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Taming Cyclops: Mixed Reality Head-Mounted Displays as Laser Safety Goggles for Advanced Optics Laboratories

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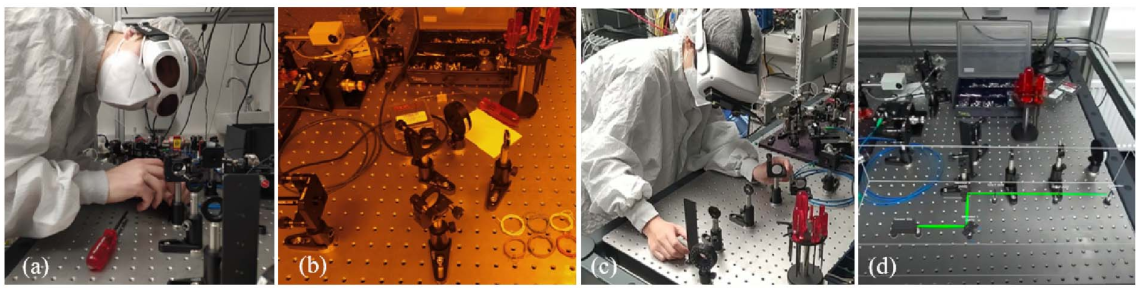

Figure 1: (a) A user operating an optics setup wearing conventional laser safety goggles, and (b) view through the conventional laser safety goggles with 70% of visible light filtered. (c) A user aligning optical setup wearing a VST-HMD, and (d) view from the VST-HMD prototype with a virtual 3D model of the optics setup.

Abstract

In this poster paper, we present a mixed reality application for laser eye protection based on a video see-through head-mounted display. With our setup, laser lab users perceive the real environment through the head-mounted display, using it as a substitute for laser safety goggles required by health and safety regulations. We designed and evaluated our prototype with a human-centered computing approach at the Deutsches Elektronen-Synchrotron where there exists some of the most advanced and extreme optics laboratory working conditions. We demonstrated that virtual reality headsets can be an attractive future alternative to conventional laser safety goggles.

Index Terms: Mixed Reality—Laser Safety—Video See-through Head-mounted Display—Human-Centered Computing;

1 Introduction

Without proper eye protection, operating high-power lasers is a dangerous activity that could cause permanent damages to human eyes. Working in laser laboratories requires wearing specialized laser safety goggles to protect users' eyes from laser radiation. Conventional laser safety goggles utilize optical filters to reduce the intensity of the incoming laser light. The wavelengths filtered and the strength of the filters depend on the wavelength and power class of the laser. This safety measure reduces the users' view of color and visibility of the environment, as shown in Figure 1 (b). In advanced optical laboratories with powerful Class III and IV lasers operating at a wide range of wavelengths, users must wear broad-band laser safety goggles which could filter up to 99 % of the visible light [1], making in-situ laboratory tasks like optical alignment and laser control impossible.

Past research in using video see-through head-mounted display (VST-HMD) as an alternative welding helmet demonstrated that virtual reality (VR) headsets can be used as an eye protector while providing task-related mixed reality (MR) augmentation [4]. Similarly, VST-HMD could also be used as a laser safety goggle, allowing users to have a clear view of the environment without visibility reduction and have full-band protection at the same time [5]. However, the prototype from previous work that is based on a cardboard viewer and smartphone [5] has limited functionalities and its' usability and efficiency were not supported by a user study. In this work in collaboration with the laser science and technology group (FS-LA) at the Deutsche Elektronen Synchrotron (DESY) [1], we followed a human-centered design approach [3], aiming to build a more usable and reliable prototype based on modern VR hardware and software.

2 Prototype Development

2.1 Field Studies

In order to better understand how researchers currently work under extreme optics laboratory conditions, we performed requirement analysis through several field studies. We visited multiple optics laboratories at DESY, where there are many high-power class IV lasers with various wavelengths ranging from infrared to ultraviolet. Following are our observations from the field studies.

Challenging and Hazardous Working Conditions Due to the usage of a wide range of high-power lasers, users at advanced laser laboratories must wear broad-band laser safety goggles. Such laser safety goggles also greatly reduce the visibility of color and the perceived brightness of the environment. Nonetheless, with less than 10 % of the normal visible light, lab users need to perform high precision tasks such as fine-tuning of optical components, contaminated mirrors or lenses replacement, laser alignment, and even

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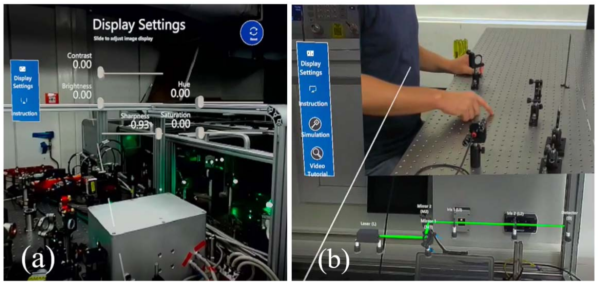

Figure 2: (a) Screenshot of viewing infrared laser radiation (the green reflected light) through VST-HMD at the accelerator injector laser lab at DESY, and (b) Screenshot of using augmented features such as CAD model and video player for optical operation tasks.

optical fiber fusion splicing [2]. All of the tasks need to be performed in a cleanroom environment, and with insufficient visibility of the environment, these high-precision tasks could cause large viewing stress to the eyes. Moreover, when the lasers operate at wavelengths beyond the visible spectrum, devices like detection cards and infrared viewers must be utilized in order to manually align the laser beam paths. The usage of these devices leads to a loss of ergonomics and workflow, and creates additional hazards.

Complex Optical Operation Workflows Advanced optics laboratories are consist of complex optical setups. Correct manipulation and operation of such setups often involve understanding a system with a large number of optical components. Even for experienced users, the operation of complex optics setups relies on lab manuals, CAD drawings of the setups, and instruction videos. Retrieving and interacting with such information based on the conventional human-computer interaction (HCI) methods in optics laboratories are challenging. Additionally, most lasers are operated with a combination of software controls and, simultaneously, manual mechanical controls. The awkward positioning of screens used for real-time feedback and the loss of color information while using the conventional laser safety goggles (for example, when looking at laser camera recordings with color-gradient of the laser beam intensity distribution) leads to poor workflow.

Limits of Conventional Laser Safety Goggles As cutting-edge optics laboratories need to include more and more lasers with various wavelengths, it becomes increasingly difficult for laboratories to find appropriate laser safety goggles. When the requirements of experiments change so that researchers need to use a laser with a different wavelength, the safety program of the laboratory has to be re-evaluated and sometimes different laser safety goggles have to be selected and purchased. Not only is this time-consuming and expensive, but also conventional laser safety goggles could not meet all the demands of advanced optics laboratories for full-band protection, as this would require filtering all the visible light.

2.2 Prototype Design

VST-HMD can help address many of the challenges we identified through the field studies. We designed a system that enables users to have high-performance MR experiences with various functionalities while the VST-HMD serves as a full-band laser safety goggles. The system was built using a stereoscopic 3D camera, ZED Mini[3], mounted on an Oculus Quest 2[4] to create high-resolution RGBD video pass-through experiences. The camera was connected to an Alienware m17 R2 laptop with an NVIDIA GeForce RTX 2080 graphics computation unit (GPU). Camera data was transmitted from the ZED Mini camera to the laptop via a high-speed type C USB3 cable. VR content was streamed from the laptop to the VR headset via an Asu AX1800 WiFi6 5G router.

Furthermore, we developed software features such as a display setting menu where users can adjust the image properties of the pass-through video, a video player for viewing operation instruction, and a CAD model drawing display of optical setups to simplify the complex optics operation workflow. Infrared laser radiation is also visible through the HMD, as shown in Figure 2. Our software was developed using the Unity game engine, version 2019.4.29f1. We used the ZED Unity Plugin, version 3.5.2, to connect the ZED Mini camera to Unity. We used the Oculus Unity integration SDK version 33 and the Microsoft Mixed Reality Toolkit (MRTK) version 2.7.2 to develop MR interactions and 3D user interfaces (3DUIs).

3 Prototype Evaluation

We evaluated our prototype through within-subject user studies, where users examine the usability of the VST-HMD via a visibility test and an optical operation task to align a safe and low-power laser. The tasks were designed together with laser experts at DESY to evaluate how well can users work with our prototype in practice. We also collected users' feedbacks with regards to the perceived safety, advantages, and limitations of our prototype through a semi-structured post-study user interview. A total of 18 participants, including 14 laser and optics experts have evaluated our prototype. The current prototype reached a mean system usability scale (SUS) [2] score of 77.906, with users having slight to no motion sickness. Due to current limitations of the prototype such as latency and cable connection, the majority of the participants preferred to have both the VST-HMD and the conventional laser safety goggles as an eye protection option, 4 participants preferred the current prototype, and 4 participants preferred only the conventional laser safety goggles.

4 Conclusion

In this poster paper, we demonstrated that a VST-HMD can be used as a future alternative to the conventional laser safety goggles to improve the working conditions of users at advanced optics laboratories. Using VST-HMD as advanced laser safety goggles will become increasingly important, not only for better eye protection but also for better user experiences and more intuitive HCI. However, a few limitations such as cable connection, video resolution, and video latency need to be overcome before a VST-HMD can replace the conventional laser safety goggles. Nonetheless, our work could inspire many future works in this application domain such as augmented reality applications for laser operation and novel VST-HMD with hyper-spectral vision.

Acknowledgments

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