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Abstract

Inside Your Head:
Use of Eye-tracking for Museum Installations and Web Sites

This paper examines potential uses of eye- and gaze-tracking both for museum installations as well as the museum Web sites. Eye-tracking is a well established technology currently commercially used mostly for design and marketing research. Since the main use of the technology is to discover a viewer's interest, it could be very well adapted for cultural heritage content. This paper presents an overview of available eye-tracking technologies and their potential use in a museum/gallery context. The second part of the paper examines the use of low cost (Webcam-based) eye-tracking technologies that can be used for educational interactions with museum Web sites by anyone who has Internet access and a Webcam.

Keywords: eye- and gaze-tracking, museums, eye-tracking applications for museums, low-cost eye-tracking, gaze-aware museum Web applications

Introduction

One could make the case that gaze-tracking is as old as humankind. Indeed, even the anatomical design of human eye, with the iris and the pupil embedded in a reflective white surface (sclera) is aimed to provide information about our gaze direction from considerable distance. In most other mammals, including our closest relatives big apes, the whites of the eyes are hidden. Gaze-direction is the first "pointing device" which one can easily demonstrate by standing on a busy street and intently gazing upwards. In a matter of seconds, passersby will start following one's gaze direction and start looking upwards. Gaze direction plays a substantial role in our social communication, starting in early infancy and continuing throughout life as regulator of conversation flow, indicator of intimacy as well as social hierarchy. So far, detection of gaze direction in natural environments was exclusively a living human capability. However, with current technological advances both in eye-tracking methodology and in the area of mobile (user wearable) sensing technologies it is becoming feasible to at least, start thinking about their possible uses. The topic of this paper is an investigation of how some of these technologies can be used in the context of interactions with museum/cultural heritage information.

Brief history of eye- and gaze-tracking

There are many accounts of the history of eye-tracking, ranging from user contributed popular descriptions (Wikipedia) to more technical ones (Duchowski 2002). For the purpose of this paper it is sufficient to note that the interest and research in eye-tracking is more than a century old, with development of different methodologies that corresponded to technologies available at different historical periods. These ranged from human observers recording eye movements to pin-hole contact lens like contraption with a tiny rod aligned with visual axis, as well as tiny mirrors attached to the eyeball (with suction cups) that would reflect light on a sensitive surface (film) leaving a trace.

Currently, the most widely spread method of eye-tracking is optical – with a video camera focused on an eye (or both eyes) and computer software analyzing the image and calculating the angle of the visual axis based on the position of the pupil or the relationship between the position of the pupil and the glint (light reflection of the cornea). The advantage of this method is that it is non-intrusive and (potentially) low cost. The disadvantage is that it frequently requires a relatively fixed head position, calibration, and is sensitive to ambient light changes.

However, gaze direction detection does not have to be optical. In neurological studies the position of the eyeballs can be inferred by using electro-oculograpy (EOG), which registers the changes in the electric potential as eyeballs move in their sockets. A portable device which can be used for HCI was described by Bulling, Roggen and Troester (2008). Although a cumbersome procedure in a clinical setting, the Japanese

Company DoCoMo (see Web reference) demonstrated that gaze direction (or, more precisely, gaze gestures) can be inferred by registering orbital muscles activity using modified ear buds, just like the ones used for listening to music. Not surprisingly, they use the gaze-gestures to control a music player (or a cell phone), where the act of looking briefly upwards increases the volume and looking downwards decreases it. Looking to the right or left advances the player to the next or previous track. These gestures are virtually indistinguishable from the ones I have suggested previously (Milekic, 2003, see Figure 1).

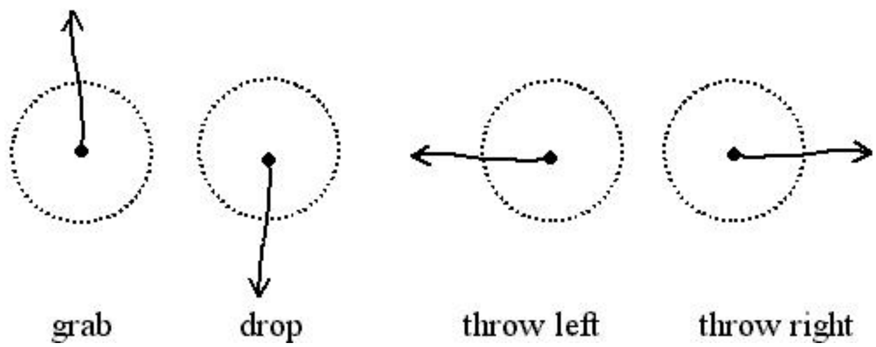

Figure 1. Eye-gestures, proposed as a way of interacting with an object on a visual display. Eye-gestures indicate fast, direction specific eye movements returning to the point of origin and thus, distinguishable from usual eye behaviors. Note that the actions triggered by eye-gestures are arbitrary and may include any of the traditional cursor-based interactions. (reproduced from Milekic, 2004)

Eye-tracking in a physical museum

Current technologies which have already found their practical use mostly in the area of consumer research allow eye- and gaze-tracking in natural physical environments. Regarding the equipment used for eye-tracking, they can be divided in two categories:

a) wearable devices (eye-tracking goggles), and

b) non-intrusive eye-tracking.

Using an analogy with the development of 3D displays which at first required wearing of specialized goggles but now can deliver (an illusion of) three dimensional images without any additional equipment, I am inclined to think that the future belongs to non-intrusive technologies although wearable devices may be necessary during the transitional period. In this section I will propose potential uses of eye- and gaze-tracking in a physical museum environment. However, with the use of web cam based eye-tracking many of the suggested solutions could easily be ported or adapted for use on a museum Web site. Regarding the character of interaction gaze-tracking applications can be further divided into (Milekic 2010):

a) Gaze-aware applications, and

b) Gaze-controlled applications

Gaze-aware applications are those where a user's gaze direction and fixation location are tracked and based on this information the application can trigger an event. The observed articles can be physical paintings, large scale projections, screens and even sculptures. The triggered events would most likely have the function to provide additional information that is relevant to an observer's interest, as specified by gaze direction.

Gaze-controlled applications are the ones where a user can actively interact with content (displayed on a screen, or projected) by using eye-movements. This approach has a large potential for use in Web-based museum applications since the content is already digitized and presented on a screen.

Of course, it is entirely possible to create applications that would use a mix of both approaches. For more illustrative examples see Milekic (2010).

Gaze-tracking vs. gaze detection

A special case of gaze-aware applications is simple gaze detection achieved by using sensors that can detect the moment when someone's gaze is directed towards them, that is, when there is visual contact. This method is based on active illumination with (for humans) invisible infra red light, producing the "bright pupil" effect, similar to the "red eye" in photos produced with a flash that is aligned with the camera lens. The advantages of this technology are that a number of simultaneous inputs can be detected, and the detection is effective at distances (currently) of 10 feet or so. At present this approach is mostly used for collecting data of how many eyeballs looked at certain advertisement (or a portion thereof) or to make an advertisement "aware" of gaze fixation (Amnesty Intl., Eye-box, see web references). It has also led to a number of interactive artistic projects which tie a viewer's visual attention to an event (for example see Knep 2003).

An interesting approach was described by Smith (Smith, J. 2005, Smith, J.D., Vertegaal, R., Sohn, C., 2005) which ties gaze-aware objects (with built-in sensors) a portable eye-tracking device and a mobile device (PDA) capable of delivering more information or triggering an action – for example, a gaze-aware lamp could be turned on just by looking at it (gaze pointing – deixis) and issuing a verbal command "on". This approach has a potential for physical museum applications because it could be used for receiving additional information from gaze-aware objects through a mobile device (such as cell phone).

A variation of this approach which I described elsewhere (Milekic 2003, Milekic 2010) is the use of a commercially available eye-tracking setup (for example, Tobii or Miramax) but equipped with a telephoto lens. This would create a "hot spot" in front of an artifact (painting) where an individual viewer's gaze direction could be detected, triggering off contextually relevant additional information.

Through your eyes, really

Velichovsky developed a concept of "attentional landscape" (in Challis, B.H. & Velichovsky, B.M., 1999) some time ago. Attentional landscape corresponds roughly to the area of foveal vision including an adjacent area of peripheral vision, while the rest of the visual field is opaque. Using this concept I developed an application (Basset, Milekic 2001) with a goal to recreate the personal experience that one had in a physical museum and somehow make it available on a museum Web site.   The application allowed a viewer to explore an artifact (painting) using the "attentional landscape" while the program recorded in real time the exploration path (Figure 2).

Figure 2.   Partial "attentional landscape" path while examining a painting

When the viewer was satisfied with the exploration (that is, when s/he has seen enough of it to form a personal opinion) s/he was asked to write a personal essay about the painting and post it on the museum Web site.   However, uploading the essay on the Web site also uploaded the individual "attentional landscape" exploration path.   As part of an on-line museum course (Visual Arts Resources for Teachers, VAST), the idea was to present a museum Web site visitor with the original painting that could be explored only using a recorded exploration path from the previous viewer, effectively providing exactly the same information (as well as exploration sequence) from the original viewer.   Knowing that the second viewer was exposed to exactly the same visual information, s/he was also asked to write a personal essay on her/his experience. After submitting the essay the second viewer could see the essay (personal experience) of the first viewer.   This created an interesting dynamic, comparing one's own experience with the experience of another person who had exactly the same (visual) experience.   Although in the original project movement of attentional landscape was tied to mouse/cursor movement, later on I connected the original image exploration with eye movements, and thus created a truly personal "view" that could be made available to another person.   In essence, one person could "see" through another person's eyes.

The concept described above was pushed further into the direction of physical experience in a museum by two of my students (MacDuffie Woodburn, J., Miller, M., 2010).   They have created a physical device (see Figure 3) that literally allowed one person to see what the other person was "looking at".   The original idea (although it was not implemented in the physical prototype) was that the device used by the person who was "looking" would also track gaze direction and create a visual "attentional landscape" by (visually) emphasizing the focus of the gaze while blurring the rest of the visual field for the person who was "watching". Even though in the original prototype the two units were physically connected, it would be easy to connect them wirelessly or, for that matter, have a "looking" person in a physical museum and make the visual feed available on the Web, or via a mobile device.

Figure 3.   "Pixel" prototype, showing the two units and their live use.

Use of eye-tracking on a museum Web site

Eye- and gaze-tracking is becoming increasingly possible using inexpensive or built-in web cams in modern laptops.   Already in 2002 one of the first papers on possible use of webcams in the area of eye-gaze assistive technology was published (Corno, Farinetti, Signorile, 2002). However, while it provided handicapped users with an alternative way of interacting with digital content, the software was slow and imprecise (see the more recent paper by Corno & Garbo, 2005 for a more sophisticated solution). Recent technological advances (faster processor speeds and better resolution of built-in web cams) have led to a surge of research on the topic, including a number of open source, freely downloadable solutions. An example is work done at ITU GazeGroup in Copenhagen which produced an open source Gazetracker program (San Agustin, Hansen, J.P. 2008, San Agustin, Skovsgaard, Hansen, J.P., Hansen, D.W. 2009, Tall 2009) as well as applications that use eye-tracking for text input (GazeTalk, StarGazer) and an application which allows eye-controlled interaction with video content on the popular YouTube site (EyeTube). Other examples include EyeWriter project (www.eyewriter.org), Processing Easy Eye Tracker Plugin (PEEP) as well as low-cost eye-tracking software like Piotr Zieliński's Opengazer which is an open-source code using an ordinary webcam (see references for Web link). The most recent version of the software also provides face-tracking and the recognition of facial gestures (for example, smile and frown detection). Although many of these solutions demonstrably work under ideal conditions, there are some of software and hardware related problems that still need to be addressed. This would include calibration issues, position of built-in Web cams (most often on top of the screen, whereas an ideal position for eye-tracking would be at the bottom of the screen), sensitivity to ambient light levels (which could be resolved with infra red illumination) and others. However, for the purposes of this section, I will assume that these problems have been solved (and indeed, every day another step forward is made), and that in near future it will be possible either to download eye-tracking software which would use the built-in web cam or that future laptops will come equipped with web cams specifically designed for eye-tracking.

Designing museum Web sites

One of the more obvious uses of eye- and gaze-tracking would be in the design of museum Web sites. However, services of this kind are commercially available (most often used to increase commercial potential of a Web site), and are not of particular interest to the author of this paper. Therefore, in this section I will focus mostly on potential uses of eye- and gaze-tracking for purposes that are more relevant to museum Web sites.

Creating museum collection folksonomies

In contrast to art historian created taxonomies, many museums Web sites are finding increased use for user-created "folksonomies", which reflect non expert users' mapping of relevant information about art artifacts (Trant, Wyman 2005). Creating folksonomies has been extremely successful both for consumer Web sites with passive data collection (like Amazon.com with "people who bought this item were also interested in….") as well as in user-contributed Web sites (like Flickr, with user-supplied tags). Currently, tagged museum collections also rely on visitor input. However, adding gaze-tracking functionality to a museum Web site would provide an easy way of creating folksonomies, using the "look and talk" paradigm. Theoretically, it would consist of gaze-aware museum Web site, with enabled built-in microphone and speech-to-text software. A visitor to a museum Web site displaying a work of art would only have to look at a particular detail (preferably with some kind of visual feedback) and verbally "annotate" it. Built in eye-tracking software would provide coordinates of region of interest coupled with "tags" created with speech-to-text software.

Voice in your head

Another possible application of gaze-aware museum Web sites would be to provide additional information about particular work of art (displayed on the screen) dependent on the detail that a viewer is looking at. Please note that this is the same principle that is proposed for individual works of art in a physical museum, except that with (hopefully free) downloaded software it can come with little or no cost to a museum. A functional prototype of such an application with a laptop equipped with (albeit primitive) eye-tracking capability was recently demonstrated at a Museums & Web '10 conference in Denver (Milekic, Roberts, Miller, 2010). For the purposes of demonstration, a laptop screen displayed an actual painting from a museum, while providing visual feedback to the viewer about their gaze focus with a magnifying glass (thus, magnifying any part of the image that the viewer was looking at, see Figure 4).

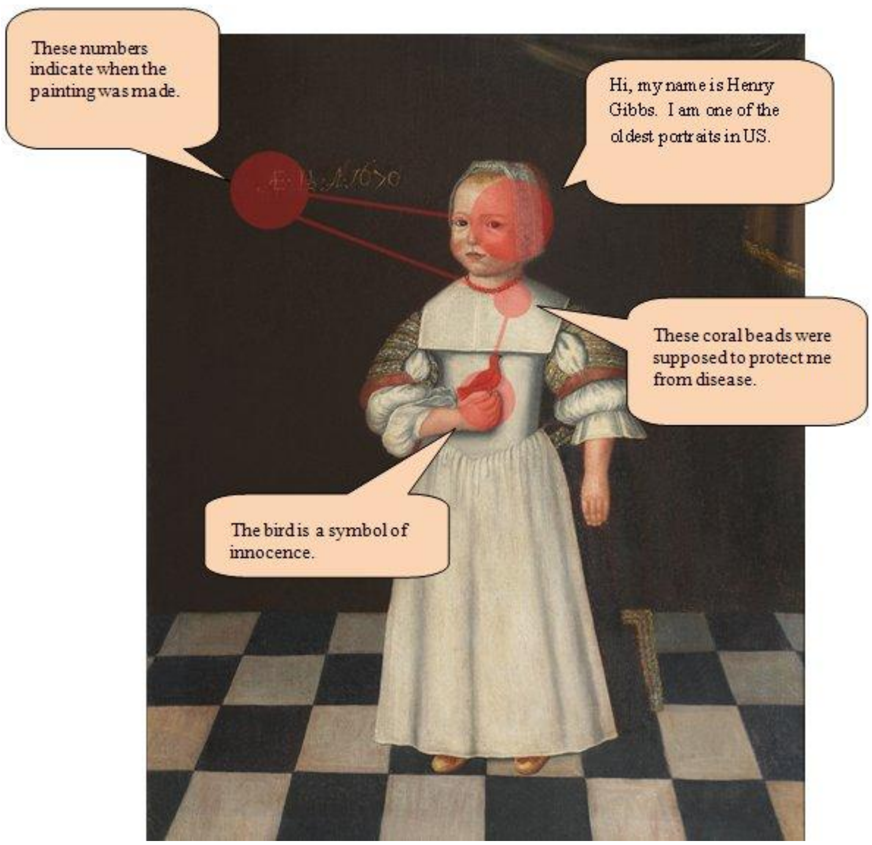

Figure 4. Example of gaze-aware voice annotation. The circles superimposed on the painting indicate a viewer's gaze focus, which would trigger appropriate voiceover.

Focusing on different details of the image would trigger an appropriate voice-over providing additional information about the painting. According to the interviews with participants, the effect was "magical" – providing a "voice in your head" which would supply relevant information about any detail that a viewer was interested in.

Museums and education

With the introduction of the digital medium (Internet) the role of museums shifted from conservation and preservation to dissemination and education (although, it seems that not all museums are aware of this paradigm shift). This shift was recognized fairly early by some academic institutions. As a result, the second largest University in the US is the University of Phoenix, which according to Wikipedia has "… a student body in North America second only to the State University of New York, it has a current enrollment of 420,700 undergraduate students and 78,000 graduate students, or 224,880 full-time equivalent students." (retrieved on October 8th, 2010). Most of these students are getting their degrees on-line. Although on-line degrees tend not to be regarded as highly as the "real" ones, the concept of distance education and knowledge transfer should be of interest to museums.

As a part of his master's thesis Roberts investigated ways to increase the efficacy of knowledge transfer (distance education) with a focus on enhancing it with eye- and gaze-tracking (Roberts, 2010). His premise is that presenting the information in a variety of ways (for example, image, text, animation, table), enhances the retention. In one of the examples (see Figure 5) he shows how a gaze-aware system could react by highlighting the relevant information on an image while the viewer is reading the text label.

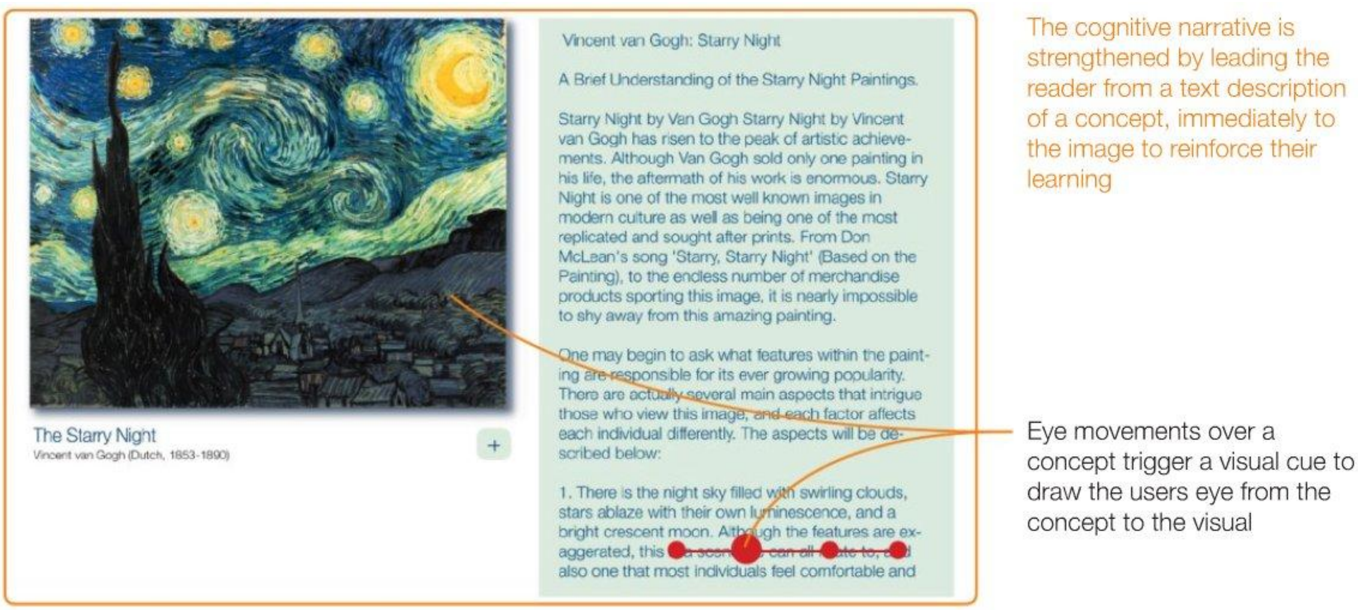

Figure 5. An example of how focusing on a certain part of the text (red dots indicate gaze fixations) would trigger a visual cue (in this case, turning the part of the image to black and white) relevant to the text being read (reproduced from Gareth, 2010).

Making museum Web sites gaze-aware can also provide a number of other useful metrics. The most obvious one is the information about *what* the museum Web site visitors are looking at and *how long* did they focus their visual attention on a particular detail. Of course, the interpretation of data would be very different if it came from viewing digital reproductions of artworks or from reading the explanatory text. There is substantial evidence from psycholinguistic studies (Rayner, Pollatsek 1987) that reading the text which imposes additional cognitive load increases (overall) fixation time and triggers a particular pattern of gaze fixations (with retrograde saccades). This information alone would be extremely helpful in gauging the efficacy of conveying relevant information through a museum Web site.

Some of the recent studies indicate that eye-tracking can dramatically influence the efficacy of knowledge transfer and retention. A study by Ozpolat (Ozpolat & Akar, 2009) provided a model that will deliver information (based on eye-tracking data) in a way that corresponds to a viewer's learning style.

Eye-tracking and research

Eye- and gaze-tracking, both in physical museums and on museum Web sites can produce invaluable research data for diverse areas of study, including visual perception, cognitive science, neuroesthetics and museum studies. One of the rare and early applications of eye-tracking in museums was the use of eye-tracking equipment in the National Gallery in London, during the exhibit "Telling Time" in 2001. However, besides demonstrating that it is possible to use eye-tracking technology in a large scale exhibits and producing some publishable data (Wooding, 2002) the study did not substantially enhance museum visitor experience.

Figure 6. "Heat map" of gaze fixations on a typical Google search page. Data indicate that most (tested) users find what they were searching for within the two top results.

Internet giant Google is regularly using eye-tracking data to refine the way Google displays search data including their image search (Figure 6). If museums were sensitive to this kind of research it would provide them with valuable guidelines for redesigning their Web sites in a way that makes the search within the site more user friendly (see Web links for more information).

Conclusion

The points made in the preceding sections and illustrative examples can be summarized as follows:

a) Eye- and gaze-tracking technologies have matured enough to be considered for use in a physical museum/gallery setting;

b) The emergence of low-cost (or built in) eye-tracking methodologies can play a major role in the design and interaction on museum Web sites and enhance the educational role of the museums;

c) Eye-tracking technologies can play a vital role in museum studies.

It seems that the major problem in adopting these technologies is the divide that exists between traditional notions of Art and Science.   It is the hope of the author of this paper that the examples provided will be the small step towards cross-discipline collaboration.

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DoCoMo eye-controlled phones: http://www.youtube.com/watch?v=_nTQlRBNrG8&feature=related

EyeWriter Initiative: http://www.eyewriter.org/

Google eye-tracking study: http://googleblog.blogspot.com/2009/02/eye-tracking-studies-more-than-meets.html

Opengazer: http://www.inference.phy.cam.ac.uk/opengazer/

Processing Easy Eye Tracking Plugin (PEEP): http://text20.net/node/14

StudioNext project at the University of the Arts, Philadelphia: http://www.uarts-eyetracking.org/