2022

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## Original Publication Citation

Jayawardena, G. (2022). Introducing a real-time advanced eye movements analysis pipeline. In F. Shic, E. Kasneci, & et al. (Eds.), *ETRA '22: 2022 Symposium on Eye Tracking Research and Applications.* (Article 35) Association for Computing Machinery. https://doi.org/10.1145/3517031.3532196

# Introducing a Real-Time Advanced Eye Movements Analysis Pipeline

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## ABSTRACT

Real-Time Advanced Eye Movements Analysis Pipeline (RAEMAP) is an advanced pipeline to analyze traditional positional gaze measurements as well as advanced eye gaze measurements. The proposed implementation of RAEMAP includes real-time analysis of fixations, saccades, gaze transition entropy, and low/high index of pupillary activity. RAEMAP will also provide visualizations of fixations, fixations on AOIs, heatmaps, and dynamic AOI generation in real-time. This paper outlines the proposed architecture of RAEMAP.

**ACM Reference Format:**

Gavindya Jayawardena. 2022. Introducing a Real-Time Advanced Eye Movements Analysis Pipeline. In *ACM Symposium on Eye Tracking Research and Applications (ETRA '22 Adjunct), June 8–11, 2022, Seattle, USA.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3517031.3532196

## 1 INTRODUCTION

The advancement of eye-tracking technology provides means to understand the underlying covert processes of the human brain when carrying out cognitively demanding tasks [McCarley and Kramer 2008]. Moreover, eye gaze metrics could be utilized to observe cognition patterns of people belonging to different behavioral and mental categories because their working memory capacity (WMC) is different [Park and Holzman 1993].

Recently we showed the utility of eye-tracking measurements in predicting Attention-deficit/hyperactivity disorder (ADHD) using machine learning algorithms [Jayawardena et al. 2019; Michalek et al. 2019]. For this, we extracted the raw eye-tracking measurements from the eye tracker and created an eye gaze metrics features set to train multiple machine learning models to predict a diagnosis of ADHD. We also assessed audiovisual Speech-In-Noise performance of adolescents with ADHD using eye-tracking measures [Jayawardena et al. 2020]. For the aforementioned studies, we utilized modified gaze analytics pipeline [Duchowski 2017] implemented in Python. Furthermore, we dynamically filtered eye movement data that falls within the detected dynamic AOIs for the analysis of eye gaze metrics [Jayawardena and Jayarathna 2020, 2021] by utilizing pre-trained object detectors. We also redesigned and developed the Low/High Index of Pupillary Activity (LHIPA) [Duchowski et al. 2020], an eye-tracked measure of pupil diameter oscillation to function in real-time.

## 2 RESEARCH OBJECTIVE

With the incorporation of the above work, we intend to design and develop RAEMAP, which will facilitate near real-time calculation of eye gaze metrics such as fixations, saccades, pupil diameters, gaze transition entropy, and LHIPA. It will also facilitate visualization of scan paths, fixations, fixations on AOIs, heat maps, and microsaccades in real-time. This paper outlines the proposed architecture of RAEMAP.

## 3 PROBLEM STATEMENT

RAEMAP will include components of the gaze analytics pipeline [Duchowski 2017] implemented in Python. The gaze analytics pipeline extracts raw gaze data from various eye tracking vendor's exported files. Upon successful extraction of raw gaze data, it classifies raw gaze points into fixations and saccades. Then, it aggregates calculated fixations and saccades for statistical analysis. It also generates visualizations of gaze points, fixations within AOIs, and heatmaps per scan path.

The current implementation of the gaze analytics pipeline processes eye movement data exported by eye-trackers, sequentially. First, it parses the exported eye tracking data files to extract each trial's data into its own file. Then, it de-noise and filter raw gaze data to classify them as fixations (or other relevant events, pupillometric data). Upon generating fixations, the gaze analytics pipeline processes data files for subsequent statistical analyses.

Since the gaze analytics pipeline utilizes split-and-merge approach, there is a large number of intermediate files generated along the way of eye gaze metrics calculations. Processing each file in a sequential manner is time consuming. Furthermore, some of the advanced gaze metrics calculations (i.e. LHIPA) are carried out off-line, with the entirety of the pupil diameter signal available. Therefore, some of the advanced gaze metrics calculations are considered inappropriate for real-time use. Hence, we design RAEMAP to facilitate real-time calculation of advanced gaze metrics by eliminating intermediate file generation. It will also process raw eye-tracking data exported from eye trackers in real-time and calculate the gaze metrics.

We will investigate the following research questions:

(1) How to calculate eye gaze metrics of a scan path in real-time?
(2) How to detect AOIs dynamically in a dynamic stimuli?
(3) How to visualize and update eye gaze metrics and statistics as they are being generated in real-time?
(4) How to incorporate prediction of ADHD using machine learning to the RAEMAP?



*ETRA '22, June 8–11, 2022, Seattle, USA*

ACM ISBN 978-1-4503-9252-5/22/06.
https://doi.org/10.1145/3517031.3532196

## 4 APPROACH AND METHODS

The base implementation of RAEMAP will include components of the gaze analytics pipeline [Duchowski 2017]. RAEMAP will be designed and developed in a manner that, upon correct mapping of variables, it will extract raw gaze data from various eye trackers in real-time. RAEMAP will support stream processing to calculate eye gaze metrics and visualize the scan path as data is being streamed by the eye tracker. This would make it possible to visualize how eye gaze metrics change during the course of a single scan path of a participant during task completion.

In the absence of real-time data, RAEMAP can be configured to utilize simulated real-time streaming of data by using StreamingHub [Jayawardana et al. 2021]. StreamingHub reads data from the original file into memory and streams the data according to the metadata, which stipulates the streaming rate. After extracting raw gaze data, RAEMAP will classify raw gaze points into fixations, and aggregate fixations related information for statistical analysis in real-time.

In addition, RAEMAP will be configured to generate transition matrices [Krejtz et al. 2015] which calculates the probabilities of transition from one AOI to another, and gaze transition entropy to determine the overall distribution of attention over AOIs in real-time. RAEMAP will also include advanced pupillometry measurement to infer the cognitive load of a person since it is directly proportional to task difficulty. We have redesigned LHIPA [Duchowski et al. 2020] to function in near real-time within RAEMAP.

We will conduct an evaluation study based on eye gaze metrics of the ADHD population to prove the utility of RAEMAP in real-time. We plan to recruit 50 participants (25 ADHD, 25 Non-ADHD) between 18 and 42 years to record eye movements during an n-back (1- and 2-back) task.

We will utilize the eye movements streamed by PupilLabs Core[1] eye tracker while participants carry out the n-back task. Each participant will be calibrated using the PupilLabs eye tracker's standard calibration method prior to the experiment. We will feed the raw eye gaze data of each participant streamed from the eye tracker to RAEMAP to generate the eye gaze metrics and pupillary measures in real-time.

Then, we will utilize RAEMAP to predict the diagnosis of ADHD using the pre-trained machine learning models. Based on RAEMAP output, we will conduct an evaluation utilizing precision, recall, F measure, and accuracy to find the best performing models. RAEMAP will also plot the visualizations of fixations, fixations on AOIs, gaze point data over time, and heatmaps, real-time LHIPA for each scan path. At the end of the task, RAEMAP will generate plots such as transition matrices.

## 5 PRELIMINARY RESULTS

With multiple publications [Jayawardena et al. 2020, 2019; Michalek et al. 2019], we proved the utility of the initial version of RAEMAP (modified gaze analytics pipeline to asses task performances and predict diagnosis of neurological disorders using eye-tracking measures. RAEMAP is now developed to extract eye gaze metrics from PupilLabs core eye-tracker in real-time. In addition, RAEMAP supports stream processing to calculate fixations and related metrics in real-time. It is also configured to utilize re-streaming pre-recorded data from StreamingHub [Jayawardana et al. 2021]. Furthermore, we redesigned and implemented LHIPA, an eye-tracked measure of pupil diameter oscillation, to function in real-time as a module in RAEMAP. Also, RAEMAP is configured to dynamically filter eye movement data from dynamic AOIs by incorporating pre-trained object detectors [Jayawardena and Jayarathna 2020, 2021].

## 6 PLANS FOR FUTURE WORK

The next developmental steps of RAEMAP will include the calculation of saccadic eye movements in real-time, generation of transition matrices [Krejtz et al. 2015] in real-time, generation of gaze transition entropy [Krejtz et al. 2015], and generation of visualizations of calculated eye gaze metrics in real-time.

## 7 BROADER IMPACT

The advanced eye movements calculated by RAEMAP and the visualizations will contribute to the knowledge of adults with neurological conditions for a better understanding of how they distribute their attention compared to neurotypical adults.

## ACKNOWLEDGMENTS

This work is supported in part by the U.S. National Science Foundation grant CAREER IIS-2045523. Any opinions, findings and conclusions or recommendations expressed in this material are the author(s) and do not necessarily reflect those of the sponsors.

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[1] https://pupil-labs.com/products/core/