with the test setup and started to leave I would stop them and ask them a few questions. All of the questions and answers can be found in Appendix VI-A. Besides the questions I also used Microsoft's product reaction cards to capture general user feedback [32]. Microsoft's product reaction cards work by letting people choose words that they would use to describe a product, it's a great way to capture both quantitative and qualitative data, and it has been used by other projects as well [23]. The normal list has 118 words, however, I used a reduced list of words (64 words) which eliminates a lot of similar words so that the list still covers the same range of feelings and experiences as the full list. I also observed the participants to see what sort of reaction they would have.

D. Participants

On day 1 there were 11 participants with 55 logged correlations being over 0.8. On day 2 there were 17 participants with 78 logged correlations being over 0.8. In total, 28 participants and 133 correlations over 0.8 was logged on both days. All of the participants were people passing by the display who were intrigued by the scene. The demographic is people who study at Aalborg University and uses the CREATE building. Half of the participants were male and the other half were female, all participants were aged between 20-30 years old.

III. RESULTS

Results from the answers show that 50% realized that they were in control of the volume of the different elements. 67% realized that their eyes were being tracked and 32% had previous experience with eye-trackers. To visualize the answers to Microsoft's product reaction cards I made a word cloud as can be seen in Fig. 5. A full list of how many times each word was chosen can be found in Appendix VI-B Table. I.



Fig. 5. A word cloud made from the words chosen from Microsoft's product reaction cards.

For the participants who realized that they were in control of the audio I observed an immediate shift in their facial

expression once they realized what they were in control of. Some participants would smile and laugh. Participants would also describe the experience as "fun and entertaining" (P3, P4, P8, P9). They would also become more focused to try and get the effect to happen again. Some participants also mentioned that they thought that you had to follow a sphere for a long time for any changes to happen. This is due to the fact that the window size is 2000ms, so a user has to follow a sphere for 2 seconds for the change to happen. This is a long time for the eye to fixate on a moving object since fixations usually only lasts for 100 to 400ms as I mentioned in I-A. The participants who did not realize that they were in control of the auditory feedback said that they were mostly confused by the set up and would look to me and ask what to do. However telling them what to do would ruin the point of the experiment so I told them to simply follow the instructions that they were first given by the initial image.

Microsoft's product reaction cards tell us that people mostly think the product is: Entertaining, Impersonal, Unconventional, Engaging, Unrefined and Approachable. Out of the total 140 words chosen, 95 of them were positive words and 45 were negative words.

IV. DISCUSSION & LIMITATIONS

In this section the limitations and results will be discussed while going over possible solutions to some of the issues and limitations.

A. Microsoft's Product Reaction Cards

The following section is an attempt to interpret these words into what the participants might have thought of the user experience. 68% of the words were positive while 32% were negative. As this is just a prototype set up to complete the study it is possible to combat the unrefined nature of the set up. The reason for why people think that the experience was impersonal might be because of the graphics of the scenery. It could also be that because that the set up was in a public space it did not feel personal because there are other people walking by and observing while you interact with the prototype. I didn't build the most beautiful scenery, so it might be a solution to use prettier graphics to display the scenery to make the experience more believable and personal. There is even a possibility of using real footage instead of computer generated graphics. The reason for why participants thought the experience was unrefined might also have been because that they were in the group of participants who did not get any correlations over 0.8. But the fact that most participants thought that the experience was entertaining, engaging and approachable tells that the experience was mostly positive for most participants.

B. Pursuits Parameters

One of the reasons for why only half of the participants realized that they were in control of the audio in the scene could be because of the window size and threshold used for Pursuits. The large window size means that a user has to look at one sphere for at least approximately 2 seconds.

This is a long time for a human to be fixated on one object without being told the premise of the study. If the participants would have been told that they needed to look at a sphere for a long duration of time it is possible that more people would have realized that they were in control of the audio. However, telling the participants that information might have revealed too much about the study. Another parameter is the threshold, if I had set that lower I do not think I would have gotten better results. I found the sweet spot for the threshold to be around 0.8 during preliminary studies. In the results there were roughly 5 correlations above 0.8 per participant. But since half didn't realize they were in control of the audio it is most likely due to the fact that they did not get enough correlations over 0.8. So that leaves us with 14 participants who got at least 10 correlations above 0.8 each. The window size could be changed to something lower like 1000ms but I found in the preliminary tests that it simply not enough for the algorithm to work with to get accurate classifications of what the user is looking at. Another factor that could maybe be optimized would be the movements that the spheres perform. The idea would be to figure out what movements would set the spheres most apart so that if you look on one sphere there is no correlation to any of the other spheres in terms of the movement.

C. Nudging The User

By using moving objects we automatically lure the user to look at them, this nudges the user to involuntarily activate the effect that we want to. This creates a sort of magic moment for the user the first time they realize that they are in control of certain elements of the scene. However currently the spheres that are used in the prototype are bland and boring. To make the objects more interesting for the user to look at and follow it might be an idea to introduce other objects. Below are a list of ideas I have for each element of the prototype to make it more interesting.

1) *Tree*: Instead of having a sphere moving in a circle around the tree I would introduce a bird flying around the tree, with this we could also introduce the sound of birds to the environment.

2) *Lake*: In the lake I would add a fish swimming back and forth in the lake instead of the sphere. The audio wouldn't change but the user might find it more interesting to look at the fish.

3) *Campfire*: Adding distinct sparks and flames rising from the campfire could be an idea for something more interesting for the user to look at. The audio would not need any changes.

4) *Rocks*: The sound currently used for the rocks is the sound of rocks being dropped on other rocks, so having small rocks falling down from the big rock in the scene might make it more interesting for the user.

D. Installations

The potential to create other forms of installations is there and in this section I will explain some of the ideas I have for potential installations.

1) *Musical Expression*: Eye-tracking has been used to some extent for musical expression [15], [14], [26], [27], but the use of Pursuits for musical expression has yet to be explored [1]. Building on my prototype I believe that it is possible to create experiences that involve musical expression using Pursuits in a public setting. Some of the considerations are that the user should not have full control over the musical performance, i.e. the performance should move forwards somewhat independently of the user [1]. Instead the user could be in control of filters, volume, effects, and maybe have a selection of loops to chose from. I think that it would be very difficult to program your own melodies and drums using your eyes, but I would not deem it impossible. There would have to be a large selection of premade components that the user can choose from, such as selecting what scale to work in, drum patterns, basslines. Maybe use a block based system such that the user can add and remove blocks from a 16 bars system and have these bars be looped. Then the user could introduce and remove elements throughout these 16 bars.

2) *Soundscapes*: Similar to the prototype it is possible to create other types of soundscapes with different themes by building on the prototype I have created. You could make nature soundscapes for different seasons of the year, city soundscapes, desert soundscapes, space soundscapes, basically your imagination is the limit. It might be interesting to set up a lot of different soundscapes in an installation and have users evaluate which ones they like the most. Those installations would need appealing visuals and movement to capture the users attention and keep the attraction on the moving objects as discussed before.

E. Final Thoughts

Overall, the results of the study suggest that Pursuits combined with auditory feedback can be used in a public setting, where the user is not aware of the eye-tracker initially and what they are in control of. There is room for improvement, but the potential is there.

V. CONCLUSION AND FUTURE WORK

I conclude that there is potential for eye-tracking to be used in a public setting. We conclude that it is possible to create experiences using audio combined with eye-tracking where the user is not aware of the eye-tracker initially.

To summarize the future work, I would expand on how the scene nudges the user to look at certain objects by changing the spheres to other things and having them perform more advanced movement. The potential for musical expression is there but has yet to be explored. Creating new and different soundscapes would also be interesting.

VI. APPENDIX

A. Questions

Below are the questions that was asked during the experiments and how many times yes and no was answered to each question.

Did you understand what was going on?

Yes	No
15	13

Do you have any experience with eye-tracking?

Yes	No
9	19

Did you realize that you were in control of the volume of the different elements?

Yes	No
14	14

Did you realize that the software was tracking your eyes?

Yes	No
19	9

B. Microsoft's Product Reaction Cards

Below is a table with each word and how many times that word was selected respectively. For the full reduced list of words used please visit [31].

Entertaining	13
Impersonal	10
Unconventional	9
Engaging	9
Unrefined	8
Approachable	8
Inviting	7
Difficult	7
Confusing	6
Attractive	6
Advanced	6
Creative	5
Complex	5
Friendly	4
Consistent	4
Useful	3
Powerful	3
Inspiring	3
Innovative	3
Cutting-Edge	3
Easy	3
Unattractive	3
Unpredictable	2
Timeconsuming	2
Ineffective	2
Simplistic	1
Reliable	1
Professional	1
Organized	1
Irrelevant	1
Dull	1
Comfortable	1
Busy	1
Annoying	1

TABLE I

RESULTS USING MICROSOFT'S PRODUCT REACTION CARDS

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