AmbiGaze: Direct Control of Ambient Devices by Gaze

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ABSTRACT

Eye tracking offers many opportunities for direct device control in smart environments, but issues such as the need for calibration and the Midas touch problem make it impractical. In this paper, we propose *AmbiGaze*, a smart environment that employs the animation of targets to provide users with direct control of devices by gaze only through smooth pursuit tracking. We propose a design space of means of exposing functionality through movement and illustrate the concept through four prototypes. We evaluated the system in a user study and found that AmbiGaze enables robust gaze-only interaction with many devices, from multiple positions in the environment, in a spontaneous and comfortable manner.

Author Keywords

Eye tracking; Ubiquitous Computing; Smart Environments; Smooth Pursuits

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Our everyday environments are populated with increasing numbers of devices that afford digital control. While these devices are diverse in form and functionality, there is a desire to provide users with uniform control across smart environments [26, 1, 25]. User research in smart homes specifically highlighted a need for *instant control*, for users to adapt their environment on impulse. Koskela *et al.* found users require control “right now" with minimal action, and “right here" across all the devices that affect their situation [14]. Commercial and research work has addressed this problem with universal remote control strategies that give users environment control via mobile intermediary devices [1, 26, 18, 5]. In contrast, we propose *AmbiGaze*, a system that employs animation of targets in the environment to provide users with direct control of ambient devices by gaze only.

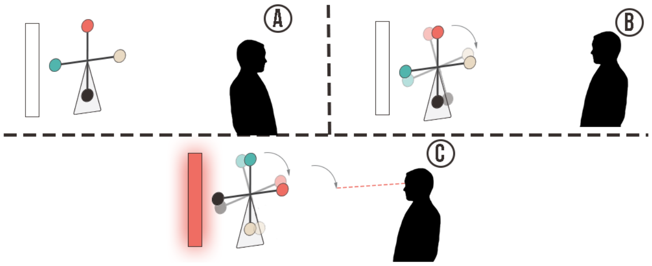

Figure 1. (A) The user approaches an AmbiGaze object. (B) When the user faces it, the object presents moving targets. (C) The user then selects options by following a target with his eyes. In the example, the light colour changes according to the windmill paddle the user is looking at.

Gaze affords implicit identification of interaction targets as we naturally attend to the devices we intend to control [2, 22]. However, gaze-only control of environments has in the past been hampered by the need to calibrate gaze to different targets, the inaccuracies introduced by the jittery movements of the eye during fixation, and the accidental activation of targets as the eyes scan the environment (the *Midas Touch*). To overcome these problems in AmbiGaze, we employ the *Pursuits* technique, using animation of targets for activation by gaze-following [23]. Put in motion, a target induces smooth pursuit eye movement when the user follows it. The smooth pursuit movement is distinct from the routine movement of the eye, and supports robust target activation by comparing the relative movement of the eyes to the trajectory of the animated target.

Figure 1 illustrates the interaction design of AmbiGaze. Users initiate control of a device implicitly by turning their attention to the device. The device responds to attention by displaying control options in animated form to the user. By following an animated target, the user triggers the associated command. The user experience is fluid as gaze is used seamlessly for both device selection and command input, and users can attend different devices in sequence.

In this paper, we investigate three questions raised by the AmbiGaze concept. First, we explore how ambient devices can expose controls in animated form. Previously, the Pursuits

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technique was used on display devices that easily afford animation of targets [23, 17, 8]. In contrast, devices in a smart environment are physically manifest, static in appearance, and not necessarily equipped with a display. We explore device augmentation with animated control through the design of four prototypes, a music player, VoD interface, electric fan, and lamp. Secondly, we consider how pursuit control can scale from single devices to smart environments, and implement the AmbiGaze system integrating the four device prototypes and managing interaction across them. Thirdly, we evaluate robustness of pursuit control from different vantage points in an environment. Whereas users face targets frontally in conventional display settings, they need to be able to control targets from different viewing angles and distances in a smart environment.

RELATED WORK

By 2010, most households in the UK had 4 or more remote controls in their living room [15], making impulsive tasks such as turning the TV on and the radio off, adjusting the volume, and dimming the lights complex to perform [14]. The problem has been addressed with universal remotes that can be switched to different target devices [26], personalisable remote controls [12], remotes that adapt control to the device they are pointed at [1, 16, 19], 'magic wands' for gestural control [25], and smartphone-based remote control [18, 5, 3]. In contrast, we provide a solution that enables users to control ambient devices directly by gaze, without need to carry or pick up any intermediary device. Though we employ a wearable gaze tracker in our prototype, the concept could be easily extended to remote trackers with no user-worn devices.

Previous work on gaze in smart environments has demonstrated ambient devices that respond to visual attention [21, 20, 22]. In AmbiGaze we expand upon attention-awareness by adding pursuit control. Rather than associating attention directly with a device command, we treat it like a "hover" state in which input options are displayed for "clicking" by smooth pursuit. This puts users in full control over the devices in their environment; they can look at devices without necessarily invoking any command, and select (where appropriate) from more input options than a single default response. Other work on direct control of ambient devices has proposed gaze pointing coupled with command gestures [11], and pointing gestures coupled with finger snapping [10] but not tried these at environment scale. In more generally related work, gaze has been used to switch input among target displays [6] and to guide visual recognition of objects in the environment [13].

Gaze input based on smooth pursuit was introduced by Vidal *et al.* for interaction with animated content on public displays, [23], and employed by Pfeuffer *et al.* for opportunistic calibration [17]. Esteves *et al.* extended the technique with animated widgets (*Orbits*) for gaze-only application control on smart watches [8, 7]. These works demonstrate three advantages of using smooth pursuits for gaze interaction. First, the technique does not require user calibration, as it only observes the *relative* movement of the eyes. Secondly, it is robust to false positives, as smooth pursuit movements cannot be 'faked': they require the eyes to lock onto a moving target. Third, it provides for interactions that are intuitive to perform, as our eyes naturally follow moving stimuli. Other techniques that involve matching the movement of moving stimuli include Motion Pointing (mouse) and PathSync (hand gestures) [9, 4]. In AmbiGaze, we leverage these insights but address new challenges for the technique: first, making it work with physical and displayless devices; secondly, matching targets correctly when their trajectories can appear substantially distorted depending on viewing angle; thirdly, scaling the technique to disambiguate input in environments with potentially many devices.

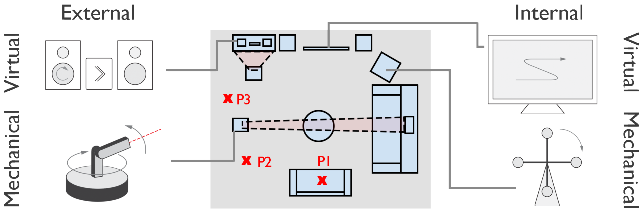

Figure 2. The AmbiGaze system integrates four ambient devices, exploring a design space in which device controls are animated by virtual versus mechanical means, by the device itself (internal) or externally.

ANIMATION OF AMBIENT DEVICES

To enable their control by pursuit, ambient devices need to expose controls in animated form. We propose a design space in which we consider different ways of rendering movement – virtual by graphics animation on a display versus mechanical by physical actuation, and generated internally by device versus projected externally onto the device. We built four prototypes as part of the AmbiGaze system to explore the design space (see Figure 2).

Virtual + Internal: In this type of implementation, the object itself renders moving graphics. These can range from the high resolution of TV screens to cruder representations on LED strips and small displays. Our first prototype is an interface for a video-on-demand (VoD) service rendered on a TV screen. When a video ends, the system suggests three possible videos for the user to watch next (see Figure 3-2). If the user follows the movements of one of the thumbnails floating on the screen, the background changes to match the video and displays its details, including the title, the synopsis and the rating. Below the video information, there is a play button with a small dot moving on an orbit around it. If the user follows the dot, the currently selected video starts playing.

Virtual + External: Our second prototype demonstrates how movement can be added to devices that do not have a display. We implemented a Music Player interface with *virtual* animated widgets that are *externally* projected onto a pair of speakers in the environment (see Figure 3-1). We attached laser-cut white plates to each of the speakers and placed another one between them to increase the contrast of the projection. We then projected one control on each of these plates: a 'previous' control on the left speaker, a 'next' control on the right speaker, and a 'play/pause' control on the central plate. All controls are orbited by small moving targets for selection, inspired by Esteves et al.'s *Orbits* [8].

Mechanical + Internal: Our third prototype demonstrates how an ambient device itself can move to elicit the corresponding smooth pursuits. We built a multi-coloured lamp controlled by an electric windmill (see Figure 3-3). Each of the windmill's paddles has a different colour. Following the movement of one of them changes the colour of an LED rod to that of the paddle. Because the colour is painted on the paddle, the representation is classified as *internal*, and because the movement is actuated by an electrical motor, the movement is classified as *mechanically* actuated.

Mechanical + External: Our final prototype illustrates how movement projected on an object can be generated mechanically. We mounted a laser pointer on a robotic arm controlled by an Arduino microcontroller. The arm is actuated to project a laser dot onto an acrylic plate mounted around an electric fan (see Figure 3-4), continually moving the dot around the fan. The user can then turn the fan on or off by following the movement of the laser dot. This way, the movement itself is *mechanically* actuated, but the representation is *externally* projected.

AMBIGAZE SYSTEM ARCHITECTURE

In our system architecture, each ambient device sends the normalised XY coordinates of their targets to a central server. Users wear head-worn eye trackers, which send the estimated (uncalibrated) gaze points to the server. The system assumes that each tracker can only activate one target at a time. Whereas the *Pursuits* algorithm is robust to false positives [23, 8], a smart environment with multiple moving targets presents additional challenges. To disambiguate between different controls, they must present different movement characteristics, such as phase, speed, or trajectory shape. In a distributed setting, it is difficult to guarantee that the objects will always present different movements.

To address this issue, we incorporated a context-awareness component that estimates the object with which the user is engaged. In our prototype we accomplished this with infrared beacons attached to the different objects. We modified the *Pupil Pro* eye tracker's scene camera with an IR filter that only lets through the light from the beacons. A separate software component recognises which object the user is engaged with depending on the number of visible LEDs, and transmits this to the server together with the gaze data. This component not only helps the system to more accurately estimate the desired object, but also serves an aesthetic purpose: the system only initiates the movement in an object after it detects that the user is looking in its direction. This minimises the overall amount of movement in the environment, which might be distracting and allow for accidental pursuits.

EVALUATION

We evaluated the system in a user study with three goals. First, to validate our concept of gaze interaction in smart environment with moving targets. Second, to characterise how quickly and how accurately users can select the desired moving targets from different positions in the smart environment. Third, to capture users' qualitative perceptions about this type of interaction for smart environments.

Figure 3. Our gaze-enabled smart environment: (1) Music Player; (2) VoD Interface; (3) Windmill Lamp; (4) Fan.

We recruited ten participants (6M/4F) aged between 21 and 48 years (mean = 32). All had little experience with eye-based interaction (mean = 2.3 on a 1-5 scale) and with smart environments (mean = 1.9 on a 1-5 scale). No participants required eye correction.

Upon arrival, participants signed an informed consent form and completed a demographics questionnaire. We explained how they could interact with the objects by facing them and following one of the moving targets with their eyes. We then asked participants to wear a *Pupil Pro* head-mounted eye tracker (30Hz). Figure 2 shows the floor plan of our experimental setup with the corresponding positions of the objects and the positions from where participants interacted with them. We then let users interact freely with the environment using a think-aloud protocol. Using a camcorder, we recorded users interactions and comments, which we later transcribed and annotated.

From three positions in the environment (see Figure 2:P1-3), users were asked to complete a series of 12 two-step tasks using two of the objects, for a total of $3 \times 12 \times 2 = 72$ interactions. For example, 'play a song in the stereo' followed by 'select a video in the VoD'. The order of tasks was counterbalanced across participants. The task was designed so that we could time not only the time to select a target, but also the time to switch from interacting with one object to another. Between each trial, we asked participants to close their eyes and face down, as a resetting step. Finally, participants completed a subjective 5-point scale questionnaire.

Results

Figure 4 shows the average completion times for the sub-tasks by position. We tested for the effect of the POSITION on the COMPLETION TIME for each subtask and found no statistically significant results. This suggests that the interaction technique performs similarly regardless of where in the environment the user is standing. On average, users took 3.2s to activate the first object and 4.3s to trigger the first target, spending .97s still looking at it. They then took 3.8s to activate the second object and 4.6s to trigger the second target.

All users were able to complete all required tasks successfully, but in many cases, they made incorrect selections before selecting the correct target. This happened in 1.6% of the sub-tasks with the *Laser Pointer/Fan*, 9.4% with the Music Player, 45%

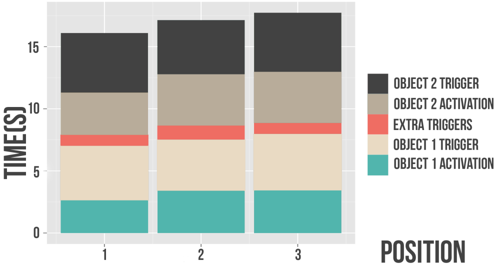

Figure 4. Task Completion Times: Users were asked to activate one object and trigger a target on it, then switch to another object and trigger a second target. The extra triggers refer to the time users spent still looking at the first object after triggering the first target.

with the *Video Player*, and 23% with the Windmill. The high error rates for the *Video Player* were due to the implementation of the video playback, which would sporadically delay the data transmission as it would switch between the videos and the menu interface. If the data from the video player arrived out-of-sync with the gaze data at the server, the correlation algorithm would match the target being followed with the one that succeeded it. This highlights the need for more responsive implementations of future pursuit-based systems. The error rate in the *Windmill* was lower than the *Video Player*, but still considerable. Incorrect selections often happened as the DC motor was powering up after detecting that the user was engaged with it. For the correlation calculation, we estimated the paddles' positions assuming it moved with a constant speed. However, this assumption does not hold when the *Windmill* is still accelerating, creating a few false selections in the first few seconds of operation. After it was running continuously, users could select the correct colours with little problem.

Users subjective responses suggest that they enjoyed interacting with the system. On a 5-point scale users rated the mental (1.8) and physical (1.5) demand as low. In a 5-point Likert scale, users agreed that the task did not tire their eyes (4), the system was quick to activate the object when they faced it (4.1), and quick to trigger the target (3.5). They also agreed that the interaction technique was easy to learn (4.7), they were able to correct any mistakes (4.5), and that they could imagine using a similar system at home (4.4). We also asked how successful they were in accomplishing the required tasks with each individual object. Participant rated the Music Player the highest (4.7), followed by the Laser Pointer/Fan (4.5), the Windmill (4.1), and the Video Player (3.9). This reflects the error rates we described above.

DISCUSSION

Our design space shows the different ways to expose functionality through animation. Internal virtual movements, can easily be displayed by screen-based devices (e.g. TVs, monitors), but they can also be enabled through animated LED strips (e.g. stereo equalisers, shop displays) and other less expressive technologies. In the case of the video player, we found that eye-based interaction elegantly supports the passive observer role in the video watching context: the user can carry on watching without having to move. Our windmill demonstrated how the object itself can move to enable *Pursuits*. The same principle could be extended to other objects with movements, such as the pendulum in a clock or movement-based ambient displays, such as Xerox's *Dangling String* [24]. An interesting property of externally projected movements is that the same device can animate multiple objects. In the case of virtual movements, the projector can be set-up to cover a wide area spanning several objects. In the case of the laser pointer, the robotic arm can work in a time-multiplexed fashion, jumping from object to object in sequence.

Our user study showed that users were able to interact with the objects from all three positions we tested. These positions were selected as they represent where users would normally stand in a similar real environment. However, more work is necessary to determine how robust the system is to extreme cases, such as large distances and small viewing angles.

To enable the seamless switch between objects, we implemented AmbiGaze using a head-mounted eye tracker. However, similar interactions could be enabled by multiple remote trackers. For example, with the decreasing costs of infrared trackers, we envision a scenario where each smart object has its own eye tracker, similar to Vertegaal et al.'s *EyePliances* [21, 20, 22]. An interesting property of AmbiGaze, is that it decouples the eye tracking from the individual applications. By comparing the correlation between the relative movement of the object with the movement of the eyes, each smart object can only tell whether it is being looked at or not. If the user is looking elsewhere, the object cannot directly know where the user is actually looking, giving the user added privacy.

Movement-based interfaces also have the potential of drawing users' attentions, creating the opportunity for more ambiguous and implicit interactions. For example, in our prototype, when the user's attention was drawn to a particular colour on one of the paddles, the colour of the light would change to match that colour. A more implicit mapping could slowly merge the current colour of the light to that of the paddle. Moreover, this could even involve multiple users, merging two or more colours into one implicitly created shared colour. The windmill could also be extended to include dynamic content on the paddles (e.g. with the use of small displays) expanded even more the space of possibilities. Even though we use the example of colours, this kind of interaction could support many types of parametric or procedurally-generated content, such as electronic music and other artistic installations, turning the direction of users' attentions into works of art.

CONCLUSION

In this paper, we presented a system that enables eye-based interaction in a smart environment. To accomplish that, we took advantage of the smooth pursuit movements performed by the eyes when following a moving target. By correlating the relative movement of the eyes with known targets in the environment, we can trigger corresponding actions in their corresponding devices. In applying this technique to a smart environment, we advance the state-of-the-art of smooth pursuit interaction by showing that this technique works from multiple viewpoints, by demonstrating that it works with other types of movement beyond those generated by TV and PC screens, and by finding that users perceive it as a natural and comfortable way of interacting with home appliances.

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