Evaluating Saccade-Bounded Eye Movement Features for the User Modeling

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ABSTRACT

This paper presents a foundation for an extensive framework expanding the use of eye movements as a source for user modeling. This work constructs a model of human oculomotor plant features during user's interactions with the goal of better interpreting user gaze data related to resource content. This work also explores the anatomical reasoning behind incorporating additional gaze features, the integration of the additional features into an existing interest modeling architecture, and a plan for assessing the impact of the addition of the features. The paper concludes with few observations regarding the promises of using OPF in a user modeling framework in studying search behavior.

CCS CONCEPTS

• **Information Systems → Novelty in Information Retrieval**

Keywords

User interest modeling; eye movements; oculomotor plant

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1. INTRODUCTION

Accurate models of user interest are valuable in personalizing the presentation of the often large quantity of information relevant to a query or other form of information request. We have previously developed and evaluated a software framework [14-16] for capturing user activity across multiple applications and combining this activity data in user interest models to aid personalized information delivery. Personalization in these models uses the information about a user or their task to adapt the presentation of resources. A user model is often the basis for such adaptation. A user model can be as simple as person's explicitly provided preferences or as complicated as a representations of the user's knowledge in different areas. In the context of a classroom setting, information in such user models could include the user's roles (teacher or student), their classes and grade levels, their preferences for how to view resources, and explicit ratings of or comments (semi-explicit) on resources they have provided, their past queries, and past resource access. The more information available about the user, the greater the potential for personalization.

1.1 Motivation and Problem Statement

The motivation behind our work is that not all gazes are created equal. Thus, systems should not treat focus activity equally when using gaze information for user interest modeling. We hypothesize that the anatomical characteristics of the human eye may be utilized to estimate set of non-visible anatomical features called "*oculomotor plant features (OPF)*" that can then be used to aid personalization in user interest modeling techniques. This paper entails a comprehensive description of the OPF capturing process and an initial hypothesis to study what features will be of most use in conjunction with traditional implicit relevance feedback indicators. This study attempts to use eye movements and these OPF values to identify the relevance of resource content.

Our objective is to develop a user modeling framework for the personalization based on the non-visible anatomical structure and its characteristics of the human eye via OPF.

2. BACKGROUND

The human eye already provides a plethora of information useful for user modeling. Eye tracking has been employed in studying user attention on the web. Yarbus et al. show that visual behavior is closely correlated to the user task when looking at a visual scene [29]. A variety of uses of gaze data have been explored as a source of implicit relevance feedback for IR. Previous work has primarily focused on identifying visual attention to make user interest predictions [2, 4] and more recently to predict a target in search results [3, 11, 27, 30]. The

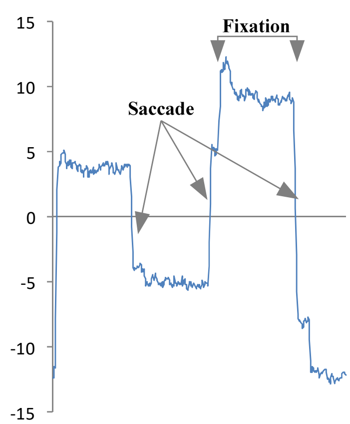

Figure 1: Sample raw eye movement signal before classification.

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human-computer interaction and information retrieval communities have investigated trends and differences in user attention patterns and cognitive processing including correlations to the relevance of reading text [6], identifying pattern differences [9], tasks types [12], and user accuracy in alternative interfaces [25].

The human oculomotor plant (OP) consists of the eye globe and six extraocular muscles and its surrounding tissues, ligaments each containing thick and thin filaments, tendon-like components and liquids. In general there are six major eye movement types: fixations, saccades, smooth pursuits, optokinetic reflex, vestibule-ocular reflex and vergence [22]. An eye-tracker provides eye gaze position information as well as other gaze related parameters (pupil dilation etc.) so that algorithmic derivation in terms of two primary eye movements, *fixations* (relative gaze position at one point on the screen), and *saccades* (rapid eye movements of gaze from one fixation point to another) can be analyzed to derive the users attention patterns (see Figure 1). The retinal image is transmitted to the brain during fixations but not during saccades. The static and dynamic characteristics of the human OP are represented by the series elasticity, viscosity, active-state tension, length-tension and force-velocity relationships and the frequency characteristics of the neuronal control signal sent by the brain to the extraocular muscles and the speed of propagation of this signal.

We next present details of the underlying OPF, an existing interest modeling architectures and then how the features are expected to provide value during user modeling.

2.1 Oculomotor Plant Features (OPF)

The goal of the oculomotor plant model is to describe a system of equations capable of accurately reproducing the features of normal human eye movements in real-time, based on the set of properties of the extraocular muscles responsible for rotation of the eye globe. A number of previous models have been proposed generally representing the oculomotor plant linearly in one-dimension (horizontal) or non-linearly [26] in three dimension (horizontal, vertical, torsional). Linear one-dimensional models have thus far failed to reproduced the saccadic amplitude-peak velocity relationships present in normal human saccades, while non-linear three-dimensional models have received limited testing and are computationally complex, making them less suitable for real-time applications. More recently, our contributions [13, 19, 20] focused on the two-dimensional linear homeomorphic model of the oculomotor plant driven by twelve differential equations, and is capable of simulating saccades with properties resembling normal humans on a two-dimensional plane (horizontal and vertical).

Oculomotor plant features: We refer to the parameters of our oculomotor plant model as oculomotor plant features[17]. These parameters describe an important anatomical and neurological properties exhibited by the oculomotor plant system. In our model, each muscle is represented by a complex anatomical structure, the properties of which can be effectively described by: *series elasticity* – the elastic resistance to rapid changes in muscle length produced by active muscles; *passive elasticity* – the elastic resistance to rapid changes in muscle length produced by inactive muscles; *length-tension relationship* – the relationship between length of a muscle and the force it is capable of exerting during activation; *force-velocity relationship* – the relationship between velocity of muscle contraction/relaxation and the force it is capable of exerting; *active-state tension* – the tension developed as a result of muscle activation by the neuronal control signal. There is also the eye globe and the surrounding tissue which also produces passive elastic and viscous properties.

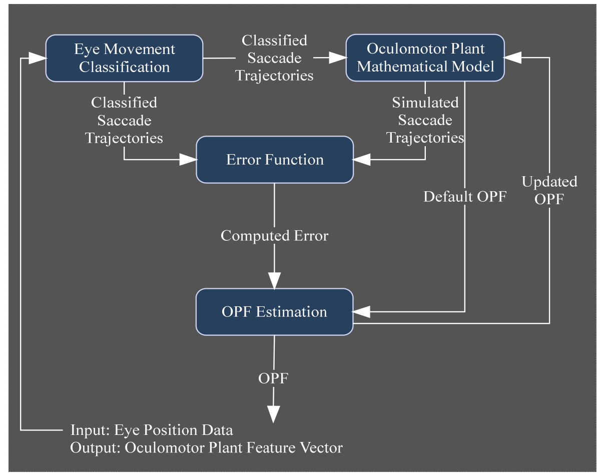

Figure 2: OPF optimization algorithm.

Saccade-Bounded OPF: In order to estimate OPF for a given saccade, the model is initiated with default parameters based on the relevant literature [1, 20] and then Nelder-Mead simplex algorithm [21] is employed as the absolute difference between the measured and simulated saccadic eye movement trajectory (see Figure 2). By estimating OPF via the recorded eye position signal and the simulated saccade trajectory, these saccade-bounded OPF values can help deduce how gaze data is incorporated into the evolving user interest model.

3. USER MODELING

User models can be developed by adapting the content consumed or produced by the user, and their specific task, background, history and information needs [28]. These models can be used to identify resources (documents) or to bring a user's attention to the more valuable content of a resource (document segments). User interest models can be developed based on explicit or implicit feedback. Explicit feedback is the most accurate indicator of user interest but rather difficult to obtain as users often cannot (or will not) express their interests. Implicit interest indicators, such as records of user activity, are easy to obtain but require more interpretation to infer user interests. Past research studies [8, 18] have shown that implicit feedback can be used to develop valuable user models.

Recognizing user interest based on observed user activity is confounded by idiosyncratic work practices. As a result, systems that aggregate evidence of user interest from a wide variety of sources are more likely to build a robust user interest model. A majority of past studies [7, 18, 24] have focused on monitoring implicit and explicit interest indicators present in a single application sources, e.g., implicit and explicit interactions with the user's web browser. Though relatively new, the idea to use eye movement data for estimating relevance has been approached [5, 10, 23]. However, these studies are operated on the raw gaze data to detect fixations, saccades and derived features from these eye movements. The proposed work differs in the use of complex anatomical structures of the human oculomotor system and dual aspect of physical and neurological components to identify relevance.

3.1 OPF-Aware User Modeling

Our interest modeling system [15, 16] incorporates user activity data from multiple applications within a personal profile server to support personalized information presentations. The user activity data collected includes a combination of implicit and semi-explicit interest information. It also shares the inferred user interests with registered applications that ask for it.

The profile server currently communicates with a web browser (Mozilla-Firefox) to present search results and also to visualize recommendations, and three other content reading and authoring applications: a PDF reader, Microsoft Word, and Microsoft PowerPoint. Records of user activity in PDF documents, Mozilla Firefox, MS Word and MS PowerPoint are stored in the server and drive the visualizations that the server generates for each of the applications registered for relevant notification request.

The design of oculomotor plant module is expected to provide insight into the user's assessment of content to the modeling system via the OPF values. The eye tracker provides a continuous eye movement signal during the user activity. An interest profile is then made up of the aggregated heterogeneous interest evidence collected from these different clients that is generated based on all the features, including the OPF values. By characterizing elements of the previously outlined OPF values, we will be able to assess how well the different designs could be used to create user interest models similar to the unification process introduced in our previous work [15, 16].

4. DATASET AND RESULTS

4.1 Apparatus, Participants and Eye Movement Invocation Task.

The eye tracking dataset used in the paper is compiled from our previous work [13, 19, 20], and is publicly available. Oculomotor behavior is recorded using the Tobii x120 eye tracker with accuracy 0.5^0, spatial resolution 0.2^0 and sampling frequency 120 Hz. 12 subjects' records were selected for the current study from the original dataset. The original data collection procedure is based on a stimulus presented as a white single "jumping point" on a black background with vertical coordinates fixed to the middle region of the screen. The sequence consists of 15 fixation points.

Next, the recorded eye movement signal from the 12 participant dataset is supplied to the *eye movement classification module* that classified these position signals into fixations and saccades. In our previous work [19], we found evidence that Velocity Threshold algorithm proves to be the better choice for systems measuring saccadic performance and utilized velocity-based model for eye movement classification with thresholds 70^0/s. The classified saccades trajectories represented by the onset and offset coordinates of the eye position and amplitude (length) of the saccade are used to generate simulated saccade trajectories based on the default OPF values. Each individual classified saccade is then compared with the simulated saccade and the corresponding saccade-bounded OPF values are extracted by minimizing the error in each pair.

Figure 3 presents six OPF values collected from the user study and the boxplot of the data including the default values (red dash-line). We acknowledge that the dataset is not necessarily based on an information task where the user engagement with information resources and "ground-truth" of user interest is not available due to the nature of stimulus invocation task. In this work, our main focus is to explore the OPF data and improve optimization methods used in the methodology to conduct further studies to collect "ground-truth" for evaluating the interest models. Results suggest that the few of default OPF values (series elasticity and passive viscosity) require further refinements due to the first quartile, median and third quartile data which deviate from the empirical default values.

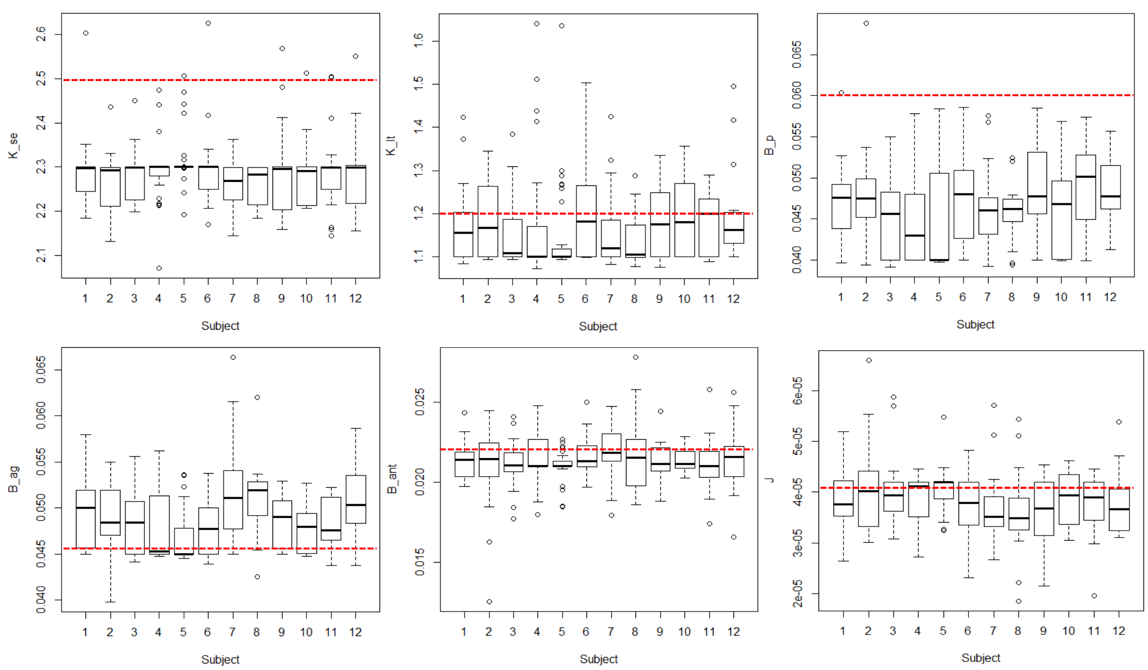

Figure 3: Boxplot of OPF values from 12 subject dataset. Horizontal dash-line depicts the default OPF values.

4.2 Future Work: Gathering OPF-Aware Data from Information Tasks

Saccades, fixations and OPF are integral parts of visual attention. Our framework and architecture incorporates saccade-bounded OPF data capture, storage and feature analysis techniques to explore the value of saccades, fixations and OPF in determining the relevance of encountered content.

The design and development of user interest models require variety of formative and summative evaluations. Results of this work will include algorithms for eye movement classification, aggregating saccade-bounded OPF and other relevant feature values and inferred user interest and development of visualization and interfaces for presenting interest-resource relationships. By giving the user a specific task and a set of resources of known relevance, we can explore the hypothesis that OPF data will be distinguishable between the relevant and non-relevant resources. The subjects' task will be to (1) read the task assigned and decide whether each resource associated with the task contains the content relevant to the task assignment, (2) Select the relevance score for each resource on a 5-point Likert-scale (1-non-relevent, 5-higly relevant) for content relevance assessment.

5. DISCUSSION AND CONCLUSION

The research outcomes are expected to provide an intuitive framework for user modeling by including oculomotor plant features during the use of eye tracking data. This will allow us to assess user behavior in relation to the relevance of resources in order to build and evaluate the possibility of using oculomotor plant features in various applications including *student learning difficulties*. We believe that understanding how the OPF values change over the course of user engagement with information resources will be valuable in the pursuit of developing more accurate interest models.

There are wide range of follow-on work related to the user modeling approach explored here. We limited our approach to features that could be computed from oculomotor plant data. Understanding how saccades relate to the fixations they precede is also an important part of moving towards a richer account of relevance learning in the context of user modeling. Most theories and models are based on fixation patterns that lack an understanding of how saccadic eye movements preceding these fixations are affected by the task environment.

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