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RESEARCH ARTICLE

Critical Component of Virtual Laboratory-Augmented Reality for Radar Surveillance Learning

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ABSTRACT

Virtual laboratories as an alternative to classical laboratories provide convenience in learning as well as operational and investment effectiveness. The combination of augmented reality in virtual laboratories increases student interest, reduces cognitive load, and provides efficiency in practicum with maximum practicum achievements. Education for radar surveillance requires innovation in providing practical tools to improve students' competence in maintaining radar surveillance equipment. This research aims to obtain an architecture of a virtual laboratory for radar surveillance. The method used is to conduct a literature review with PRISMA to obtain general components in an augmented reality-based virtual laboratory and conduct interviews with radar experts to obtain the characteristics of radar learning. The results obtained are that there are 4 main elements in a radar-based virtual laboratory and 12 critical components, then for the characteristics of radar learning there are 5 main components, these 2 elements are then combined to create the architecture of an augmented reality-based virtual laboratory in radar surveillance learning.

1. INTRODUCTION

Virtual Laboratory (VL) provides a solution to overcome the lack of maximum traditional/classical practicum learning, high laboratory costs, student interest, and expertise in carrying out laboratory activities [1], VL has a solution for low costs in preparing laboratory equipment [2] in laboratory experiments that require materials and spare parts, students can carry out activities well, carrying out experiments with a virtual learning system. Surveillance radar engineering education is part of the preparation of radar technicians who maintain and repair equipment used for piloting flight traffic, so that flight operation services run well and safely [3]. Learning surveillance radar engineering requires laboratory mockups [4] and comprehensive training so that students can maintain and repair radar equipment. Cognitive abilities [5][6], understanding of the system[7], and functions and problem-solving abilities in radar learning are challenges for developing radar laboratories [8]. Immersive technology for learning has been widely used, Immersive Technology has also been adopted in the aviation sector, for maintenance [9], overcoming spatial problems [10], and increasing situational awareness, but there is still little use of immersive technology, especially augmented reality for surveillance equipment technology. The use of Augmented reality for virtual laboratories makes it easier to visualize and carry out laboratory activities with various learning designs [7], both remote, online, and blended learning so that students and teachers can interact well in the virtual ecosystem. Refer to regulations from the International Civil Aviation Organization (ICAO). The implementation of radar surveillance technology education achieves its ability to be able to carry out maintenance and repairs, educational facilities are also equipped with infrastructure, such as radar equipment or standardized radar mock-ups [11]. Regarding the needs and opportunities of radar education as well as the use of virtual laboratory and augmented reality technology in the educational sector, there is a challenge to develop radar surveillance technology for civil aviation [12]. Implementing virtual laboratories based on augmented reality for learning both theory and practice, especially in aviation education, is an opportunity to develop [9], [13], [14], this research aims to get an architecture from a virtual laboratory combined with AR radar surveillance learning. So the research question (RQ) is as follows;

- RQ1: How is the implementation of technology relevant to the features of the virtual laboratory with AR?

- RQ 2: What is the architectural design of the virtual laboratory integrated with AR in Radar Surveillance learning**?**

2. THEORETICAL FOUNDATION

2.1 Research trend in virtual laboratory

Virtual Laboratory is the use of software to create simulations of real laboratory activities for practical activities. The benefits of virtual laboratories [2] include: 1). reducing costs for equipment preparation, as well as providing a virtual experiment experience which is of course much cheaper; 2). Virtual laboratories can provide models of objects, laboratory activities, and learning that cannot be realized and visualized with classical activities; 3). virtual laboratories are more interactive, can respond to user needs in various ways, and are more personalized; 4). Virtual Laboratory has more freedom to create elements and parameters, providing more varied operating modes; 5). Virtual laboratories provide a level of freedom for each part of the laboratory and there is no need to add costs to add facilities to virtual laboratory activities; 6). Virtual laboratories can demonstrate learning without requiring large real facilities, Virtual laboratories can also be used easily by students without guidance from a teacher and activities can be done remotely; 7). Students not to worry while learning and have more confidence, virtual laboratory can be easily used, and for experiments, students can redo/undo at any time without losing data. Disadvantages of virtual laboratories include how to interact with laboratory equipment, measuring instruments, growing practical skills such as using instruments, to interconnect, measuring, and methods in experiments [2]

2.2 Augmented reality laboratory

Laboratory activities are part of learning to prove theory, and skills obtained from laboratories are students' learning experiences from applying what they have learned [15][16], the benefit of Augmented reality for laboratory activities to enhancing laboratory science skills, and the use of time for practical work is shorter [17] Laboratory activities are part of learning to prove theory, the skills obtained from the laboratory are students' learning experiences from applying what they have learned [15][16], AR for laboratory activities to improve laboratory science skills and shorter use of time for practicums [17]

2.3 Radar surveillance learning

Surveillance radar is a complex flight observation equipment, to observes aircraft movements as information for air traffic guidance to ensure the safety of flight operations [4]. Radar has 3 main parts, namely transmitter, receiver, and processing system. Based on research by Purwaningtyas, et.al, there are deficiencies in radar learning, namely in troubleshooting, because real infrastructure requires large investments and learning is less than optimal so it requires a laboratory that can meet the purpose of students learning [8]. The use of AR in the aviation sector is widely used to increase efficiency in aircraft engine maintenance [18]. Augmented reality for science laboratories increases self-confidence and self-control [19], and for systems that have high complexity the use of AR for laboratories shows faster laboratory activities with good grades achieved [20]. So the potential for deficiencies in radar learning, as well as it is the potential for improving and increasing the quality of learning using virtual laboratories

3. RESEARCH METHODOLOGY

Systematic literature review to identify, assess, and interpret things relevant to research with specific research questions. To the first research question by conducting a systematic literature review for general components in virtual laboratories for learning radar surveillance we explore by using the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) method that consists of 4 stages, namely: identification process, screening process, eligibility, and inclusion stage. Identification is the process of identifying articles that have the potential to answer research questions and are sourced from digital databases. In this study, a database indexed by Scopus is used. Next is the screening process, at this stage, the articles are filtered by setting inclusion and exclusion criteria, where these criteria are considered to have the potential to be up-to-date and relevant to the research being conducted, articles that have been screened are then checked again by looking at the title, abstract, The methods and results of the research carried out are relevant to the research questions from the review we conducted. At this stage it is the eligible stage, then articles that have been declared eligible will be analyzed according to the research questions and relevant knowledge domains.

Identification process

To identify articles that will be reviewed to answer research questions, the initial stage is to search digital databases, in the research by determining articles that have a good repository and are indexed by Scopus from the Scopus.Com page, then manual searches from other database sources as well conducted at SpringerLink.Com, IEEE Xplore, Wiley Online. To find articles that match the research objectives, keywords are determined in the search, in this study the keywords are determined as follows:

1. *(virtual OR* online *AND* laboratory *) AND (* architecture *OR* component *OR* design*) AND* augmented *AND* reality *)*
2. virtual laboratory *OR* Online Laboratory *AND* Augmented Reality *AND* Architecture 2017 – 2023, computer science, computer application in engineering education
3. Architecture *OR* Component of *AND* Virtual *OR* Online *AND* Laboratory *AND* Augmented Reality

Screening process

At the screening stage, by setting criteria, namely inclusion criteria and exclusion criteria, determining criteria, based on the the needs of virtual laboratories and the use of augmented reality for education, especially for laboratory management needs, the author makes specifications for inclusion and exclusion criteria as shown in table 1 below:

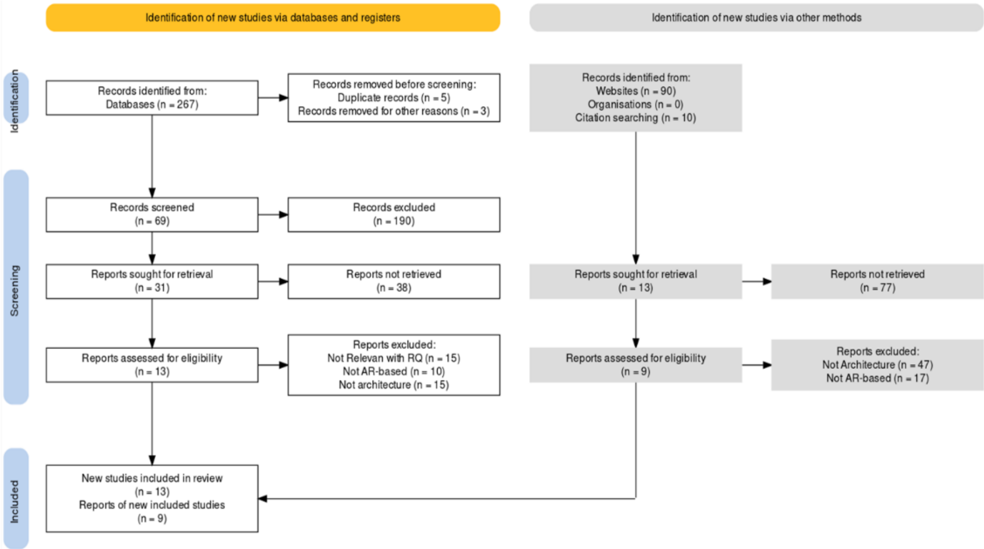
Table 1: Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
1. Articles in English 2. The article is the result of research 3. The article aims to create or apply utilize or evaluate a Virtual Laboratory that uses Augmented reality or Immersive Technology 4. The article aims at learning using Virtual Laboratories 5. Articles published in 2017 – 2022 6. Articles in the computer science domain	1. The article is not complete 2. Article sourced from Scopus which has been discontinued 3. Duplication of articles

Eligible process

After screening the articles by determining inclusion and exclusion, the next process is to select eligible articles, where we will use these eligible articles for analysis. In this eligible process, we read the articles that we get from the screening process as a whole and then choose which articles are by our research objectives, where the articles selected in this process are considered to be able to answer the research questions that we set.

At this stage, a total of 267 articles were found, these articles were referred to a search from the Scopus database of 69 articles and a manual search found 26 articles. Furthermore, articles declared eligible will be designated as included and will be analyzed using meta-analysis concerning the



knowledge and needs of au[g] **Figure 1: PRISMA flow process** ries in radar surveillance technology training. The overal

4. RESULT

From the search through the next process stages, 25 articles were obtained, the publications of these articles were:

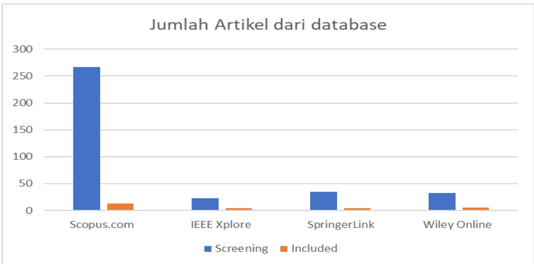


Figure 2: The papers from the digital library

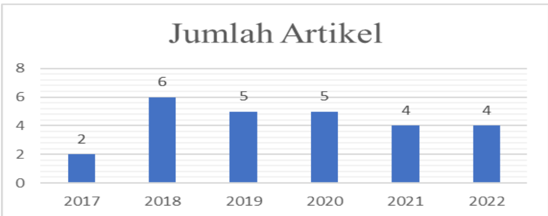


Figure 3: The papers and year of publication

Figure 2 shows the data of articles we found, and the most articles issued in the year 2018, this is potential to study VL integrated with AR The benefit of Augmented Reality in aviation training provides a learning. Experience that makes students more engaged, reduces cognitive load and creates visualizations to increase situational awareness.

Case studies, experiments, and literature reviews from virtual laboratories with augmented reality from 2017 – 2022 provide opportunities for the development of virtual laboratories in radar education. Comprehensive SLR with the PRISMA protocol resulted in 25 articles included for further analysis

4.1 RQ1: How is the implementation of technology relevant to the features of the virtual laboratory with AR?

AR-based virtual laboratories for laboratory activities make it easy for students to overcome the shortcomings of traditional laboratories, technology, platforms, and elements of virtual laboratories have different characteristics in the benefits of virtual laboratories, immersive Augmented Reality technology provides visualization and interaction that increases learning success and students feel comfortable in activities. To classify the components and designs of virtual laboratories, thematic analysis is used for augmented reality-based virtual laboratories. This category is divided into emerging technology, design, interaction models, and potential solutions.

From the general components of the Virtual Laboratory integrated with augmented reality, there is the opportunity to be integrated into radar learning. This integration requires a design concept, which requires input from radar experts and education providers.

Table 2: Classification of element and fiture of virtual laboratory

Element	Fiture
Lab Management Platform	LMS, Lab Configuration, Development
Virtual Resources	3D Modelling, Sensor, Interactivity, Material Design,
Emulation Software	Software, Interface, virtual lab, Laboratory Manager,
Infrastructure	Hardware, Database, Server, Cloud

Hardware. In the virtual laboratory architecture, hardware is an essential component, hardware is the device used for the virtual laboratory, including a compatible Central Processing Unit (CPU) [21] which is compatible, then a web camera in the field of marker scanning techniques so that it is a more fixed and precise position of the camera towards the scene axis [22] [23], the use of glass for augmented reality includes Vuzix which provides a natural human-machine interface [24][25],), then the connectivity system is also important in building a virtual laboratory to carry out the functions of each part, connectivity in virtual laboratories supports the design of collaboration activities or those using distance learning methods that use the Learning Management System (LMS) [21][26], [27], other hardware used for interconnection in the design of virtual electronics laboratories includes Bluetooth Low Energy (BLE), a markerless method for precise identification and for carrying out instrument measurements on objects carried out in practice and smartphones can communicate well with using Bluetooth[28], the Internet of Things (IoT) is also used to manage sensor data and synchronize clients for multiple users [29]

Software. In the AR-based virtual laboratory component, software is an essential component, software is a component used to build laboratory models and objects, from the review article software used in developing virtual laboratories in the aviation sector and in the engineering sector includes Unity 3D, software is essential and widely used to build AR applications even though it is mostly used for game development [30], as a user interface and experience in applications as well as characteristics of objects [31], creating scripts to control objects, and having a graphic editor [32]. The operating system is also essential for the application to work, from a review of the articles on the operating systems used based on Windows and Android [33][34][28], so that the objects that have been created in 3D, you can give a script and move the 3D object by coding it first in Blender 3.1 software, so that it looks attractive on the home page/splash screen using Figma to create an attractive interface[35]. To connect objects with devices from the literature review, Vuforia SDK was obtained [30][34], ARCore SDK untuk markerless AR ARCore SDK for markerless AR [36]

3D modeling. In essential AR applications to provide visualization to users, several software used to create 3D objects include 3DS Max, Google Sketchup, ClipArt [35], MAYA[33][30], Autodesk inventor [37]. CAD model.

Platform, To run a VL with AR, from the literature review it can be built in several ways including Mobile Augmented Reality using a smartphone and is more flexible, other ways include using a desktop PC, the user sees the visualization using a PC to get high fidelity and perform alignment with easy [30][38], Web-based AR that can be accessed via LMS [26]

Sensor. Sensors are a way to visualize virtual objects using devices and platforms that have been developed, several methods in this process based on the review of articles obtained include: haptic, marker, and markerless

Material design is an important part of the virtual laboratory, where classical learning and practicum are moved to a virtual platform and provide better information than classical learning and laboratory activities. The material design includes providing general information in the form of text, video, practical activity scenarios, bill of materials, material cards, gamify, experimental teach bank, and tasks and feedback

Development, In developing AR-based virtual laboratories, several works of literature have suggested development frameworks including Multimedia Development Life Cycle (MDLC), Development and evaluation desktop Simulated Testing Environment (DSTE), Bounded Input Bounded Output (BIBO), Massive Open Online Course (MOOC), Digital Twins

Interactivity, This section is how users interact with AR-based virtual laboratory applications, and several interactivity models with capturing, tracking, and using virtual buttons

Laboratory configuration, This configuration is a design used in laboratory setup that is adapted to the learning design, including web-based lab, Remote Lab, Online Lab, Asynchronous using LMS, and Collaboration Lab

The interface is an interface that connects users with devices, an essential interface in user interest and engagement with the virtual lab application used, interface development including Web Interface, HTML 5, Jquery, Bootstrap, and Unity 3D UI.

Database, the activities, and student's ability to operate and carry out laboratory activities is the expected achievement in achieving competency, so laboratory activities need to be documented and analyzed on student abilities, database development models in virtual laboratories in augmented reality virtual laboratories, including by Node JS Server, MySQL, Apache Server

Refer to the review of the literature and synthesize in Table 2 and the critical component as mentioned before, the result of our proposed element and feature of virtual laboratory integrated augmented reality as in Figure 4.

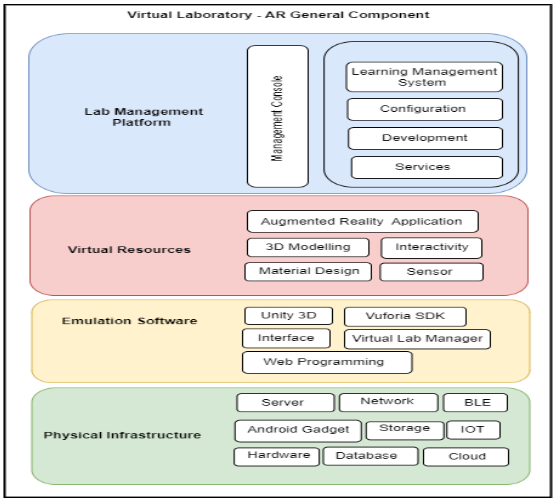


Figure 4: General component of virtual laboratory integrated augmented reality

4.2. RQ 2: What is the architectural design of the Augmented Reality Based Virtual Laboratory for Radar Surveillance Learning?

To find out the typical nature of surveillance radar engineering learning, an exploration was carried out with experts, namely radar technician users (A), experts who carry out certification testing for radar technician personnel (B), and radar instructors (C).

Case 1, professionals from air navigation service, radar education for the competency certificate requirements that technicians must have based on regulations, the obstacle they face is a lack of understanding of the basic material during the rating test. Because technicians carry out practical activities, maintenance, and operation of equipment, the learning experience required apart from basic material is knowledge to carry out troubleshooting, technicians do not understand the basic concepts of equipment operation, systems, functions, or parts of modules which when carrying out maintenance and repairs require treatment. specifically, for example, removing the module must use the right tools, taking measurements also with the appropriate conditions and pins as per the technical document. Learning on radar is very complex and requires visualization and understanding of the radar blocks, and to make it easier to access, personalization of learning is needed. Moreover, there are several brands of radar in Indonesia and during training, we usually only discuss one brand of radar, so if a technician is studying at a training institution and there are different brands when working, it will be difficult and require familiarization.

Case 2. Professionals from the Directorate of Aviation Navigation, radar surveillance education for technicians are part of the competency in the field of ATS engineering, specifically surveillance, as the main support for the flight traffic movement monitoring system, radar is very essential in the safety of flight operations, so radar performance must be good during service. Radar education is expensive due to limited facilities, making the training participants less than optimal in completing the learning, and during exams, the completion of the theory exam is less than optimal. In radar learning, the required components are apart from classroom facilities, also practical mockups and modules, but the training institutions are not optimal in completing the facilities so the training participants have not mastered the concepts and practicums, especially troubleshooting. It is hoped that the development of virtual laboratories can complement the shortcomings of traditional learning and practicums, with student elements, instructors, mockups, and modules that have appropriate quality and learning outcomes.

Case 3, radar teaching professionals, there are several difficulties in learning radar, including not all training institutions have mockups, and there is only 1 radar mockup in the training institution at the Indonesian Aviation Polytechnic Curug, the transfer of knowledge to students is not optimal because the basic understanding still cannot be mastered quickly due to complex equipment. In terms of learning, it is less effective because the instructor repeats the material for each group in the class, and the time students have to understand the equipment is limited because they take turns. The virtual laboratory allows for development, as a pre-laboratory activity and students can familiarize themselves with the equipment in a personalized way, and the virtual laboratory has student achievements by giving quizzes. Providing troubleshooting exercises in the VL is more fit for students and trainees to understand the concepts, operations, and functions of radar more quickly, both for maintenance and repairs. It is hoped that instructor involvement can be developed in virtual laboratories so that teachers can understand the activities and achievements of student activities and learning, both theoretical and practical.

From the interviews with the 3 experts, a qualitative analysis was then carried out with NVIVO 12. Combining the augmented reality-based virtual laboratory in radar learning, by mapping the general components in the AR-based virtual laboratory with user needs in radar learning, the mapping of the general components and the characteristics as in Figure 5, there are 5 characteristics Next, the author proposes an architecture based on the SLR results, where there are 4 elements for the architecture, namely: Laboratory Management Platform, Virtual Resources, Software Emulation, and Infrastructure. From the components that have been obtained from systematic literature reviews and interviews with experts, the next step is to create an architecture for an augmented reality-based virtual laboratory for radar learning. The architecture is based on the components and characteristics of radar learning, as in the following Figure 5.

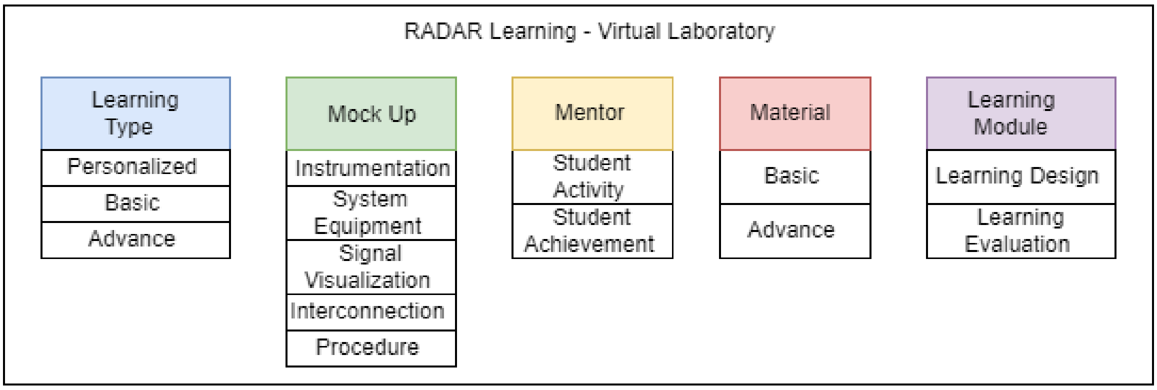


Figure 5: Radar learning characteristic

DISCUSSION

This research aims to find technology that is an essential component of a VL integrated with AR for learning radar surveillance. Where this laboratory will be more flexible [39] and increase learning independence [40][41]. To obtain general components in virtual laboratories based on AR by using the PRISMA method, from searching with keywords that match the research questions, 267 articles were obtained, then through the screening process, 26 articles were obtained. From the review, it was found that there were 4 main elements for virtual laboratories, namely lab management platform, virtual resources, emulation software, and physical infrastructure.

Then to get the characteristics of radar learning by conducting interviews with 3 experts, namely from the Directorate General of Civil Aviation, the Air Navigation Service, and instructors from radar, from this interview we got 6 characteristics of learning for radar surveillance to find out how learning outcomes can shape students' cognitive. abilities[42]–[44], because cognitive function plays an important role in human factors in aviation [45]. Changes in learning, especially practical equipment using virtual laboratories, will reduce costs [46] for investment, then increase efficiency [18] and learning flexibility [5]. Characteristics of radar learning include personalized learning, learning according to needs independently as per the concept of the intelligent tutor system which provides convenience and independence of learning[47], then Mock Up, which is an important part of learning for practicums, with virtual laboratories being an opportunity to provide the needs for learning outcomes, especially practicums [1], [8], [13] based on augmented reality will provide new experiences in learning that further increase student interest [7], [48]–[51] then the mock-up also has the function of providing measurements or instrumentation [19], its function will make it easier to reduce the complexity of learning [9], [18], then mentors where mentors can give orders in laboratory activities and theoretical learning, mentors to monitor student activities, and see student learning achievements [47], then the material consists of basic and advanced according to the needs of students, the next characteristic is learning modules to provide learning models and evaluation models that refer to international and national learning rules [4]. The architecture in

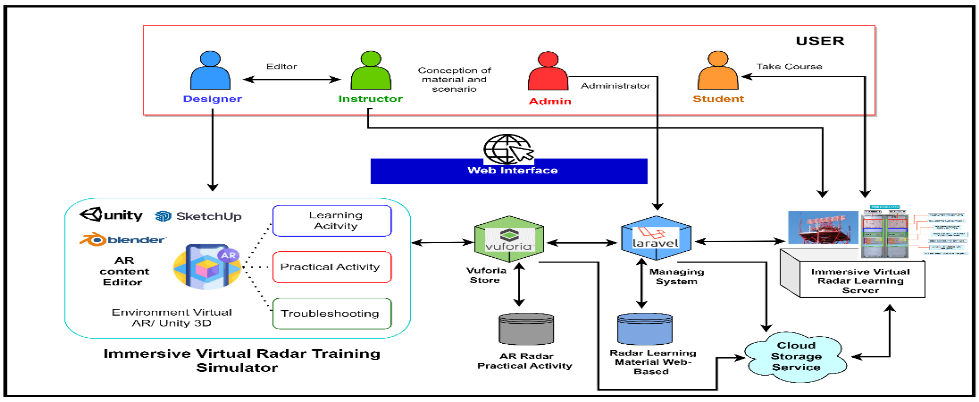


Figure 6: The architecture of radar engineering immersive laboratory

Figure 6, thi[...]loped in a web platform, th[...]ar Engineering Immersive Laboratory (REIL)

5. CONCLUSION

This research aims to obtain the architecture of a REIL for learning in radar surveillance. To get the design of the architecture, a literature review was carried out first to get the critical components as a structure for the formation of the virtual laboratory, then interviews were conducted for the learning characteristics and 5 characteristic components were obtained, in radar learning apart from visualization, cognitive improvement and reduction of equipment complexity when studying things. The problems include students' ability to find problems or damage to radar equipment and take corrective steps. In further research, exploration can be carried out to design troubleshooting methods in radar learning.

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