Towards Gaze-Based Interaction with Urban Outdoor Spaces

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Abstract

In this paper we envision gaze-based interaction in and with large-scale outdoor spaces. We propose interaction using the gaze on real-world objects located and moving in urban environments, such as buildings or cars. A novel classification scheme is introduced which describes gaze-based interaction based on whether the user and the object(s) interacted with are stationary or moving. The classification scheme can be used for exploring the design space of mobile gaze-based interaction. We discuss the challenges specific for the dimensions of the classification scheme, focussing on the recognition of the object of regard, as well as on interaction design.

Author Keywords

Gaze-Based Interaction; Location-Based Services; Tourist Guides

ACM Classification Keywords

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

Introduction

Eye tracking technology is starting to become mobile and pervasive, enabling gaze-based interaction with mobile displays (e.g., smartphones [8] or wearables [11, 13]) as well as with public displays (e.g., [30]). Other approaches

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interpret the user's eye movements independent of the content or object looked at and can be used without a display (e.g., eye gesture [14] or activity recognition [4]). While the display used in the former approaches distracts the user's visual attention from the real world, the latter approaches are agnostic of the content (on the screen) or object (in 3D space) the user is looking at.

There are scenarios in which it would be desirable to take the object looked at into account without disturbing the viewing experience by a display. While such direct gaze-based interaction with objects has been proposed for indoor and typically small-scale spaces (e.g., [28, 3]),similar approaches for large-scale outdoor spaces are missing so far.

We argue here that, in order to fully tap the potential of pervasive gaze-based interaction, systems and interaction techniques need to be developed which enable gaze-based interaction with objects in large-scale outdoor spaces, such as buildings in a city. A number of potential applications would benefit from this, including gaze-based tourist guides, wayfinding assistants [9], or location-based learning tutors that are aware of the learner's visual attention. Here we focus on the influence of movement on the development of such systems and interaction techniques (both, movement of the user and movement of the object looked at).

Overall, our contributions are as follows:

- We develop a vision of gaze-based interaction in and with outdoor spaces and introduce a classification scheme based on whether the user and the object(s) looked at are static or moving.
- Using the classification scheme, we identify the main challenges of gaze-based interaction in and with outdoor spaces, including the recognition of the object of regard and interaction design under time constraints and in environments the system designer cannot fully control. We discuss how well approaches from related work are suited for tackling these challenges.

Figure 1: A tourist with an eye tracker exploring a city panorama.

Location-Aware Mobile Gaze-Based Interaction

One of the earliest, most basic and most practically applied UbiComp ideas is probably that of a *Location-Based Service* (LBS) – a service that is provided based on the user's location [27]. A classic example is that of a tourist guide providing information about a point of interest (POI) when the user's location is inside a certain trigger area or 'geo fence' (e.g., close to a church). Clearly, the notion of the term LBS nowadays is that of a context-aware service which adapts to a number of context variables, with location being one of the most important ones [26].

LBS may serve as a motivating example for the type of gaze-based interaction we are aiming at: many of the classic LBS examples, including tourist guides, could use gaze

User reaches a vantage point A(I):
System: from here you have a perfect view on the medieval city center. Can you see the church with the green roof to your right?
User: (visual search, looking at a church)
System: great, you found it. This is St. Peter's church. It has been built in the 14th century ...

⋮

Some time later, user walking through the center A(III):
System: now if you turn left at the small café to your right you will see the town hall.
User: (starts walking, looking at a café)
System: right, this is the café I was talking about. Please turn left there.

⋮

User can see the town hall now A(II):
System: the town hall in front of you was built by the famous architect ...

Figure 2: Example for gaze-based interaction with a tourist guide. The types of interaction (A(I), A(II), and A(III)) are based on the classification scheme introduced in Table 1.

as one more context variable to which the service is adapting. Though both technologies, positioning and mobile eye tracking, are available, to our knowledge there are no LBS yet that adapt to a user's gaze.

For example, a gaze-aware tourist guide could notify the visitors of a city about interesting buildings, based on the interest she has shown in other objects before (see Fig. 1). The guide could provide audio information on objects of interest while the tourist is exploring the panorama or help the tourist find the way (see example in Figure 2).

A system like the one described in the example, will offer a true pervasive experience with outdoor environments, and the user will be able to focus on the task at hand, such as exploring a panorama [15] or a building facade. Current tourist guides are distractive, and usually, the user has to switch her visual attention between her mobile device and the environment.

A classification of gaze-based interaction based on the movement of user and object(s)

The type of gaze-based interaction outlined in the previous section takes place in (often large-scale) urban environments through which the user is moving. The degree of mobility supported is an important design decision. For instance, should the tourist guide provide information only for a limited set of pre-defined vantage points or at any place inside the historical city center? Does the tourist guide provide information on buildings only, or also on moving objects (such as, the famous horse carriages in Vienna, Austria)?

We here suggest distinguishing different types of movement and using this as a criterion for a classification of mobile gaze-based interaction (see Table 1). The classification is suggested for mainly two purposes. First, it helps in further exploring the design space of mobile gaze-based interaction. While some of the resulting classes of gaze-based interaction have been treated quite well in literature, not much research exists on others. Second, we will use it for discussing the specific challenges connected with each of the classes and connect them with the existing literature (see later sections). These challenges occur not only on the level of the enabling technology (e.g., computer vision), but also on the level of interaction design.

The classification scheme is based on two dimensions: first

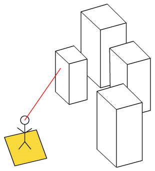
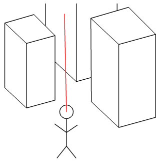
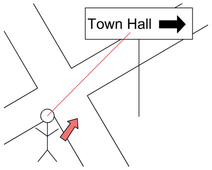
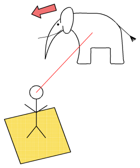
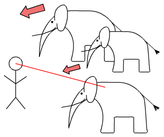
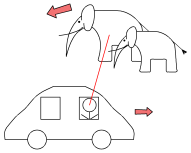
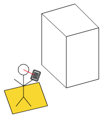
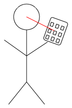
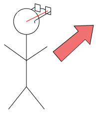
Movement of the object(s) interacted with.		**Movement of the user.** Interaction happens while user is ...		
		(I) standing. Interaction available only at certain locations	(II) standing. Interaction available at any location	(III) moving
	(A) Stationary object(s)	*Location-constrained gaze-based interaction with objects* Examples: touristic vantage point, public screen 	*Location- and gaze-based interaction with objects* Example: exploring a city plaza 	*Gaze-based assistance during locomotion* Example: wayfinding assistant 
	(B) Object(s) moving independent of the user	*Location-constrained gaze-based interaction with moving objects* Example: visitors' vantage point in zoo 	*Location- and gaze-based interaction with moving objects* Example: exploring a zoo by foot 	*Gaze-based assistance during locomotion on moving objects* Example: safari 
	(C) Object(s) moving with the user	*Location-constrained gaze-based interaction with portable object* Example: gaze-based scrolling while reading touristic information on a nearby POI 	*Gaze-based interaction with portable object* Example: gaze-based interaction with a mobile map 	*Gaze-based interaction with portable object during locomotion* Example: gaze input to HMD during wayfinding 

Table 1: Classification of gaze-based interaction based on types of user and object movement. Note that these are not exclusive, i.e., a system may combine several of these interaction types.

(see rows in Table 1), we distinguish whether the object the user is interacting with is (A) stationary (e.g., a building, a public screen, a road intersection), (B) moving independently of the user (e.g., an animal, a car passing by), or (C) moving with the user (e.g, a smartphone, a head-mounted display (HMD), a paper map).

In the second dimension (see columns in Table 1) we consider the movement of the user during the interaction and distinguish three cases: (I) the user is standing and the interaction only takes place at pre-defined places (e.g., in the geo fence of an LBS or in front of a public screen). (II) the user is standing and can interact at a position of his or her choice (e.g., anywhere on a city plaza or on an archeological site), and finally (III) the user is locomoting during the interaction. Locomotion in cases (I) and (II) may take place between interactions, but not during the interaction. Note that locomotion refers to "the movement of one's body around an environment" [21, p. 258] (e.g., walking from location A to location B which are 100 meters apart), which does not include motion of parts of the body while standing at the same location (e.g., head movements).

By combining the two dimensions, nine different classes of mobile gaze-based interaction can be identified. Table 1 illustrates each of these classes with an example. We here do not consider content-independent interaction (based on eye movements), such as eye gestures [14] or activity recognition [4], because they are independent of the user location and no object is gazed at. Note that a particular system may fall into more than one class if it allows for more than one type of interaction.

Challenges for mobile gaze-based interaction

There are particular challenges a system developer or researcher needs to solve for gaze-based interaction in urban spaces with moving user and/or object(s). These challenges affect the system on two different levels. On the first and more basic level it affects the ability to determine the object the user is gazing at (the object of regard, OOR). The second level is the design of the interaction.

In this section we describe the challenges on these two levels, how the existing literature approaches them, as well as open research challenges.

Object of regard detection

In order to enable interaction with objects in the real world, such as buildings or cars, it is necessary to determine the object the user is looking at. Mobile eye trackers measure the point of regard (POR) as a point on a image recorded by a field of view (FOV) camera. The goal of OOR recognition consists in mapping this POI to an object in the environment or to a reference system in which the objects are known. Many of these challenges have also been studied in augmented reality literature (AR) [5]. As can be seen in the literature discussed below, previous approaches for solving the problem of detecting the object of regard focus mainly on indoor spaces.

Some researchers [6, 19] use an extra sensor, such as a motion capture system or a magnetic sensor, to calculate the head position and the orientation of the gaze of the user, and thus being able to calculate the POR in the real world. This kind of approach has so far only been used in indoor environments. In principle, one could build a similar approach based on satellite positioning for outdoor scenarios, but this would probably suffer from well-known drawbacks of the positioning method (e.g., inaccuracy, especially w.r.t. elevation).

Regarding movement, these approaches have several limitations. First, the user's movement is limited to the range of the extra sensor. The above-mentioned approaches are therefore ideal only for scenarios in which the interaction is limited to pre-defined places (column (I) in Table 1). Second, these approaches require knowledge about the position of objects in the real environment for the intersection with a gaze vector. Such object databases may be easy to maintain for stationary objects (row (A) in Table 1), but more difficult for moving objects (row (B)), for which it must be possible to determine the position of the object relative to the user. Third, the update rates of the sensors need to be sufficient to cope with fast locomoting users (column (III)) and fast moving objects (row (B)).

A second type of approaches uses computer vision to analyze the video from the eye tracker. For instance, methods based on Simultaneous Localization and Mapping (SLAM) have been proposed [23, 25]. With these approaches, 3D gaze coordinates in the world are produced making them ideal candidates for interaction with stationary objects (row (A) in Table 1), while they are less suited for interaction with moving and portable objects (rows (B) and (C)). Though SLAM in general can be applied to both, indoor and outdoor environments, eye tracking research has only considered them for indoor scenarios so far.

Some approaches have used object recognition, which is also based on computer vision. The main idea of these approaches consists in extracting a part of the video frame close to the fixation and recognizing the object using feature matching (e.g., [28, 3]). These techniques can cope with stationary and moving objects, making them suitable for interaction scenarios of types (A) and (B). With portable objects (type (C)) this will only work well if the visual appearance of the object is not changing (i.e., not for displays). Moreover, these approaches will have problems if many similar objects are present in the environment, such as road signs or similar buildings. Also, they require an intensive data collection and they are not guaranteed to operate in real-time [28].

Another class of approaches is based on object tracking, using for example visual markers [24] or the colorful edges of a phone [22]. With the help of the markers, they map the POR to a more suitable coordinate system, such as the display coordinates of a smartphone. These approaches are suitable for all interaction scenarios but do not work well if we do not have full control over the object interacted with, such as most objects in outdoor environments. For instance, it is not always feasible to install the necessary markers in outdoor environments, such as on the rooftops of a city panorama (row (A)), and even less possible for objects that appear and disappear dynamically (row (B)).

A general problem all approaches based on computer vision will have to face is that movement influences the camera sensors used during an eye tracking session, possibly leading to significant effects, such as image blur [18]. These inaccuracies will propagate to the computer vision algorithm, thus potentially leading to lower accuracy.

Finally, for interactions with portable objects (row (C) in Table 1), we could also use remote eye tracking from smartphone cameras [17]. This technique maps the gaze of the user to the smartphone screen allowing us to implement interactions with the phone. A disadvantage is that it cannot be extended to handle interactions with objects in the environment (rows (A) and (B)).

Interaction design

Once the system has recognized the OOR, it needs to provide a suitable interaction to the user (suitable in terms of efficiency, effectiveness, and user experience). The appropriate interaction is dependent on the class in which the scenario falls. A very simple explicit interaction design for the tourist scenario, for instance, would provide information on a mobile phone on the building looked at based on dwell time. That simple interaction design would not be suitable for a fast moving objects (row (B) in Table 1), because until the user has read the information from the mobile phone the object will probably have gone out of scope (i.e. left the FOV of the user).

An obvious limitation for the interaction with objects in the environment (row (A) and (B) in Table 1) is that, unless augmented reality is used, no screen is available to present the information to the user.

A common approach to eye-based interaction with moving objects consists in using smooth pursuits ([29, 7]). These approaches usually correlate the relative movement of the eyes with known targets, and trigger actions on devices based on the eye movements. The main advantage of these approaches is that they do not require a registration step, and probably they could be extended for interactions with moving objects in the environment (row (B) in Table 1). If we could correlate the movement of the objects with the eye movements, then we could trigger interactions with these objects.

If the user and/or object are moving (see column (III) and row (B) in Table 1) the interaction design needs to cope with that locomotion. The system must be able to decide which objects are of relevance and the importance of the information they carry. There is no point in presenting information about a locomoting object, which has no interest for the user or has already gone out of scope. So, the system has only limited time for recognizing the user's interest, the speed of the locomotive object, and the estimated duration of the interaction (i.e. how likely will the object interacted with disappear from the FOV before the planned interaction is over) to provide a suitable feedback. Moreover, the system needs to ensure that the user is able to identify the feedback with the correct OOR [14].

A challenge related to interacting in outdoor environments without a display (i.e., rows (A) and (B) in Table 1) is that they are less controllable than indoor environments. There is no easy way of communicating to the user which objects in the environment can trigger an interaction (*gazable objects*). This leads to two problems well-known in eye tracking literature: Midas touch [12] and gaze guidance [10]. The first is particularly relevant if many gazable objects are in the scene (e.g., a dense city structure seen from a vantage point), while the latter is more relevant for few gazable objects.

Approaches for guiding visual attention in the literature include those which use the visual sense, and those relying on the auditory sense. Visual approaches for attention guidance include changing the geometry of the stimulus [16] or by brief subtle luminance or warm-cool modulations [1]. The latter technique was also extended to an indoor real-world environment by using a projector [2] which is not suited for outdoor environments and only works for stationary objects (A). An auditory approach to visual attention guidance was presented by [20] who used a gaze-contingent auditory feedback (sonification). This could potentially be useful for gaze guidance while interacting with objects in outdoor environments.

Moving objects (row (B)) make both problems, Midas touch and gaze guidance, particularly challenging. A moving object is more likely to attract the user's gaze without her having the intention to trigger an interaction. It is also challenging to guide a user's gaze towards a moving object, especially if the trajectory is unpredictable.

Finally, with portable objects (row (C)) one must also consider the small display size for efficient interactions. Also if a combined approach is consider (e.g. a mixture between C(1) with A(1) or B(1)), one must also consider the fact that interactions with these devices distract the user from the environment and frequent attention switches between the device and the environment are needed.

Conclusion and Outlook

In this paper we presented a vision of gaze-based interaction with and in (potentially large-scale) urban environments. We proposed a novel classification schema for mobile gaze-based interaction. Since in the envisioned interaction scenarios the movement of the user and interaction objects are important factors, our classification is based on whether the user and/or object(s) are stationary or moving. We discussed the challenges we must tackle before we are able to realize the vision and connected these challenges with the existing literature.

The classification scheme also provides a potential path one might want to take as next steps: one could start with the case of stationary objects and users (A(I)), later extend the system to account for movement of the user (A(II), A(III)) or objects (B(I)), and then to account for both (B(II), B(III)).

Assuming that the state-of-the-art computer vision techniques will continue to improve, these kind of problems will be resolved and in the future a generalizable system for outdoor environments might be developed.

But still open questions regarding the interaction designs remain. Methods that have been proven successful in indoor environments and objects (e.g. smooth pursuits [29] – see previous section) will need to be extended and tested for outdoor environments and moving objects. Furthermore, it will most likely be necessary to develop new interaction paradigms for some of the aforementioned scenarios.

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