IMETA: An Interactive Mobile Eye Tracking Annotation Method for Semi-automatic Fixation-to-AOI mapping

László Kopácsi
laszlo.kopacsi@dfki.de
German Research Centre for Artificial Intelligence
Saarbrücken, Saarland, Germany

Michael Barz
michael.barz@dfki.de
German Research Centre for Artificial Intelligence
Saarbrücken, Germany
University of Oldenburg
Oldenburg, Germany

Omair Bhatti
omair_shahzad.bhatti@dfki.de
German Research Centre for Artificial Intelligence
Saarbrücken, Germany

Daniel Sonntag
daniel.sonntag@dfki.de
German Research Centre for Artificial Intelligence
Saarbrücken, Germany
University of Oldenburg
Oldenburg, Germany

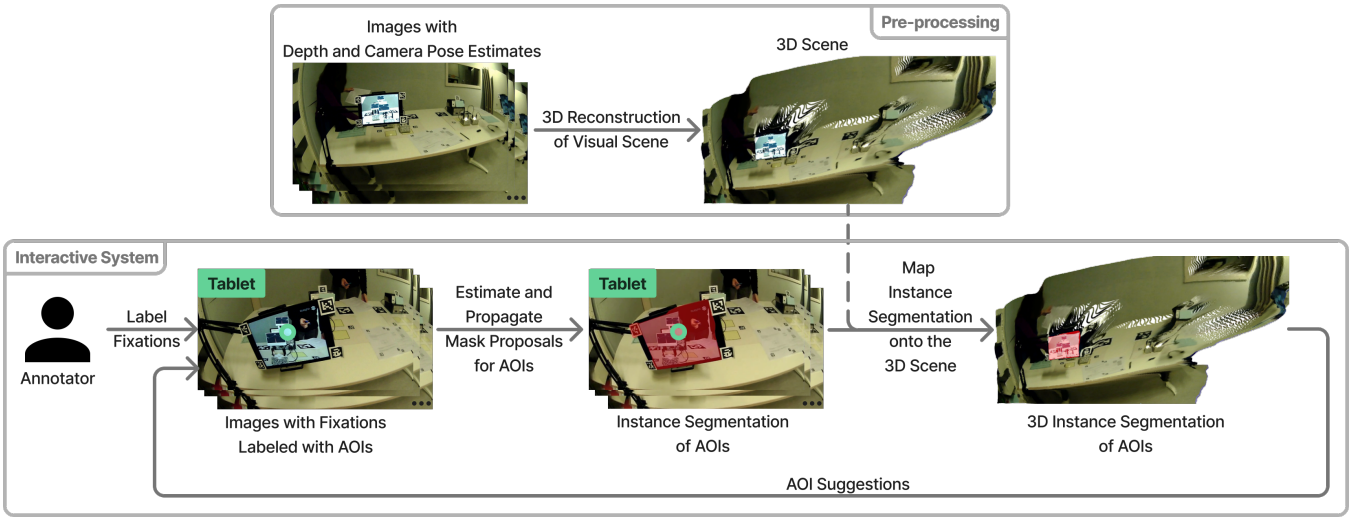

Figure 1: High-level overview of the proposed system. In this example, the 3D scene is reconstructed using a monocular depth prediction method called AdelaiDepth [35], and the video object segmentation is performed using XMem with f-BRS [5, 25].

ABSTRACT

Mobile eye tracking studies involve analyzing areas of interest (AOIs) and visual attention to these AOIs to understand how people process visual information. However, accurately annotating the data collected for user studies can be a challenging and time-consuming task. Current approaches for automatically or semi-automatically analyzing head-mounted eye tracking data in mobile eye tracking studies have limitations, including a lack of annotation flexibility or the inability to adapt to specific target domains. To address this problem, we present IMETA, an architecture for semi-automatic fixation-to-AOI mapping. When an annotator assigns an AOI label to a sequence of frames based on the respective fixation points, an interactive video object segmentation method is used to estimate the mask proposal of the AOI. Then, we use the 3D reconstruction of the visual scene created from the eye tracking video to map these AOI masks to 3D. The resulting 3D segmentation of the AOI can be used to suggest labels for the rest of the video, with the suggestions becoming increasingly accurate as more samples are provided by an annotator using interactive machine learning (IML). IMETA has the potential to reduce the annotation workload and speed up the evaluation of mobile eye tracking studies.

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CCS CONCEPTS

• **Human-centered computing** → **Interactive systems and tools**; Empirical studies in HCI; • **Computing methodologies** → *Machine learning*.

KEYWORDS

mobile eye tracking, areas of interest, annotation, interactive machine learning, 3D reconstruction, video object segmentation, fixation to aoi mapping

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1 INTRODUCTION

The annotation of objects in videos is an important task for analyzing visual scenes and understanding the interactions and relationships between objects in a scene. It also provides training data for machine learning models, which can be used to improve object recognition and scene understanding tasks. However, traditional annotation methods require extensive manual segmentation of objects, which can be time-consuming and error-prone. Mobile eye tracking studies, which involve the use of head-mounted eye tracking devices to measure visual attention to specific areas of interest (AOIs) in a scene, present additional challenges for annotation due to the uniqueness of the scene videos for each participant and the potential for sudden movements and unusual viewpoints of the AOIs. Accurate annotation of mobile eye tracking data is therefore a challenging and time-consuming task.

Current approaches for annotating AOIs in mobile eye tracking data include manual annotation by one or more annotators [15, 30], the use of fiducial markers attached to target stimuli [2, 17, 21, 36], or the use of computer vision models [3, 7, 8, 13, 14, 16, 20, 22, 26, 28–30, 33]. However, each of these approaches has its own limitations. Manual annotation is tedious and susceptible to errors, the use of fiducial markers is obtrusive and not suitable for uninstrumented environments, and computer vision models may be limited by their reliance on pre-trained models that cannot be adapted to a specific target domain or a lack of flexibility with no possibility to adapt the model during the annotation process [3, 7, 8, 13, 14, 16, 20, 22, 26, 28–30, 33].

To address these limitations, we propose a novel interactive machine learning approach for the semi-automatic annotation of AOIs in mobile eye tracking data using a combination of interactive video object segmentation and 3D reconstruction. A high-level overview of how the proposed interaction system is expected to work is shown in Figure 1. The eye tracking recordings displayed in the figure are from a mobile eye tracking dataset collected at Saarland University for the purpose of investigating the effects of augmented reality (AR) support in a laboratory-based learning scenario [1, preregsitered at Open Science Framework].

2 RELATED WORK

Interactive video object segmentation is a method for segmenting and tracking objects of interest in a video. It involves using user input to guide the segmentation process and improve the accuracy of the resulting object masks. In the context of semi-automatic fixation-to-AOI mapping in mobile eye tracking studies, interactive video object segmentation could be used to efficiently annotate AOIs in the video by allowing the annotator to provide labels for a sequence of frames marked with fixation positions, and using the fixations to estimate and propagate the mask proposal of the AOI.

However, interactive video object segmentation has its limitations. It can struggle to re-identify highly similar objects, and can be sensitive to sudden camera movements, in such cases requiring a large amount of user input [5, 6, 11, 31]. It may also only provide reliable results under certain constraints, such as when the camera is static [9, 12]. To overcome these limitations, we suggest using 3D scene reconstruction in addition to interactive video object segmentation.

3D scene reconstruction is a process for creating a 3D model of a real-world environment or scene from images or video. It involves extracting geometric and semantic information from the images or video and using this information to build a 3D representation of the scene. There are various approaches to reconstruct 3D scenes from posed RGB-D images [18], some that only require the existence of depth or posed images besides RGB [19, 24, 34, 37], and a handful that can work with monocular RGB videos only [4, 10, 27, 32].

3D scene reconstruction can address the issues with interactive video object segmentation, such as re-identification, unusual viewpoints, and spatial and temporal consistency. By reconstructing the visual scene in 3D, we can map the AOI segments to 3D, minimizing the impacts of these problems by splitting the video into shorter segmentation tasks and aggregating the predicted AOI segments in the 3D scene. The resulting 3D segmentation of the AOI can then provide label suggestions for the rest of the video, streamlining the annotation process. We propose an IML framework that combines these technologies to tackle the limitations of current approaches for annotating AOIs in mobile eye tracking videos.

3 INTERACTIVE MOBILE EYE TRACKING ANNOTATION

Interactive Mobile Eye Tracking Annotation (IMETA) is a novel approach for semi-automatic fixation-to-AOI mapping in videos recorded by mobile eye trackers. The proposed architecture of IMETA is shown in Figure 2. A web interface shall serve as a user interface for IMETA and the logic itself is planned to be implemented as an interactive machine learning service.

The method begins with a pre-processing step to reconstruct the 3D scene from the mobile eye tracker recordings. This step requires camera poses and depth information for each frame, which can be estimated using monocular scene reconstruction methods. If this information is already recorded by the mobile eye tracker, this step can be skipped.

Through the frontend, the annotator can label fixations and correct AOI suggestions. The annotator is presented with an image marked with fixation positions. When a new fixation is labeled, a state-of-the-art interactive video object segmentation method,

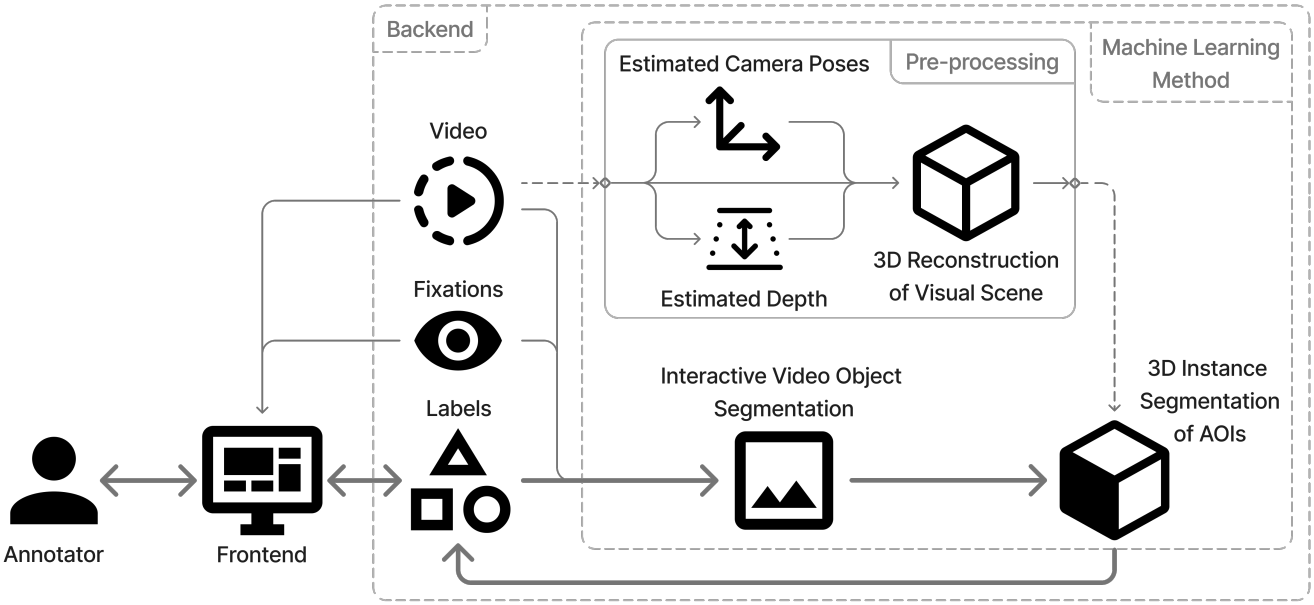

Figure 2: Proposed architecture of IMETA. It consists of a pre-processing step to reconstruct the 3D scene from the mobile eye tracker recording, an interface for interactive fixation-to-AOI mapping, an interactive video object segmentation method to estimate the mask proposal of the AOIs, and a module to map the AOI segments onto the 3D scene. The resulting 3D instance segmentation of the AOIs can then be used to generate label suggestions for each fixation. The arrows indicate the flow of data through the different components of the architecture.

called XMem [5], estimates the mask proposal for the fixation, and propagates and aggregates the masks for the duration of the fixation. These segments are then mapped onto the 3D scene to create a 3D instance segmentation of the annotated AOI (i.e., the attended object). By mapping the fixation positions onto the 3D AOI segmentation and checking their corresponding label, we can automatically label the rest of the video. The 3D segmentation can be further refined by confirming or correcting label suggestions, and by labeling additional fixations. Based on the available annotations, the accuracy of the system is calculated, and the annotation can be stopped when the desired threshold is reached. We expect that by annotating only a handful of fixation sequences, the proposed system can automatically determine the AOI labels for the rest of the video. Furthermore, given a static environment, a single annotated video could generalize for all recordings from the same environment.

4 CONCLUSION

In this paper, we proposed IMETA, a novel system for semi-automatic fixation-to-AOI mapping in videos recorded by mobile eye trackers. IMETA combines monocular 3D scene reconstruction with interactive video object segmentation to annotate AOIs. By utilizing 3D reconstruction, IMETA aims to overcome the challenges of traditional video annotation methods, such as the need for re-identification, handling unusual viewpoints, and ensuring spatial and temporal consistency. We believe that IMETA has the potential to greatly reduce annotation workload for evaluating studies that use mobile eye tracking videos.

However, the reliance on monocular 3D scene reconstruction methods may be a potential limitation, as it may not always provide accurate camera pose and depth estimates. Our future plans include using it with an AR headsets that include eye tracking capabilities or with head-mounted eye trackers equipped with RGB-D cameras, to overcome the limitations of monocular 3D reconstruction methods. The 3D reconstruction and segmentation of the visual scene could be done in real-time by the experimenter using the headset. Further, 3D scene reconstruction is typically constrained to static environments. We plan to integrate a solution to enable dynamic environment support similar to Kimera [23]. IMETA could then serve as an interactive annotation tool for annotating AOIs in mobile eye tracking studies on-the-fly. We plan to evaluate the performance of IMETA through experiments and user studies.

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