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Self-Directed Learning using Eye-Tracking: A Comparison between Wearable Head-worn and Webcam-based Technologies

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***Abstract*—The COVID-19 pandemic has accelerated our transition to an online and self-directed learning environment. In an effort to design better e-learning materials, we investigated the effectiveness of collecting psychophysiological eye-tracking data from participants in response to visual stimuli. In particular, we focused on collecting fixation data since this is closely related to human attention. Current wearable devices allow the measurement of visual data unobtrusively and in real-time, leading to new applications in wearable technology. Despite their accuracy, head-mounted eye trackers are too expensive for deployment on large-scale deployment. Therefore, we developed a low-cost, webcam-based eye tracking solution and compared its performance with a commercial head-mounted eye tracker. Four-minute lecture slides on the 3rd year electronic engineering course were presented as stimuli to eight learners for data collection. Their eye movement was collected within the pre-defined area of interest (AOI). Our results demonstrate that a low-cost webcam-based eye-tracking solution, combined with machine learning algorithms, can achieve similar accuracy to the head-worn tracker. Based on these results, learners can use the eye tracker for attention guidance. Our work also demonstrates that these webcam-based eye trackers can be scaled up and used in large classrooms to provide real-time information to instructors regarding student attention and behaviour.**

***Keywords*— Engineering Education, Eye Tracking, Wearable Device, Visualization.**

I. INTRODUCTION

Eye-tracking is one of the methods that can be used to collect psychophysiological data from participant behaviour in response to learning stimuli [1]. Instead of relying on information from the user, such data can be an objective method of obtaining gaze data and help instructors acquire accurate, real-time information from their learners. There are a variety of eye-tracking technologies available in the literature, including wearable devices and webcam-based applications. Wearable eye trackers are expensive and require additional equipment, which prevents them from being used in a large-scale setting. In contrast, webcam-based eye trackers can only record in one direction while providing a low-cost approach to monitoring eye movement patterns [2].

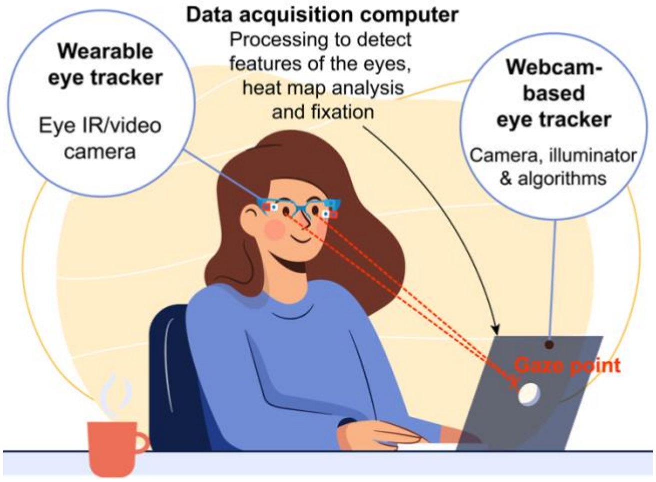

Fig. 1. The system-level architecture of wearable and webcam-based gaze aware attention monitoring systems.

Head movements can cause inaccuracy and drop tracks.

In addition to the range of wearable devices that currently exist for the learning enhancement [3], wearable eye trackers are placed and positioned on the head, enabling them to record subtle eye movements in different head movements and directions. Furthermore, the eye movement detecting cameras are embedded very close to the eyes, ensuring high accuracy. On the other hand, the main advantages of a low-cost webcam eye tracker are (1) large scale deployment in lecture theatres and classrooms, (2) remote operation from anywhere with only access to a webcam, and (3) no additional peripheral components are needed, which means overall system cost is low. Furthermore, webcam-based eye trackers offer privacy by design as the gaze tracking application is running on the personal devices of end-users and captures the 2D gaze location coordinates along with time stamps.

This work investigates and compares the performance of wearable head-worn eye trackers with webcam-based platforms (Fig. 1). This work aims at collecting fixation data due to their connection to attention. Furthermore, it also provides an exclusive prospect to develop a large-scale remote learning study to explore and evaluate the visual perception for new outlooks to enhance the instructional design of multimedia learning and teaching. We will therefore discuss the merits and demerits of wearable and webcam-based eye-tracking devices.

The main contributions of this work are:

- Developed a self-directed eye-tracking-based learning platform to support remote learning.
- Proposed a novel approach to quantify student engagement based on gaze metrics.
- Studied the main differences between wearable and webcam-based for self-directed learning.

This paper is organised as follows: Section II provides the opportunities for eye-tracking devices in education. Section III discusses the setup preparation, data collection and implementation. Section IV presents the experimental results and discussion by summarising the advantage and disadvantages of wearable and webcam-based eye-tracking devices in education. Section VI draws the conclusion and future work.

II. Eye-Tracking for Education

Eye-tracking is a process of measuring the motion or position of the eyes. The eye-tracking technology has become an invaluable tool for understanding attention, visual and human behaviours and has been found in more and more applications such as the education [4, 5]. By accurately analysing student eye movement behaviour in an online environment, Universities can improve teaching delivery and perhaps attract underrepresented students to their degree programs [6].

Eye-tracking is a very promising technology that can be used to improve remote teaching-learning. For instance, researchers are already using this technology in many psychological studies, including the attention monitoring of students. However, most of the studies use the expensive commercial-grade eye tracker with very limited scope. In fact, wearable headset devices such as eye trackers have come a long way during the past decade [3]. Researchers have investigated ways of developing wearable eye trackers for various applications, including education. Examples of commercial wearable eye-tracking devices include Pupil Core [7] and Tobii Pro [8]. Most of these modern eye-tracking devices entail a reasonably pocket-sized setup.

To improve the educational performance, there is an essential need to get feedback from students and monitor how they can follow the course contents and materials. In the traditional classroom, teachers have the flexibility to observe the visual behaviour of students during lectures. This visual feedback assists the teacher to judge student engagement levels. However, this visual feedback is not available in particular; moving from on-campus instruction to e-learning poses a significant challenge for the teacher to gauge the student attention level. The availability of a webcam on the student end provides a unique opportunity to capture the gaze movement on a large scale without any additional cost. Using such eye-tracking, different parameters such as attention and psychophysiological data can be analysed for enhancing course materials in response to learning stimuli.

III. Setup Preparation and Data Collection

Before beginning the data collection, it requires to study the dedicated setups for both wearable and webcam-based eye trackers. Learners are seated at a predefined distance of 70 cm away from a laptop screen [9]. A Pupil Core headset is worn to the learner's head to track and collect eye movements data. Afterwards, we need to calibrate and adjust the learner's eyes within the eye tracker setup software and save their User Profile. The wearable eye tracker does not need to re-calibrate every time, while in the case of webcam-based, we require to re-calibrate. Furthermore, the webcam-based solution is more sensitive to head movement and has a low sample rate due to the limitation of the webcam. This Section elaborates on different setup preparation steps, calibration procedures and data collections, as shown in Fig. 2.

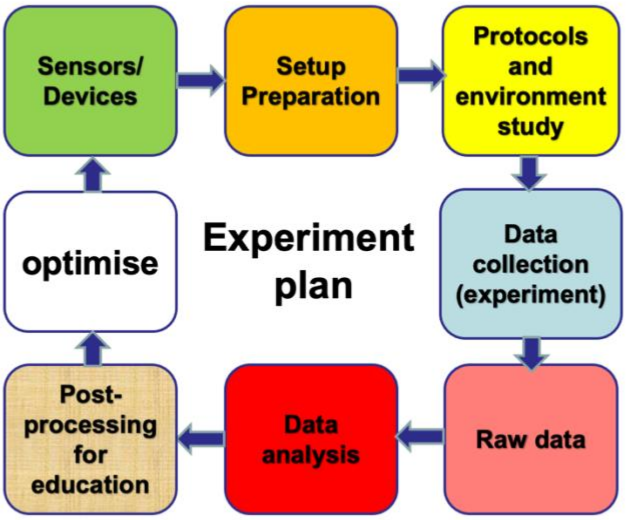

Fig. 2. The steps for data collection and experiment plan.

A. *Setup initialisation*

By connecting the Pupil Core eye tracker to the laptop and running the pupil capture application, the device is ready to use. The data collection is conducted individually for each participant for both eye tracker and webcam. A short introduction is given before the participant is asked to participate in the experiment. The wearable eye tracker is equipped with two different types of cameras: a world camera and one infrared camera per eye. The world camera records the participant's field of vision, while the infrared camera can capture the eye movements.

For collecting raw data, a four-minute lecture was prepared using PowerPoint slides that were adapted from [10]. Eight learners anticipated the experiment by observing the lecture slides.

For Pupil core, surface tracker plugins within every page to track area of interest (AOI) based on text or image AprilTag Markers [11]. Every defined surface was automatically saved in a file called the pupil capture settings directory. The primary step in the attention monitoring setup is to run the interface using Pupil Core applications on the participant computer. Once the application was opened, it initialises the webcam after obtaining consent from the participant. After headset device initialisation, the world camera appears on the screen, and live face and gaze detection are run, as shown in Fig. 3. Afterwards, the eye infrared cameras commence the face and gaze detection. On the other hand, we developed a webcam-based eye-tracking application using the open-source library Webgazer.js and perform the analysis on raw data to obtain the gaze metric using PyGaze library [12]. The webcam-based solution is an end-to-end application named as EXECUTE (Exploring Eye Tracking Data to Support E-learning.) that captures and analysis the gaze data.

B. Calibration procedure

The Pupil Core eye tracker has two software (Pupil Capture and Pupil Player). For the initialisation, after wearing the eye tracker, the device can be adjusted according to the participant's head form to provide a comfortable fit and accurate measurements. The word camera records the person's field of vision, and two infrared cameras do the pupil detection and eye movement. Pupil Core's algorithms automatically detect the learner's pupil. It runs two detection pipelines in parallel, the 2D and the 3D pupil detection.

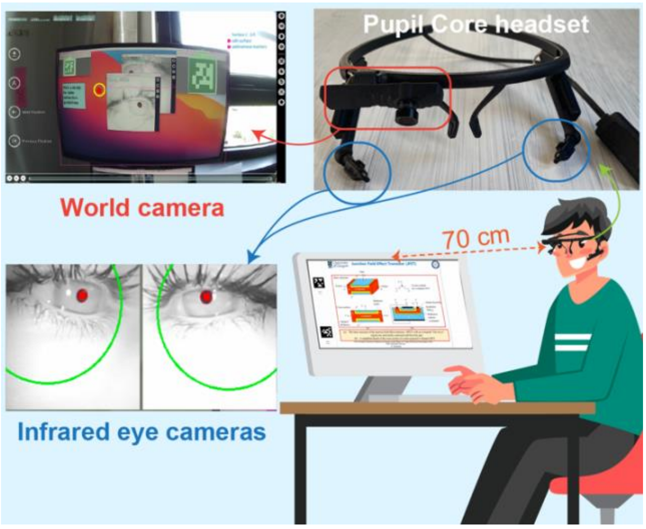

Fig. 3. The experimental setup for the wearable eye-tracking device. It shows the Pupil Core headset (top right) with its view from the world camera (top left) and pupil detector camera (down left).

After ensuring that the participant's pupil is clearly detected and tracked and that the headset is comfortable for the participant, we can start the calibration process.

Screen marker calibration choreography requires participants to look at a certain point on the screen. During the calibration procedure, the learners are asked to fixate a list of target or reference locations within the world camera's field of vision. The Pupil Core software collects these reference locations and pupil data during the calibration. Subsequently, it correlates them in time and calculates a mapping function used to estimate the gaze for future pupil data.

For the webcam-based eye-tracking approach, once the initial face and gaze detection is done, the subsequent step is to perform the calibration and validation process. The calibration is performed to evaluate the position of the gaze point on the screen when engaging with visual stimuli. In this step, 30 points appear from the top left to the bottom right corner of the screen on a predefined location. The learners calibrate the system by clicking and seeing the point simultaneously and evaluate the gaze coordinate location using ridge regression. When the calibration process is done, four-point validation is carried out to check the accuracy of the real-time gaze estimation. For this purpose, four points appear randomly on the screen for a short period of time, and the participant just stares at the dots and measure the accuracy based on the pre-defined AOI.

C. Raw data collection

The collected data include fixation on the surface, gaze position on the surface, heatmap on the surface and surface gaze distribution. The collected fixation data provides information such as world timestamp, world index fixation id, start timestamp duration, dispersion norm positions of *x* and *y*, as well as *x*, scaled and *y* scaled.

For the webcam-based eye-tracking approach, following the calibration and validation process, the next step is the collection of raw data samples which are the 2D screen coordinates of gaze point along with the time stamp. The sampling rate achieved using the webcam interface is 30 samples per second. Eight learners (students) from our research group were asked to watch short introductory stimuli to collect the data set. The video lecture consists of various slides with three pre-defined AOI per slide to simplify the process of data filtering and gaze feature extraction.

D. Data processing and feature extraction

In the case of webcam-based, the data processing is performed manually to get fixation and heatmap analysis. In this regard, the 2D raw gaze points were adapted into eye movements using a dispersion-based filter with an open-source tool, PyGaze [12].

However, with the wearable eye tracker, there is no need for manual steps for the data processing for the fixation. The AOIs are defined in advance for each presentation slide using AprilTags in the stimuli, as shown in Fig. 4.

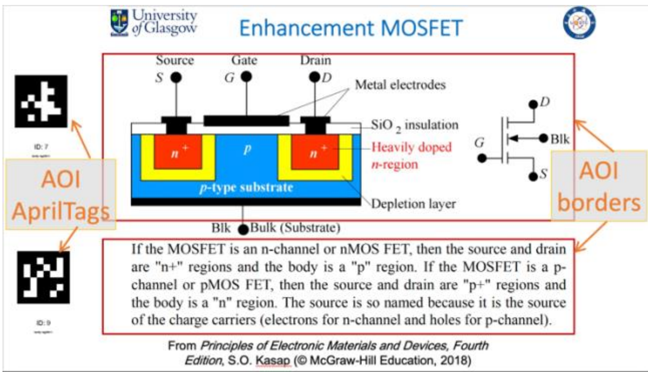

Fig. 4. The predefined AOIs using AprilTags in the wearable eye tracker. PowerPoint slides were adapted from [10].

IV. EXPERIMENTAL RESULTS

The experiments were conducted for both wearable and webcam-based eye-tracking devices. The gaze plots and heatmaps have been used to visualise the collected data to communicate the important aspects of visual behaviour clearly. Fig. 5 shows the field of vision from the learner's headsets after it has been moved to the Pupil Capture application. Heatmaps of gaze data on the slide.

The experiments were also analysed and prepared using heatmaps features representing great data visualisation, as shown in Fig. 6, for wearable and webcam-based eye-tracking devices. In the heatmaps achieved from both devices on eight learners, their visual attention seems to be more drawn towards the text written down the page; however, the Pupil core eye tracker has collected more detailed data covering a wider area of the page. The webcam-based solution has low sampling as a result, the details captured were low as compared to the wearable device. However, the information was good enough for detailed analysis.

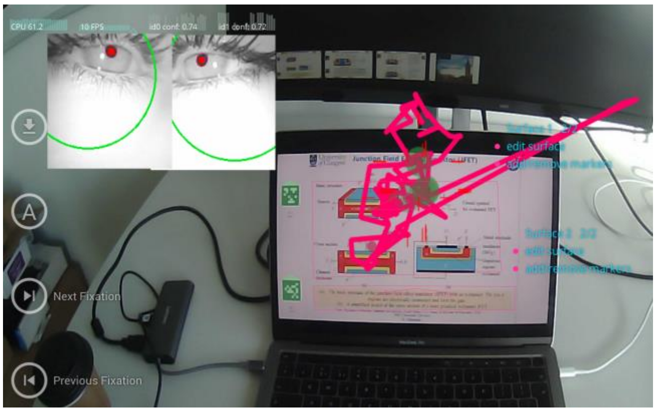

Fig. 5. The gaze plot and fixation using the wearable eye-tracking device.

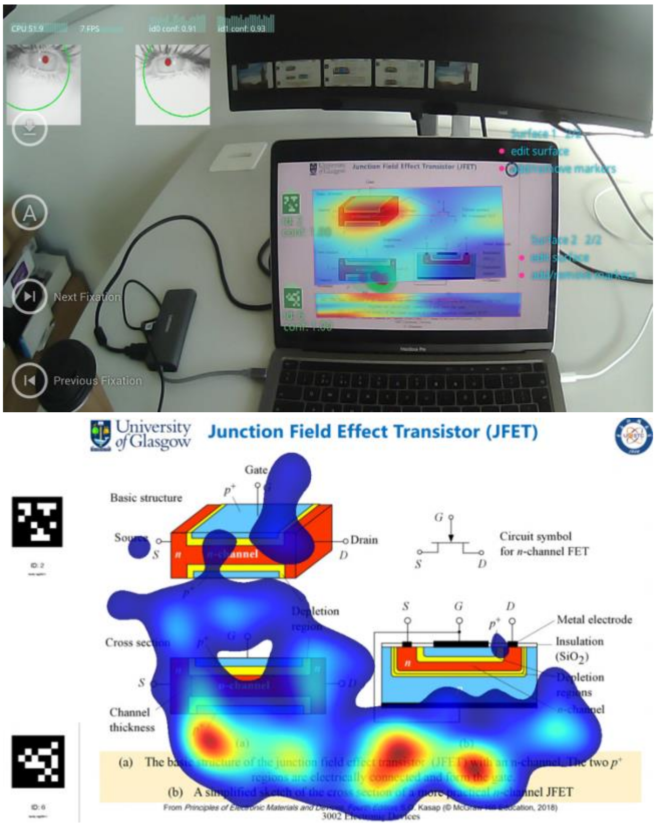

Fig. 6. The heatmap for wearable eye tracker (top) and webcam-based (bottom).

V. Conclusion

This paper describes a comparison between wearable and webcam-based eye-tracking technologies and their use in education and learning practice. The deployment of eye-tracking is yet to be implemented in educational environments and is promising new opportunities to enhance student engagement and learners-teacher interaction. The goal of this study is to introduce a comparison between wearable eye-tracking technologies and web bases eye-tracking applications to reduce distortion, improve students' attention and enable the improvement of education. In this study, we have run the experiments on eight learners in our research group in two different wearable and web-based setups. As Future work, based on our results, we aim to implement a self-directed learning platform to provide a wide head movement flexibility with wearable head-worn eye-tracking devices for attention guiding function. This platform can inform learners about the ignored or skipped parts from the learning material as well as provide indications about tricky sections.

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