Challenges and Design Space of Gaze-enabled Public Displays

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Abstract

Gaze is an attractive modality for public displays, hence the recent years saw an increase in deployments of gaze-enabled public displays. Although gaze has been thoroughly investigated for desktop scenarios, gaze-enabled public displays present new challenges that are unique to this setup. In contrast to desktop settings, public displays (1) cannot afford requiring eye tracker calibration, (2) expect users to interact from different positions, and (3) expect multiple users to interact simultaneously. In this work we discuss these challenges, and explore the design space of gaze-enabled public displays. We conclude by discussing how the current state of research stands wrt. the identified challenges, and highlight directions for future work.

Author Keywords

Gaze-enabled displays; Public Displays; Gaze Interaction

ACM Classification Keywords

H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction

As hardware prices fall, public displays continue to become more ubiquitous. Interactive displays can now be found in public spaces such as shopping malls, airports and train stations. Meanwhile, their interactive capabilities have re-

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cently been in a continuous rise as sensing technologies become cheaper and easier to integrate.

While interactive displays support modalities such as touch and mid-air gestures, gaze is increasingly becoming popular. Gaze, in general, is an attractive modality as it is fast, intuitive, and natural to use. Additionally, gaze has the potential to tackle the main challenges of public displays [22], such as detecting passerby's attention, making displays immediately usable and enabling at-a-distance interaction.

Although gaze detection and gaze-based interaction are already well established for desktop settings. The domain of gaze-enabled public displays is unique and imposes new and different challenges that are relatively under-investigated. In this paper we draw attention to challenges that are particular to this setting; we identify three main challenges of gaze-enabled public displays. Moreover, we explore the core dimensions of a design space for gaze-enabled public displays – including gaze utility, detectable eye movement types, gaze-input methods, eye tracking techniques and eye tracker types. From there, we discuss where the current state of research stands with respect to the identified challenges, and highlight directions for future work.

Challenges of Gaze-enabled Public Displays

Although the use of gaze for public displays brings in a lot of benefits [22], this combination raises challenges that are specific to gaze-enabled public displays. To our knowledge, no work has successfully tackled all three challenges together, while accurately tracking the user's gaze. Nevertheless, individual solutions to each challenge do exist.

Challenge 1: Calibration

Interaction times on public displays are often very short [37], resulting in requiring public displays to be *immediately usable* [35]. Although gaze is a fast modality [45], a prerequisite to classical gaze detection is to calibrate the eye tracker for each user. While calibration is justifiable in desktop settings, where users interact for longer periods of time, being a time-consuming task that is perceived to be “tedious” and boring [41, 53] makes spending time for calibration unacceptable in public settings.

Challenge 2: User Positioning

Public displays expect users to interact from different locations, distances and orientations relative to the display [37]. On the other hand, most commercial remote eye trackers require users to keep their head facing the tracker in a confined tracking box about 60 cm away from the tracker [23]. While head-mounted eye trackers allow for freedom of movement, they require person-specific calibration and gaze mapping to each display.

Challenge 3: Supporting multiple Users

Public displays are meant to be mediums for connecting multiple people in a community [33] and users often approach and interact with public displays in groups [13, 20, 37]. The honeypot effect is often noticed in public display installations [20, 37], where passersby are attracted when a user is interacting with the display. In gaze-enabled displays however, passersby usually take turns to interact [20] since eye tracking systems typically support one user at a time.

Design Space

Gaze can be employed in many ways for public displays. Previous work suggested classifications for gaze interaction applications [30] and physiological computing systems [15], however these classifications do not entirely apply to gaze-enabled displays. For example, Majaranta and Bulling define gaze-based user modeling and activity recognition as one core application of gaze [30]. Althoguh it is possible to utilize existing user models and classifiers on gaze-enabled displays [17], monitoring users for extended periods of time is infeasible on public displays.

We classify the uses of gaze on public displays into three categories: (1) Explicit Gaze-based Interaction, (2) Implicit Gaze-based Interaction, and (3) Quantifying Attention.

Explicit Gaze-based Interaction

Users of systems that employ explicit gaze-based interaction intentionally use their gaze for control. We further classify this category into **Gaze-only Interaction**, where gaze is the sole input method, and **Gaze-supported Interaction**, where gaze is used to support another modality.

Gaze-only Interaction. Singlemodal gaze interaction carries a lot of advantages for public displays. Displays are in many cases inaccessible (e.g. behind glass windows). In cases where displays are unreachable for touch-based interaction, mid-air gestures or gaze are used for interaction. While mid-air gestures can be embarrassing to perform in public [5], gaze is subtle and can hardly be noticed by others. Being fast [45] and intuitive [51], gaze can offer displays *immediate usability*, which is a main requirement of public display interaction [35]. Consequently, there has been an influx in the past years of public display deployments that use gaze-only for input.

Interaction via dwell-time requires precise gaze points, which can be made available after calibration. But due to the problems associated with calibration on public displays, only a few displays employ dwell-time interaction. For example, in work by San Agustin et al. [43], users browsed through messages by fixating at the desired message.

Other systems utilize novel calibration-free gaze-input techniques. For example, EyeVote [23] and SMOOVS [29] rely on Pursuits [52], which is an increasingly popular calibration-free technique that relies on smooth pursuit eye movements performed when following a moving stimulus. SideWays [56] and GazeHorizon [58] use the pupil-canthi-ratio [57] to estimate horizontal gaze direction without calibration. EyeGrip [17] identifies objects of interest in scrolling scenarios by detecting the Optokinetic nystagmus eye movement. Gaze gestures are among the popular methods for calibration-free gaze-input [14] in which users would perform eye strokes, for example, by moving their eyes to the right, to signal particular commands. Recent work explored interaction using voluntary eye convergence [24] and divergence [25], which are movements of both eyes in inward and outward directions respectively.

Other approaches focused on detecting gaze at particular locations on the display. For example, a system by Sippl et al. [46] estimated the user's horizontal and vertical gaze, to determine which of four quadrants the user is looking at.

The aforementioned techniques can be used on both: remote and mobile eye trackers. While many of them do not require calibration, neither free user movement (Challenge 2) nor settings with multiple users (Challenge 3) were considered in their evaluations.

Gaze-supported Interaction. Researchers have experimented with combining gaze with different devices and input modalities. This could result in speeding up interaction [38, 55], refining input [26] or improving accuracy. [48, 49]. Moreover, the involvement of an additional modality helps overcome the Midas effect, in which the system mistakes the user's perception for control.

The earliest work about combining gaze with another modality is the work by Zhai et al. [55] where the MAGIC technique, which wraps the mouse pointer to the gaze area, was first introduced. More relevant to our context is the work of Stellmach et al. [48, 49], in which gaze was employed alongside touch input, detected via a handheld touchscreen, to facilitate target acquisition and manipulation on large unreachable displays. These systems work by limiting the interaction space to the area the user is looking at, then using touch to further specify selection commands.

Other works focused on combining gaze with multi-touch surfaces. Gaze-touch [38] allows manipulation of targets by looking at them and performing hand gestures anywhere on the screen. Recent work integrated gaze into touch and pen interaction to enable indirect input [39, 40], where user's gaze decides the area affected by touch and pen input.

A system by Mardanbegi et al. [32] detects head gestures by makeing use of the eye's vestibulo-ocular reflex [8]. Mid-air gestures have also been used with gaze [9, 54]. For example, Chatterjee et al. [11] introduced a text editor where users move a cursor using gaze and pinch gestures.

While many of these systems are not necessarily built for public displays, the concepts behind them are applicable to the domain. One concern however would be the placement of eye trackers, as users may occlude them while providing input using other modalities. The majority of gaze-supported systems rely on precise gaze points, and hence require calibration (Challenge 1). Few systems combine calibration-free gaze methods with other modalities. For example, gaze-gestures were combined with touch-input for observation-resistant multimodal authentication [21].

Implicit Gaze-based Interaction

Systems that support implicit gaze-based interaction are those that can automatically trigger reactions by monitoring the user's gaze. In contrast to their explicit counterpart, these interactions do not require users to intentionally control their eyes; the system rather monitors the user's natural eye behavior and reacts accordingly. Hence, these systems are characterized by faster learning curves, as users do not have to learn anything prior to interaction.

Examples of systems that support implicit gaze-based interactions are like PeepList [18], which builds a user model to estimate the importance of the perceived information to the user then generates a list of content sorted by importance. Mubin et al. [34] developed an intelligent shopping window where the system responded to user's gaze towards products, which was determined via head tracking. Brudy et al. [6] used a Kinect to detect the head orientation of multiple users in front of a public display. This information was then used to mitigate shoulder surfing, by hiding sensitive information surrounding the user's body when another passerby is looking at the display. Gaze Locking [47] uses a remote RGB camera and a classifier to detect eye contact to displays and trigger actions accordingly. The system does not require calibration and can detect multiple users. Although not reported, the system seems capable of detecting eye contact for moving users as well.

While many of these systems address the three main challenges, a drawback is that they either do not offer real gaze tracking but rather detect eye contact, or assume a gaze vector based on face detection and head pose estimation. While the user's face and head orientation are indeed good cues for the user's gaze, they are not accurate as users could move their eyes while keeping their head still.

Quantifying Attention

Gaze can be used to quantify attention to displays [22, 50]. Systems in this category are built with the aim of understanding where passersby look. However in contrast to the previous categories, these systems do not react to the user's gaze, but rather monitor the user's gaze silently for post-hoc analysis and diagnostic purposes. This could be used to compare different settings for the displays as well as to evaluate methods for attracting user attention.

Using face detection and machine learning, ReflectiveSigns [36] schedules content to be displayed based on previous experiences of which content attracted passersby attention the most. In their evaluation of methods of measuring user attention towards public displays, Alt et al. [2] experimented with several attention cues including head pose, and gaze direction. In their implementation, a feature-based approach was adopted using 3 Kinect devices to determine if user's gaze is directed towards the display. The described approach is flexible to the user's position and does not impose limitations on number of users. However as it only detects gaze towards the display, the approach might need to be augmented with a calibration phase before accurate gaze points on the screen can be collected (Challenge 1).

Mobile eye trackers are useful for studying user attention, but because passersby do not typically wear them, it is challenging to perform in-the-wild studies using them. Dalton et al. [12] recruited 22 participants in a study where mobile eye trackers were used to study if visitors to a mall notice displays. They found that passersby do gaze at displays but for very short periods of time (mostly < 800 ms).

For systems of this category to serve their function, most of them were built with flexibility to user positioning (Challenge 2) and support of multiple users (Challenge 3). However they sacrifice accuracy at the expense of being robust against the other two challenges, hence many of them rely on face detection, head pose estimation and body posture.

Discussion

In this section we discuss current solutions to the three identified challenges with respect to eye tracking techniques and technologies.

Mobile Eye Trackers

While head-mounted trackers have recently become affordable [19], they are still special-purpose equipment that require augmenting individual users [28] and therefore not in wide-spread use yet. Moreover, the use of mobile eye trackers require displays to be networked. For example, in their evaluation of GazeProjector [27], Lander et al. connected the participants' eye trackers with three displays via WiFi.

Calibration (Challenge 1) is less of a concern in the case of mobile eye trackers. In a scenario where they are used to interact with public displays, the user would likely need to calibrate the mobile eye tracker only once based on the scene-view [27]. Flexible **user positioning (Challenge 2)** is also feasible using mobile eye trackers, but would require determining the display's position relative to the user; for example, GazeProjector [27] utilizes feature tracking to determine the user's position relative to the surrounding displays, whose positions are predefined in the system. Other approaches rely on visual markers that define the display's borders [31] **Multiple users (Challenge 3)** can interact with displays via gaze when wearing mobile eye trackers. For example, the Collaborative Newspaper [28] allows users to collaboratively read text on an on-screen newspaper.

Indeed there is a vision of having eye trackers already-integrated into daily Eyewear [7], and also the vision of having Pervasive Display Networks [13] in the future. However, a pervasive integration on such a big scale would require taking concepts from lab settings to the field, which is currently challenging to investigate using mobile eye trackers unless participants are explicitly hired [12]. Until passersby wearing mobile eye trackers becomes the norm, there is a need to study user behavior on gaze-enabled public displays using other means, such as remote eye trackers.

Remote Eye Trackers
In addition to mobile eye trackers, eye tracker manufacturers focused on producing remote IR-PCR (Infrared Pupil-Corneal Reflection) eye trackers. Remote eye trackers augment the displays rather than the passersby, allowing in-the-wild studies and observation of user behavior around the display, which are crucial aspects in public display research [3]. The downside is that they are mainly developed for desktop computers, hence commercial remote eye trackers are intended for stationary settings where the same single user interacts indoor at almost the same distance.

Challenge 1: Calibration. The usability problems associated with calibration have received considerable attention in the past years, resulting in a number of calibration-free gaze-enabled systems. Some works estimated gaze with relatively low accuracy using RGB and depth cameras, these methods relied heavily on head-tracking and face detection [2, 6]. Other works, such as Pursuits [52] and the pupil-canthi-ratio [57], focused on developing calibration-free gaze-interaction techniques rather than estimating a precise gaze point.

Another direction of work in this area is to make calibration easier and blend it into public display applications. Pfeuffer et al. [41] introduced pursuit calibration, where users calibrate by following a moving object on the screen. Khamis et el. [23] developed Read2Calibrate, which calibrates the eye tracker as users read text on the display such as welcome messages and usage instructions.

Challenge 2: User Positioning. Since commercial eye trackers impose strict user positioning requirements, researchers investigated ways to guide users to the *sweet spot* [3] at which remote eye trackers would detect their eyes. In their evaluation of GazeHorizon, Zhang et al. [58] guided passersby using an on-screen mirrored video feed as well as distance information. Other gaze-based systems used markers on the floor in addition on-screen instructions [20, 56]. GravitySpot [1] actively guides users to target positions in front of displays by using visual cues and position-to-cue mapping functions that are dynamically updated based on how far the user is from the sweet spot.

Another promising approach is to use active eye tracking [10], by tilting, panning and zooming into the eyes to loosen up restrictions on user movements [4, 16]. However, it remains a challenge even for state-of-the-art active eye trackers to cope with very large displays and the vastly dynamic environment of public displays, where users not only interact from different positions, but also *while* passing by [44]. Such drawbacks could be tackled by engineering active eye trackers with large ranges to cope with users at different positions. Another solution is to mount several cameras that would hand the tracking over to one another, thus enabling eye tracking for large displays.

Challenge 3: Supporting multiple Users. Commercial IR-PCR remote eye trackers track only one user at a time [42]. Pfeuffer et al. [42] built a collaborative information display that uses two remote eye trackers. Users were required to stand infront of the eye trackers to begin interaction.

An alternative is to use video-based techniques that can track multiple users. However a drawback is that tracking quality in video-based approaches is heavily influenced by many factors such as varying light conditions and reflections of eye glasses [30].

Conclusion and Future Work
In this work we identified three main challenges that are specific to gaze-enabled public displays. Furthermore, by presenting an overview of the design space of gaze-enabled displays we summarize uses of gaze for public dis-

plays, and point out promising techniques and approaches that tackle individual challenges.

While addressing the three challenges using mobile eye trackers seems straight forward, realizing these approaches requires having an infrastructure of Pervasive Display Networks, and also assumes that passersby are already augmented with mobile eye trackers.

On the other hand, approaches using remote eye trackers show promise, yet more work is needed for enabling more robust and accurate calibration-free gaze detection. Active eye tracking has the potential to offer promising solutions that are flexible to user positioning and number of users (Challenges 2 and 3), but also need to cover larger ranges than current state of the art eye trackers.

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