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Application of Virtual Reality (VR) Technology in the Assessment of Eye Hazards Caused by Laser Radiation And Selection of Individual Eye Protection Equipment

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Abstract. This paper discusses the issues of eye protection against harmful laser radiation and provides an example of the use of virtual reality (VR) technology for laser safety training. A newly developed VR application dedicated to the selection of protective eyewear in the context of identified real-life threats caused by harmful high-energy optical radiation is presented. The VR application for selecting protective eyewear to operate different types of lasers presented in this paper demonstrates how VR technology can be used to better illustrate the issues involved in assessing eye risks from laser radiation. The application was developed in the Unity 3D environment based on a scenario developed by the authors.

Keywords: VR technology, laser radiation, optical radiation hazards, eye protection equipment

1. INTRODUCTION

Virtual reality (VR) technology mirrors the real world. After putting on the VR goggles, the user is able to interact with the elements of the designed virtual reality. The technology can also be used to support traditional teaching methods. At the moment, VR technology is only used as a supporting element to forms considered traditional. The primary, as commonly perceived, use of VR technology is entertainment (mainly computer games). With the development of VR technology, the presentation of reality in the virtual world is becoming more and more attractive in perception. It has already become not only an area of interest for computer game enthusiasts, but also for people developing programs and educational tools [1]. Thus, users of VR technology now include not only computer gamers but also learners. With VR, the learner has the ability to navigate and interact with experiences in the same way they would in the real world. They may dynamically interact with the virtual world not only to change its elements, but to learn the effects of those actions. The image surrounds the viewer on all sides, adding to the sense of realism and engagement. VR applications usually have their own voiceover that guides the learner through the virtually created world. With VR, it is possible, for example, to learn how to behave in dangerous situations without suffering health and life consequences [2]. There is much research on the effectiveness of using VR technology as a teaching resource. In their study, researchers from the University of Maryland prove the thesis that people remember information better when it is presented to them in virtual reality than conveyed using a two-dimensional image generated on the screen of a personal computer, smartphone or tablet [3]. Research in this area (training effectiveness) is also conducted by the team of A. Grabowski [4]. Virtual reality technology has also found applications in safety management in the work environment [5].

When writing about the advantages of VR as an innovative teaching medium, one cannot ignore its disadvantages as well. Currently, one of the biggest drawbacks is the lack of effective solutions to effectively integrate visual stimuli with the body, mainly with the sense of balance. If the user of a VR application is introduced to motion, especially involving some acceleration, the image begins to move, but the labyrinth does not redirect the signal to the brain. In reality, the person is sitting in a chair wearing goggles and the position of the goggles does not change. As a result of this action, a cognitive error is created, which can result in the VR user developing motion sickness. This is probably also related to the still rather imperfect equipment for participating in the virtual world. Another barrier to the widespread use of VR is the high cost of purchasing and manufacturing equipment to enable its professional use, as well as the costly and time-consuming programming of applications. Nevertheless, it can be predicted that as this technology becomes more widespread, the costs associated with its implementation will decrease.

VR also requires a radical selection of the information that reaches the viewer, and the tools for this selection are still being developed. A summary of the most important advantages and disadvantages of using VR in the educational process according to Mikolajczyk [6] is presented in Table 1.

Table 1. Advantages and disadvantages of using VR in education

Advantages	**Disadvantages**
Total immersion in the learning process to foster engagement.	Possible motion sickness during use.
Ability to analyse data on user behaviour/actions on an ongoing basis.	Uncomfortable equipment making immersion difficult for the user.
High scalability of teaching activities.	High manufacturing and purchasing costs for both hardware and software.
Can be used anywhere, any time.	Lack of tools to radically select the information reaching the user.
An attractive, modern form of education.	Little systemic support, need to find teaching solutions on their own.

2. EYE HAZARDS FROM LASER RADIATION

Laser radiation, is in optical radiation that can be emitted in the wavelength range from ultraviolet (from about 180 nm) to far infrared (up to about 1,000,000 nm). Such characteristics of laser radiation as monochromaticity, coherence, and directionality make the irradiance (E, expressed in W/m^2) likely to be very high. Similarly, the irradiance values (H, expressed in J/m^2), that is, the amount of energy carried by them, even in relatively short pulses, can also have very large values. Large, in this case, means those that can cause eye or skin injuries if a person is inadvertently exposed to laser radiation.

The effects of high-energy laser radiation on the eyes or skin can be divided into two main types: thermal and photochemical. When eyes are exposed to laser radiation, thermal effects include corneal burns and damage or burns to the retina. The thermal effects of laser radiation on the skin include reddening or burning, and if the safe values are significantly exceeded, even tissue coagulation and skin charring. Photochemical effects, resulting from the interaction of laser radiation with the eye, can manifest as cataracts or inflammation of the eye's cornea and conjunctiva, as well as damage or burns to the retina, among other things. Exposure of the eye to laser radiation, the hazard of which is photochemical in nature, can also cause eye cancer. The photochemical effects of laser radiation on the skin include skin redness, burns, pigmentation or photoageing [7].

A particular hazard to the eyes is the radiation emitted from lasers whose beam can be manipulated manually (so-called handheld lasers). Data on reported eye injuries caused by handheld laser-emitted beams were obtained using a questionnaire developed and made available by the Canadian Ophthalmological Society and the Canadian Association of Optometrists. Verified data were obtained from 903 respondents (263 ophthalmologists; 646 optometrists), of whom 157 (17.4%) reported that they had encountered at least one handheld laser eye injury [8].

The Swedish Radiation Safety Authority (SSM) has published a report on eye damage from everyday handheld lasers [9]. The quality of lasers varies and they are often mislabelled with output powers above their declared value in the specification, in which case they inadvertently emit near-infrared wavelengths. The report shows that the following health effects occurred as a result of 34 reported eye incidents involving lasers emitting green, red and infrared radiation:

- ≤ 5 mW laser, red – transient loss of central vision;
- ≤ 5 mW laser, green – destruction of the retinal pigment epithelium (RPE);
- ≤ 7 mW laser, green – visible RPE damage;
- ≤ 20 mW laser, green – retinal oedema and haemorrhage;
- < 5 mW IR-A laser (wavelength in the range of 825–880 nm) – oedema and focal retinal detachment.

3. EYE PROTECTION AGAINST LASER RADIATION

According to current legislation, laser radiation does not have to be considered as a factor harmful to health when operating class 1, 1M, 2 or 3R lasers in accordance with the requirements specified by the manufacturer and when operating class 3B and 4 lasers to which safety measures have been applied to classify these devices as class 1 [10]. However, laser equipment is also used in such a way that it is not possible to completely eliminate radiation (especially scattered radiation) to which humans may be uncontrollably exposed. This includes jobs such as laser welding or cosmetology, physiotherapy and other medical treatments using laser radiation. In medical applications, laser radiation with doses well above the MPE is used in an evident manner, when it is necessary to obtain a specific therapeutic effect by deliberately affecting the patient’s skin. This does not mean, however, that in such cases laser radiation should not be considered harmful to health. In this example, the knowledge of MPE values is also necessary to determine the designation (degree of protection) of filters used in glasses or goggles that protect against laser radiation. It is imperative that this type of personal protective equipment be used by both staff and patients. The spectral optical density of filters that protect against laser radiation of a given wavelength is determined from the following formula:

$$\mathrm{OD}_\lambda = \log_{10}\frac{\mathrm{H}_0}{\mathrm{MDE}}, \tag{1}$$

where: OD_λ – spectral optical density of the laser protection filter,
H_0 – expected exposure level of the unprotected eye,
MPE – maximum permissible exposure.

It is clear from formula (1) that, when the eye is at risk from exposure to laser radiation under conditions where eye protection in the form of laser protective glasses or goggles is required, it is necessary to know the irradiance or irradiance under conditions of actual exposure, as well as the MPE value for the laser radiation presenting a potential hazard. Without knowing these values, it is not possible to correctly determine the designation (degree of protection) of the laser radiation protection filters required under the given conditions. Fig. 6 shows a schematic diagram of how to determine the marking to be placed on laser protective eyewear.

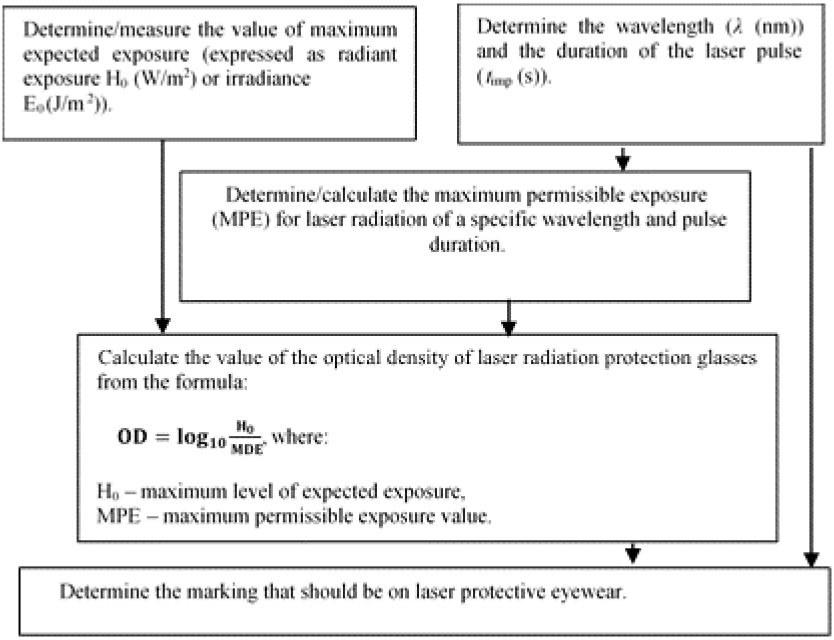


Fig. 1. Procedure diagram for determining the marking to be placed on laser radiation protective glasses (Central Institute for Labour Protection – National Research Institute)

When MPE values are exceeded, the employer is required to zone off such areas and restrict access if technically possible [11]. It is also necessary to inform employees of the fact that MPE values are exceeded at the sites in question and of the potential risks involved.

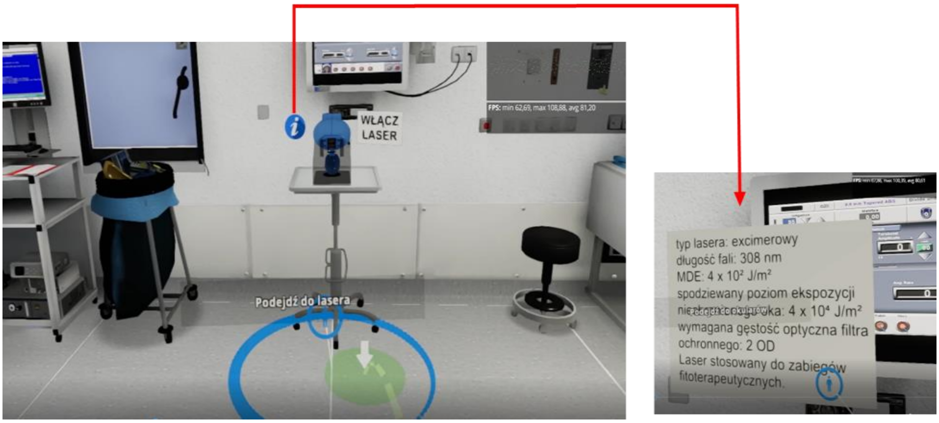
This information includes, among other things, the causes of diseases caused by exposure to optical radiation, their symptoms and methods of detection (including preventive medical examinations).

4. VR APPLICATION – SELECTING PROTECTIVE EYEWEAR

The designed simulation involves selecting eyewear that protect against laser radiation emitted from a device that is approached by a person participating in the experiment~~.~~ The person is immersed in an environment containing three medical lasers and a set of 10 pairs of protective eyewear. The activities that a simulation participant performs can be divided into four major phases:

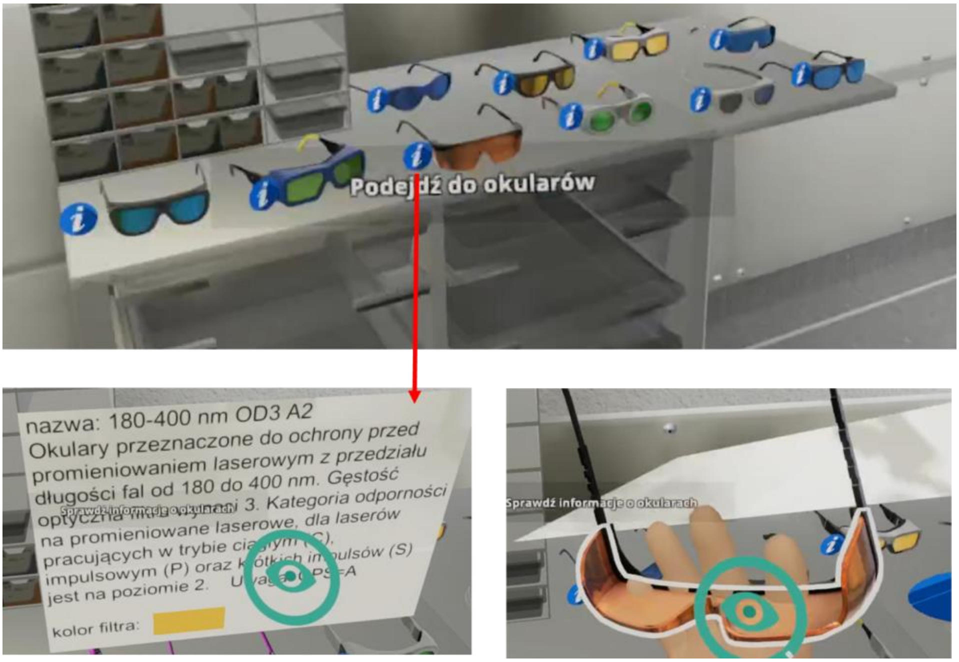
1. Entering the medical office, which houses three lasers. Reading laser information. Selecting the laser for which the protective eyewear will be selected.
2. Walking up to the laser protection eyewear area. Reading protective eyewear information. Selecting protective eyewear for the previously selected laser.
3. Walking up to the laser selected in phase 1 with the eyewear selected in phase 2. Checking whether the eyewear was selected correctly.
4. Returning to the protective eyewear area (if the glasses have not been properly fitted). Re-reading protective eyewear information. Re-selecting the protective eyewear for the previously selected laser and proceeding to phase 2.

Figures 2 through 4 show screenshots of the activities performed in the phases listed above.



typ lasera: excimerowy
długość fali: 308 nm
MDE: 4 x 10² J/m²
spodziewany poziom ekspozycji nie[illegible] oka: 4 x 10⁴ J/m²
wymagana gęstość optyczna filtra ochronnego: 2 OD
Laser stosowany do zabiegów fitoterapeutycznych.

Fig. 2. Entering the surgery, exploring the surroundings and the lasers.



nazwa: 180-400 nm OD3 A2
Okulary przeznaczone do ochrony przed promieniowaniem laserowym z przedziału długości fal od 180 do 400 nm. Gęstość optyczna filtra wynosi 3. Kategoria odporności na promieniowane laserowe, dla laserów pracujących w trybie ciągłym (C), impulsowym (P) oraz krótkich impulsów (S) jest na poziomie 2. Uwaga: CPS=A
kolor filtra:

Fig. 3. Reading protective eyewear information and putting on glasses.

ziom ekspozycji
oka: 4 x 10^4 J/m²
tość optyczna filtra
OD
ny do zabiegów
znych.

Fig. 4. Verifying the correct selection of laser protective eyewear.

From the figures shown above, it can be seen that the information that can be obtained about the lasers and protective eyewear is limited to the data necessary for proper selection of eye protection. In the case of the lasers, these are such data as:

- wavelength of the emitted radiation,
- pulse duration,

- maximum permissible exposure (MPE) for radiation emitted by the laser,
- required optical density (OD) of the protective filter and the area of laser application.

The maximum permissible exposure and optical density were calculated for a given laser according to currently applicable principles [12]. It is not the task of the simulation participant to calculate these values, which, depending on the emitted wavelength and the pulse duration, can be expressed by advanced mathematical formulas, and knowledge of empirically determined correlation coefficients is necessary for the calculation [7]. The participant immersed in virtual reality can read the necessary laser data, which he or she must then correlate with the information on the protective eyewear. Protective eyewear information also includes data on the wavelength or wavelength range and the mode of operation of the laser(s) for which it is intended.

5. DISCUSSION

The designed scenario of tasks to be performed by the participant focusses on very simple and basic activities. The message refers only to the most important information and its physical use. By correlating laser and eyewear information, the user makes a selection of appropriate eye protection. This simple simulation teaches the basic knowledge about lasers and eyewear and also enables the participants to make the correct choice of eyewear in a controlled manner without consequences.

Despite the requirements imposed on laser manufacturers regarding safety information, many laser devices, especially handheld lasers, do not provide information that clearly informs users about the hazards associated with the emitted radiation. There is also no clear information about the correct markings for protective eyewear. A quick look at the wide range of lasers on sale online is enough to see that the offered lasers are often only labelled with information such as: '*high power – use protective eyewear*.' However, there is not even the slightest mention of what the '*high power*' means or how to select the protective eyewear. The information that protective eyewear should be used is merely signalling a problem but does not solve it in any way. It is extremely disturbing that lasers with power/energy values well above the MPE are available without reliable information about the risks involved. Very often, the only information that is available is that of the laser class. Four classes are generally defined (1, 2, 3R, 3B and 4) [13]. Class 1 lasers are eye-safe lasers. Within this class, a distinction is made between Class 1M (a higher risk, where the beam can be observed through such devices as binoculars or other instruments of so-called telescopic optics) and Class 1C (for medical applications only). Class 2 lasers are safe for temporary exposure. This should be understood to mean that the aversive reflexes of the eyes significantly reduce or eliminate the risk of optical damage.

Class 2 also includes Class 2M (telescopic optics, binoculars). In the case of Class 1 (safe) and Class 2 (safe for temporary exposure) lasers, the user is therefore relatively aware of the risks arising from potential eye exposure to radiation from lasers falling into these classes. Many more doubts arise with higher grade lasers. Class 3R lasers are described as relatively low risk. The description of this class further states that in most cases the risk of injury is rather low. Such a statement may raise many questions. The section on eye protection against laser radiation cites the results of a study showing that for a red laser of less than 5 mW (lasers of this power can be classified as 3R), destruction of the retinal pigment epithelium was found, and for a red laser of similar power there was a transient loss of central vision. Users of 3R lasers, which are described as typically hazardous if the radiation interacts with the eye, may have similar interpretive concerns. The definition of Class 4 lasers no longer causes such ambiguity in interpretation, as such lasers are defined as high risk. They are also dangerous to the eyes and skin when interacting with diffuse radiation.

The discussed ambiguities in the interpretation of the effects of laser radiation on the human eye confirm the importance of proper selection of protective eyewear. In laser safety training, the issue of selecting protective eyewear for actual laser radiation hazards is one of the most important elements. The principles of this selection should be clearly and comprehensibly communicated to trainees. Due to the relatively advanced mathematical tools for determining the parameters necessary to calculate the required level of protection, this very important element of training is treated marginally by trainees. A common misconception is that the supplier of the laser equipment is also required to provide properly selected protective eyewear. Unfortunately, this is not always the case. The incorporation of elements of virtual reality technology into training for the assessment of eye risks from laser radiation and the selection of protective eyewear can significantly improve the quality of training and, most importantly, contribute to a better understanding by trainees of the correct selection principles.

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Zastosowanie technologii rzeczywistości wirtualnej (VR) w ocenie zagrożeń oczu wywołanych promieniowaniem laserowym i doborze środków ochrony indywidualnej oczu

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Streszczenie. W artykule omówiono zagadnienia ochrony oczu przed szkodliwym promieniowaniem laserowym oraz przedstawiono przykład zastosowania technologii rzeczywistości wirtualnej (VR) do szkoleń w zakresie bezpieczeństwa przy obsłudze laserów. Zaprezentowano autorską aplikację VR dedykowaną do doboru okularów ochronnych wobec zidentyfikowanych rzeczywistych zagrożeń wywołanych szkodliwym, wysokoenergetycznym promieniowaniem optycznym. Przedstawiona w artykule aplikacja VR doboru okularów ochronnych do obsługi różnego typu laserów pokazuje sposób, w jaki technologię VR można wykorzystać dla lepszego zobrazowania zagadnień związanych z oceną zagrożeń oczu wywołanych promieniowaniem laserowym. Aplikacja została opracowana w środowisku Unity 3D na podstawie opracowanego przez autorów scenariusza.

Słowa kluczowe: technologia VR, promieniowanie laserowe, zagrożenia promieniowaniem optycznym, środki ochrony indywidualnej oczu