Pervasive and Mobile Computing 30 (2016) 71–83

Contents lists available at ScienceDirect

Pervasive and Mobile Computing

journal homepage: www.elsevier.com/locate/pmc

PeepList: Adapting ex-post interaction with pervasive display content using eye tracking

Rudolf Kajan [a,*], Adam Herout [a], Roman Bednarik [b], Filip Povolný [a]

[a] Graph@FIT, Brno University of Technology, Czech Republic
[b] University of Eastern Finland, Finland

ARTICLE INFO

Article history:
Received 29 April 2015
Received in revised form 5 November 2015
Accepted 9 December 2015
Available online 23 December 2015

Keywords:
Eye tracking
Pervasive displays
Multi modal interaction
Multi-device environment

ABSTRACT

Short intensive interactions with unfamiliar pervasive displays coerce users to perform cognitive operations with uncertainty and risk of not being able to access the information of relevance later. We developed a new way of interaction with pervasive displays by harnessing the eye tracking technology to extract information that is most likely relevant to the user. These extracted bits of important information are presented to the user and sorted according to their estimated importance—in the PeepList. The users can interact with the PeepList without explicit commands and they can access the customized PeepList ex-post in order to review information previously consumed from the pervasive display.

We carried out a user study involving 16 participants to evaluate the contribution of PeepList to efficient pervasive display interaction. The tests revealed that the PeepList system is unobtrusive, accurate, and in particular it reduces the interaction times by 40% when complex tasks were presented to the participants. A feasible user model can be built in under 30 seconds in 50% of all interactions, and in one minute, a majority of all interactions (70%) lead to a useful user model. Experimental results show that eye tracking is a valuable real-time implicit source of information about what the user is searching for on a pervasive display and that it can be used for real-time user interface adaptation. This considerably improves the efficiency of obtaining and retaining required data.

1. Introduction

Pervasive dynamic displays become ubiquitous [1], as static information posters and bulletin boards are being replaced by digital technologies. The traditional displays are enriched by the means of user interaction, typically by either some form of touchscreen functionality, or through interaction with the display from a distance (e.g. by mobile phone-based interaction [1,2], or by depth cameras [3,4]).

Multiple research groups are dealing with the challenges of public and pervasive displays and the novel ways of interaction with them [5], for example by enabling passers-by to simply walk up to a display and to navigate content using their eyes only [6]. Pervasive displays are already being used in a large variety of contexts—as a medium for advertising in public spaces [7], a platform for content exchange similar to traditional public notice areas [8], or for creation of public spaces that promote community interaction and place awareness [9].

The problem we consider in this work concerns the fact that interaction with many pervasive displays is often – compared to personal desktop or laptop devices – sudden, short, and arbitrary, and the user is not familiar beforehand with the user

* Corresponding author.
E-mail addresses: ikajanr@fit.vutbr.cz (R. Kajan), herout@fit.vutbr.cz (A. Herout), roman.bednarik@uef.fi (R. Bednarik).

http://dx.doi.org/10.1016/j.pmcj.2015.12.004
1574-1192/

interface. Users interact with shared pervasive displays in bursts, and the usage time is constrained, for example, by the physical space that a limited number of users can occupy in front of the information board (e.g. pervasive displays located at expo venues, hospitals, hotels, fast-food counters, nearby escalators, and in public transport). Therefore, the display systems cannot explore long-term user models in these situations, and, instead, effective short-term, one-shot models have to be created. Additional motivation lies in the fact that short intensive interactions with pervasive and mobile information coerce users to perform demanding cognitive operations [10] and introduce risk of not being able to access information later. In order to create interaction that is both efficient, rewarding, and engaging [1], new forms of interactivity should be developed.

One of the solutions is to harvest the relevant information and user preferences from the pervasive display and transfer it to the users' profiles and their devices so that the relevant information is available also *ex post*—after the initial interaction. This way the users are able to re-access information from the primary interaction with the pervasive display during the secondary interaction on a personal device (usually a smartphone, tablet, or other personal device with networking capabilities).

A rudimentary existing materialization of this idea is the implementation of the history pane in the current web browsers [11]. The web browser history pane collects the browsing information invisibly and the user refers to it only from time to time—exactly to re-visit the information previously accessed. Such functionality decreases the need to recall the URLs visited and allows for distribution of the user data across multiple devices. By supporting a way to re-access the content after the interaction with the display, users are able to further utilize previous information in an unobtrusive way on their personal devices—for example after observing a food court display, users are able to access the detailed information about food items, such as allergens or nutritional values. In another case, after looking at a pervasive display with a floor plan of an unfamiliar building or subway and planning a path, users are able to re-access parts of the plan or path.

In this work, we set to solve the problem of automatically recognizing user's items of relevance from gaze during short interactions with a dynamically generated pervasive display. Furthermore, we demonstrate that such knowledge can be collected in real time to facilitate secondary interactions on the user's personal device. We conducted an experiment in which a number of users interacted with a pervasive display while their gaze was recorded and concurrently, a ranked list of items of presumed relevance was generated—the PeepList. We evaluate the performance of such automatic ranking from gaze and its effects on further search tasks on a private device. Our approach aims at modeling the user on-the-fly without any training phase. This allows the service to be fast and not force a previously learned model of the majority of population on the individual approaching the display. In addition, content changes to the user interface do not necessitate re-training.

The main contribution of this article is showing that gaze can be a valuable source of information regarding the user's items of relevance and that a relevance-sorted PeepList of items from the pervasive display can be considerably more helpful than a mere list of all the items from the pervasive display. The experiments show that the sorted PeepList speeds up *ex post* interaction (i.e. secondary interaction on a personal device) tasks up to two times (compared to having the list of items unsorted). We also propose a novel way of collecting and processing the information from the pervasive display by the means of eye tracking and verify its usability experimentally.

2. Related work

Gaze tracking has come a long way, all in technological, applied, and methodological directions [12]. Current eye trackers offer spatial and temporal precision combined with unobtrusiveness that make them promising devices for ubiquitous sensing and implicit interaction [13]. Such attentive user interfaces and gaze-based user modeling do not react to explicit commands based on gaze, but instead listen in the background and adjust the interaction in implicit ways.

Provision of novel gaze data analysis techniques further paves ways to improve attentive user interfaces and user modeling techniques in estimation of knowledge, skills, interest, and other cognitive processes [14–18]. Kandemir and Kaski [19] exploit gaze data to learn relevance indicated explicitly by users. In an art gallery scenario, users were wearing a head-mounted eye tracker and pressed a button each time spotting an interesting piece of art. The patterns of gaze associated with interest were learned by a machine learning algorithm to provide predictions of interest for future use. Qvarfordt and Zhai showed that it is possible to estimate users' preferences based on eye-gaze patterns and manage computer information output accordingly [20]. However, estimating relevance in interactions with pervasive displays that contain *dynamically generated content* is still a very challenging task for many reasons, including the severely limited application of supervised learning in this context. For long, gaze has been frequently employed as an indicator of attention in various studies [12,21,13]. Applications of gaze-based user models for adapting subsequent interaction and content have not been previously extensively reported. For example, Alt et al. [22] described a prototype of a system and its evaluation, showing they can achieve an increase in attention to web-ads. Buscher et al. [23] examined the effect of incorporating gaze-based attention feedback on personalizing the search process, showing that when reading behavior is taken as feedback, considerable improvement in the search results accuracy is achieved. Expanding the proposal to employ gaze as an implicit feedback for information retrieval, Buscher et al. recently coined the term "Attentive documents" [24]: documents that keep track on how they are consumed.

The information harvesting can essentially be treated as content generation [25]; besides it, another challenge of interaction with pervasive displays is the personalization and private interaction with the content. One of the prevailing ways to personalize interaction with a pervasive display is to employ users' mobile devices, such as in the personalized weather information described by Davies et al. [1]. Attempts to enhance interaction with pervasive displays have previously