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Use of VR/AR techniques in Remote Laboratories: a systematic review

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***Keywords*— Virtual reality, augmented reality, remote laboratories.**

***Abstract*—** *Educational technology is now a necessity for teaching and learning and this necessity became even bigger with the pandemic of COVID-19, where many students can't access the facilities of their educational centers. Virtual Reality (VR), Augmented Reality (AR) and Remote Laboratories are great trends for the future of education. While remote laboratories bring the opportunity of access to experimentation that many students don't have, VR/AR provides an immersion that completely changes the user's experience. These tools bring several opportunities for the classroom, mainly when working with STEAM subjects. Therefore, this paper seeks to verify the current situations of integration of VR/AR techniques in remote laboratories presented in research papers. Through systematic research, the authors researched open access papers published in the last five years (period 2017-2021). The databases chosen were IEEE Xplore, Science Direct, and Scopus. After finding the papers, it was possible to identify successful situations of integration of VR/AR techniques in remote laboratories and also to verify expectations and trends for VR/AR integrated to remote laboratories that the authors of these papers presented. After the publishing of this paper, the authors will seek to research further on VR/AR and remote laboratories to develop research projects and educational software.*

I. INTRODUCTION

Virtual Reality (RV) and Augmented Reality (RA) are emerging trends for the future of many fields of knowledge such as medicine, industry, entertainment, and education. They bring many opportunities for the education of STEAM (Science, Technology, Engineering, Arts and Mathematics) subjects [1].

Everyday technology becomes more participative in the classroom, and the advent of the COVID-19 pandemic brought even more evidence for this fact. Therefore, the use of techniques such as RV/AR brings many opportunities for the educational field.

In the past, AR used to be an expensive technology mainly used by the industry [2].

Today, it is possible to find several software which makes use of AR for educational means. Meanwhile, VR is becoming more popular each day in entertainment, for example, in games [3]. Although, it also has great potential for the development of educational software.

Remote laboratories and VR/AR have much-discussed tools in the educational context. They offer a practical and motivating way for teaching students and are therefore an interesting subject for scientific research [4]. Remote laboratories are laboratory experiments that can be

controlled and monitored remotely from a distant location [5], so it offers many advantages in education scenarios in comparison to a classic laboratory. It is even more important to think about a scenario where students can't access the school or university facilities.

The integration between RV/AR techniques and remote laboratories is a very interesting concept to work on because there is a high demand for excellent laboratory equipment in many fields of education, such as medicine and engineering. Thus, the research and development on this integration have great potential for educational and economic means.

This research paper aims to verify situations of integration of RV/AR techniques and remote laboratories developed and published in the last 5 years and it will be done through systematic research.

II. MATERIALS AND METHODS

The research method chosen for this paper is a systematic review. A systematic review of the scientific literature in a specific area is important for identifying research questions, as well as for justifying future research in said area [6]. Additionally, they identify and minimize bias via transparent, explicit, and systematic methodology. [7]

According to Khan et al [8], there are five main steps for conducting a systematic review:

Table 1: Five steps in a systematic review

Step	Description
1	Framing questions for a review
2	Identifying relevant work
3	Assessing the quality of studies
4	Summarizing the evidence
5	Interpreting the findings

Source: Adapted from Khan et al [8]

During the first step, the researcher needs to define the problems to be addressed by the review. Once the review questions have been set, modifications to the protocol should be allowed only if alternative ways of defining the populations, interventions, outcomes, or study designs become apparent [8].

The second step is the moment to research relevant work in databases. The study selection criteria should flow directly from the review questions and reasons for inclusion and exclusion should be recorded.

Assessing the quality of studies is related to selecting studies for a more refined quality assessment based on defined criteria.

Related to the fourth step, data synthesis consists of tabulation of study characteristics, quality and effects as well às the use of statistical methods for exploring differences between studies and combining their effects (meta-analysis) [8].

Finally, in interpreting the findings; the issues highlighted in each of the first four steps should be met. The risk of publication bias and related biases should be explored [8].

For this paper, the research question is to verify situations of implementation of VR/AR techniques in remote laboratories.

The databases chosen for this research were IEEE Xplore, Scopus, and Science Direct. The keywords chosen were "augmented reality", "virtual reality" and "remote laboratories" and the filters were only open access papers that were published in the last 5 years (2017 to 2021) - the first idea was to research publications newer than 2019, but only one paper was selected after applying all the filters for the systematic review.

As the following table presents, 34 results were found.

Table 2: Results from Databases

Especificações		Results from Databases			Total
		IEEE Xplore	Science Direct	Scopus	
Keywords	1. Augmented Reality 2. Virtual reality 3. Remote laboratories				

Type of publication	1. Open access only papers	21	180	44	245
Publication date	1. Last 3 years				

Source: Authors

The following topic, Results, presents further information related to the results found after applying these filters.

III. RESULTS AND DISCUSSION

This topic aims to present the results found in the systematic review. It has three subtopics: "Results of the systematic review", "Situations of integration of VR/AR techniques and remote laboratories" and "Expectations and trends for the future".

RESULTS OF THE SYSTEMATIC REVIEW

This subtopic presents the results of the systematic review and the description of all steps taken to develop this research.

After finding the last results found in the table presented in the Materials and Methods topic, five more filters were applied. They were: analysis of the relevance, reading of title and abstract, exclusion of double papers, reading of introduction and conclusion, and complete reading. The following table presents the remaining papers after applying the filters:

Table 3: Filters applied to the results found in the databases

Specifications		Results in databases			Total
Filters		IEEE Xplore	Science Direct	Scopus	
1	Analysis of relevance	21	180	44	245
2	Reading of title and abstract	6	10	20	36
3	Exclusion of double papers	6	10	20	36
4	Reading of introduction and conclusion	6	10	3	19
5	Complete reading	4	2	2	8

Source: Authors

The first filter, analysis of the relevance, was related to verifying the keywords and if the paper was available for download. All the papers found were suitable to keep the research.

After that was the moment to read the titles and abstract. Many papers were dismissed because they were not about remote laboratories, but only about augmented reality or virtual reality. Also, many of them were about the application of VR/AR techniques in the fields of industry and health. From Science Direct just a few papers remained, but they needed to be dismissed because they did not approach remote experimentation.

The filter for exclusion of double papers did not exclude papers because none of them were doubles.

After reading the introduction and conclusion, from the 20 papers from Scopus, only 3 were selected because most of them were not about the integration of remote laboratories and VR/AR techniques - they were about the creation of simulations.

In conclusion, only 8 papers were selected for complete reading: 4 from IEEE Xplore, 2 from Science Direct, and 2 from Scopus.

It is possible to conclude that just a few research works related to VR/AR techniques integrated into remote laboratories were developed in the period 2017-2021. Although, some papers affirm that it is a trend to explore for the future.

SITUATIONS OF INTEGRATION OF VR/AR TECHNIQUES AND REMOTE LABORATORIES

From the papers found in the systematic review, x presented situations of integration of VR/AR techniques and remote laboratories. This subtopic presents these situations.

The following table shows the papers presented on this topic and their authors.

Table 4: Situations of integration of VR/AR techniques and remote laboratories

Paper	Authors
Virtual reality for remote-controlled robotics in Engineering Education	A. Rukangu, A. Tuttle and K. Johnsen
Adding augmented reality to laboratory experimentation	J. Rodrigues, T. Andrade, P. Abreu and M. T. Restivo
Using marker-based augmented reality and natural user interface for interactive remote experiments	A. Maiti, A. D. Maxwell and A. A. Kist
Programming and testing a PLC to control a scalable industrial plant in a remote way	M. Márquez, A. Mejías, R. Herrera and J. M. Andújar
Augmented reality for remote laboratory improving educational learning: using elevated particle swarm optimization in object tracking scheme	S. M. Zandavi and V. Chung
Remote and virtual labs for engineering education 4.0	J. Grodotzki, T. R. Ortelt and A. E. Tekkaya
Remote lab meets virtual reality - Enabling immersive access to high tech laboratories from afar	P. Trentsios, M. Wolf and S. Frerich
Factors affecting Chinese university students' intention to continue using virtual and remote labs	M. Zhang, C. Su, Y. Li, and Y. Y. Li

Source: Authors

In the paper "Virtual reality for remote-controlled robotics in engineering education," they use virtual and augmented reality to build and test a remote UR-10 robotics lab that allows students to work together on a hands-on robotics-based lab [1]. In conclusion, the authors find out that the use of a virtual reality interface coupled with a digital twin of a UR10 robot allows them to investigate the suitability of different user interfaces.

The paper "Adding augmented reality to laboratory experimentation" proposes the use of augmented reality in laboratory experiments as a way to enrich the user experience in conducting the required procedures as well as reinforcing students' skills [2]. According to the authors, as the experiment involves controlling the level of a water tank, the user controls the water pump through a virtual command provided by AR. Finally, the three AR applications developed by the authors are available for download.

The paper "Using marker-based augmented reality and natural user interface for interactive remote experiments" introduces a method to use augmented reality and a natural user interface to create interactive laboratory experiments [9]. The new system allows hands-on experience with virtual objects as a part of the remote laboratory's activity.

The authors of "Programming and testing a PLC to control a scalable industrial plant remotely" present a scalable industrial plant that puts plug and label to bottles. Although it is not a study related to education, it is still a combination of real and virtual elements [10]. The element which puts the plug is virtual, implemented using augmented reality techniques and the labeler is a real element.

The algorithm proposed by the authors of "Augmented reality for remote laboratory improving educational learning: using elevated particle swarm optimization in object tracking scheme" regarding target tracking in AR remote labs represented better performance in comparison with classic and other improved PSO [11].

"Remote and virtual labs for engineering education 4.0" presents the main achievements of the ELLI (Excellent Teaching and Learning in Engineering Science) project at the TU Dortmund University - which is the center of the development of remote and virtual labs for mechanical engineering education with a focus on manufacturing technology [4]. The second phase of the project will integrate other technologies to remote experimentation, such as augmented and virtual reality.

Since virtual reality is one of the strongest trends in the consumer and gaming industry, while remote labs are becoming more popular in engineering education, "Remote lab meets virtual reality - enabling immersive access to high tech laboratories from afar" combined these two domains. As the whole nature of this approach is experimental, the authors aimed at a variable degree of immersion and established two different approaches for the creation of a virtual environment [3].

"Factors affecting Chinese university students' intention to continue using virtual and remote labs" presents results related to the satisfaction of Chinese students while studying with the help of remote labs integrated with VR/AR [12].

EXPECTATIONS AND TRENDS FOR THE FUTURE

Most of the papers found in this research presented expectations and trends related to VR/AR and remote laboratories.

VR/AR are great trends for the future of education - mainly in the fields of engineering and health, where the students must have the opportunity to practice concepts they learn during theoric classes. Most of the papers found in the systematic review were related to the integration of remote experimentation of VR/AR for educational means. Most of them affirm that both remote laboratories and VR/AR are growing trends.

A few years ago, AR was an expensive technology mainly used by the military and aerospace industry [9]. At present, there are many different types of devices that allow distinct AR implementations in multiple areas such as medicine, entertainment, industry, and education. So some authors [2, 3, and 4] believe it is considered mandatory to introduce it in every engineering curriculum.

On the other hand, virtual reality is currently one of the strongest trends in the consumer and gaming industry, while the typical remote lab in engineering education is also a very popular tool [1]. There is a high demand for high-end lab equipment in engineering education, especially for courses that require practical hands-on lab exercises [1]; therefore, a system that allows students enrolled in remote courses to experience hardware-intensive classes just as they would in an in-person course - especially in light of the COVID-19 pandemic - is a real necessity.

Thus, it is possible to notice that the integration of AR/VR techniques and remote laboratories is a great trend to create a more immersive experience for students from many areas of knowledge.

IV. CONCLUSION

The systematic review allowed the authors to verify the situations of implementation of VR/AR techniques in remote laboratories published in the last 5 years. As these concepts are great trends for the future of education, just a few results were found, but they proved to be excellent research works that show examples of implementation of these situations.

It is a great field to explore and there is much space to develop new and innovative projects to perpetuate the use of these tools. It can also be said that the COVID-19 pandemic brought another motive to encourage the use of practices such as VR/AR and remote laboratories because so many students do not have the opportunity to access hands-on laboratories.

Therefore, after the publishing of this paper, the authors will seek further information on the integration of VR/AR techniques and remote laboratories to develop projects and software to integrate these technologies in STEAM education.

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