X-DisETrac: Distributed Eye-Tracking with Extended Realities

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Abstract

- Humans use **heterogeneous collaboration mediums** such as in-person, online, and extended realities (AR, VR) for day-to-day activities.
- Identifying patterns in **gaze and pupillary responses** provide informative cues on **individual and collective behavior** during a collaborative task [1].
- Despite the increasing ubiquity of different mediums, the **aggregation and analysis of eye-tracking data is complex, challenging, and remains unexplored** [2].

We propose **X-DisETrac: Extended Distributed Eye Tracking**, a versatile setup for eye tracking for extended environments.

Overview

Consider a set of users collaborating on heterogeneous collaboration mediums (see figure 1),

- Define a **shared Area of Interest** (AOI) across all collaboration mediums.
  Example: *A common user interface for all users.*
- **Collect and transmit** individual user interaction data.
- Aggregate and process to **generate advanced measures**.

We extend DisETrac[3] by modifying the experimental setup and communication protocol and introducing components to tackle the complexity of heterogeneous environments.

We define three types of data streams in X-DisETrac.

1. **Eye-tracking:** Gaze and pupillometric data extracted from the eye trackers.
   Examples: *Gaze position*, *pupil dilation*, *fixation position*
2. **Configuration:** Details on sensor specifications, operating configurations, connectivity status, and data acquisition and transmission errors.
   Examples: *sampling rate*, *latency*
3. **Environment:** Events in the experimental environment and the shared AOI of the experiment.
   Examples: *viewpoint changes*, *clicks*

We use periodic synchronizations to eliminate the effects of clock drift and sequence numbers to detect missing data.

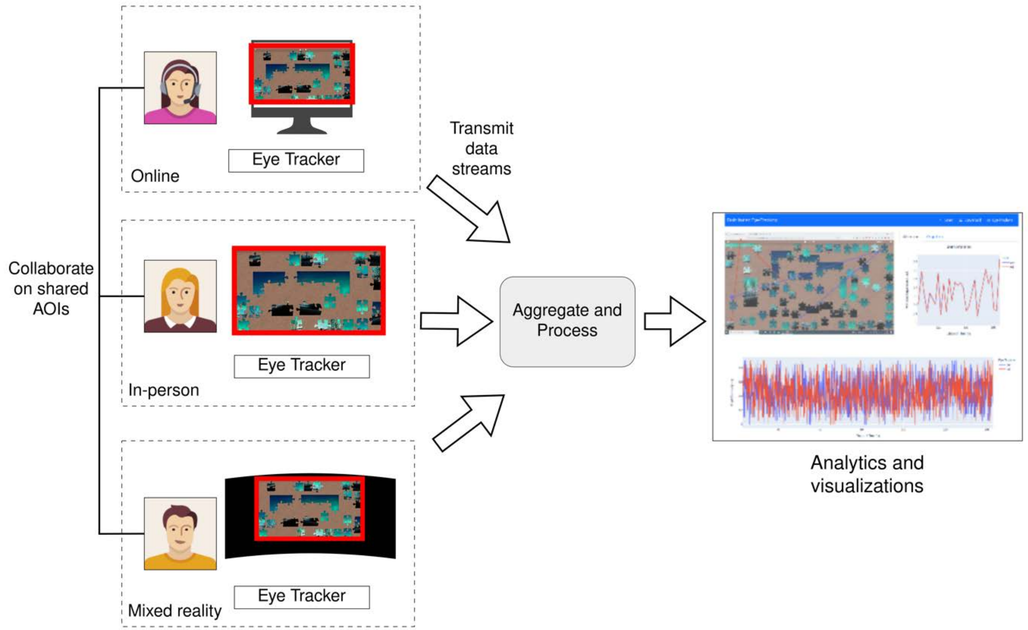

Figure 1. Proposed architecture of X-DisETrac. We use eye-tracking data captured on a shared AOI in each environment to generate advanced measures and visualizations. The illustration uses a puzzle-solving interface (highlighted in red) as the shared AOI.

Gaze and Pupillary Aggregation

- Consider a user u in a collaborative environment of U users. At a given instant t, the data streams comprise of
  $G_{u,t}$: Gaze direction/vectors from the eye tracker.
  Example: *3D gaze positions* (x, y, z)
  $E_{u,t}$: Environment parameters for the user and the shared AOI.
  Example: *Relative location of shared AOI*
- Define the user gaze on shared AOI as $S_{u,t}$.
- To derive $S_{u,t}$, we use a **transformation function** (T_u) specific to each user space defined as,

$$S_{u,t} = T_u(G_{u,t}, E_{u,t}) \tag{1}$$

- Similarly, using pupillary data in the data streams we can obtain,
  $D_{u,t}$: Pupillary dilation of the user u at t.
  Example: *Pupil dilation in mm.*
  $D_{u,b}$: Baseline pupillary dilation of the user u.
  Example: *Average dilation in last* δt *seconds*
- Use Relative Pupillary Dilation (RPD) defined as,

$$RPD_{u,t} = \frac{D_{u,t} - D_{u,b}}{D_{u,b}} \tag{2}$$

- Usage in X-DisETrac,
  $S_{u,t}$: **Fixational and saccadic** measures
  $RPD_{u,t}$: **Pupillary** measures.

Eye-Tracking Measures

- **Attention Distance:** Distance between gaze positions of two users in the shared AOI space.

$$\Delta S_t = |S_{u_1,t} - S_{u_2,t}| \tag{3}$$

- **Joint Attention Distance:** Distance from gaze centroid to the gaze position of a user in shared AOI space.

$$JAD_{u,t} = S_{u,t} - \frac{\sum_{i \in U} S_{i,t}}{|\,U\,|} \tag{4}$$

- **RPD Ratio:** Ratio of RPD in comparison to other collaborators.

$$RPDr_{u,t} = \frac{RPD_{u,t}}{\sum_{i \in U} RPD_{i,t}/|U|} \tag{5}$$

Results

- We examined the utility of the system using a **pilot study of 10 participants** on a collaborative activity (5 sessions, 2 per session).
- Our study setup streamed and processed data with a **mean latency** of 202.5 ± 308.9 ms.
- We did **not observe relationships** between proposed measures and user performance in the activity.

Conclusion

- X-DisETrac **simplifies eye-tracking analytics** using an **abstract model for aggregating** complex eye-tracking data streams.
- In the future, we plan on a more complete and comprehensive evaluation of the proposed system.

References

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[3] B. Mahanama, M. Sunkara, V. Ashok, and S. Jayarathna, "Disetrac: Distributed eye-tracking for online collaboration," in *Proceedings of the 2023 Conference on Human Information Interaction and Retrieval*, CHIIR '23, (New York, NY, USA), p. 427–431, Association for Computing Machinery, 2023.

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