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Remote laboratory development for online learning of modern physics experiments: initial development

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Abstract

This study aims to design, develop, and test the quality of the remote laboratory system for online physics experimental learning on modern physics. The research used the ADDIE development model (Analysis, Design, Development, Implementation, Evaluation). The analysis was carried out by studying the literature on curriculum texts and recommendations from the Physics Education Association regarding laboratory learning. The product was designed by adopting the basic architecture of remote laboratory systems developed in science. Product development was undertaken to produce laboratory equipment, a graphical user interface with LabVIEW, and an e-learning system with Moodle. A remote laboratory system of data acquisition and e-learning tools on modern physics topics has been successfully developed with good-quality results. It is suitable for use in supporting online learning of modern physics experiments. The implications of this research show that the developed remote laboratory system can be an effective solution to support online learning of modern physics experiments, offering a high-quality alternative for physics teaching in the digital age.

Keywords: remote laboratory, remote experiment, modern physics experiments

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I. Introduction

The development of online learning technologies has significantly changed education [1], providing wider access and unprecedented flexibility. However, this transition poses challenges, especially in fields of study that rely heavily on laboratory practice, such as physics. Laboratory experiments are a core component in physics learning that not only help students understand theoretical concepts and train skills such as data collection, analysis, and critical thinking [2], [3]. Unfortunately, replicating the conventional laboratory experience in an online environment is a challenging task.

Modern physics experiments, which often require sophisticated equipment and controlled environmental conditions, face additional constraints in online learning [4]. Limited access to physical laboratories, high costs [5], and logistical challenges reduce students' opportunities for experiment-based learning experiences [6]. In addition, the absence of direct interaction with experimental devices can create gaps in understanding of complex physics concepts, ultimately impacting the mastery of essential scientific competencies in the 21st century.

Remote laboratories offer a potential solution to overcome these barriers [7]. By utilizing advances in communication and information technology, remote laboratories allow students to conduct experiments in real-time from different locations using internet-connected devices [8]. This approach not only increases accessibility for students in different geographical areas but also provides an authentic experimental learning experience. For example, Putra et al. emphasized that remote laboratories can provide hands-on experience through the real-time operation of experimental devices, which is particularly relevant for modern physics, where validation of experiments is indispensable [9].

In addition, the development of remote laboratories often involves inter-institutional collaboration. Consortia, such as iLabs and Labshare, have created frameworks for designing and implementing remote experiments so educators can utilize existing tools without starting from scratch [10]. These frameworks spur innovation and encourage resource sharing between institutions, ultimately improving the quality of education. Furthermore, integrating machine learning technologies in remote laboratories provides advanced data analysis capabilities, critical for modern physics experiments requiring complex data interpretation [11].

The COVID-19 pandemic has accelerated the adoption of remote labs, especially when educational institutions suddenly shifted to online learning. Gamage et al. [12] noted that this situation encourages the exploration of various approaches to ensure educational sustainability, including in laboratory practice activities. Remote laboratories provide flexibility, allowing students to conduct experiments according to their schedule, thus accommodating diverse learning styles.

This research aims to overcome limitations in modern physics experiments by developing a remote laboratory for online learning. The main focus is to design an interactive and accessible platform to explore the principles of modern physics, such as quantum phenomena and relativistic effects. This research also contributes a scalable and cost-efficient alternative to conventional laboratories while improving the inclusiveness and quality of physics education. This research aims to empower students to gain hands-on experimental experience, even in regions with limited resources or access by bridging the gap between theory and practice.

II. Methods

This research is a type of research and development [13]. The ADDIE Model is used [14]–[16]. Instructional designers widely use the ADDIE model to plan and create practical learning experiences. The stages of the ADDIE model are Analysis, Design, Development, Implementation, and Evaluation. However, in this study, the stages are carried out only up to the development stage. The quality of the experimental tool was investigated by looking at the accuracy and precision of the tool in generating experimental data.

At the design stage, instructional problems are clarified, instructional goals and objectives are determined, and the learning environment and student knowledge and skills are determined. The graduate learning outcomes in the physical education curriculum, undergraduate laboratory curriculum standards and recommendations, student characteristics, the learning environment in the digital era, and the challenges of educational development in Indonesia were analyzed. The design stage includes setting learning objectives, learning content, laboratory instruments, material analysis, and learning planning. A review of the remote laboratory design and products developed related to technical aspects and learning content is carried out at this stage. At the development stage, the developer makes experimental equipment, data acquisition hardware, and software and develops e-learning content based on the results of the design stage. At this stage, testing of the developed system, device testing, and validation testing of the e-learning device are conducted.

Modern physics topics were taken as cases in the development of the remote laboratory, including atomic spectroscopy and the statistical character of nuclear radiation counting. The developed remote laboratory components are equipment, a data acquisition system, a Graphical User Interface (GUI) using LabVIEW programming language [17], [18], and a remote laboratory learning management system (RL-LMS).

III. Results and discussion

Figure 1 shows the design of the Remote Laboratory Hardware System developed. An experimental apparatus is an experimental device that can be accessed remotely and used in experiment activities. The data acquisition system is hardware and software in an interface with graphic elements to control the experiment devices. LabVIEW is a graphical programming language used in building data acquisition applications [19]. A lab server is a personal computer (PC) used to run data acquisition applications, where this PC is connected to the experimental apparatus through an interface device. A web server is a PC that receives and responds to requests via a browser. The Moodle Learning Management System software, which contains remote laboratory learning content, is installed on the PC.

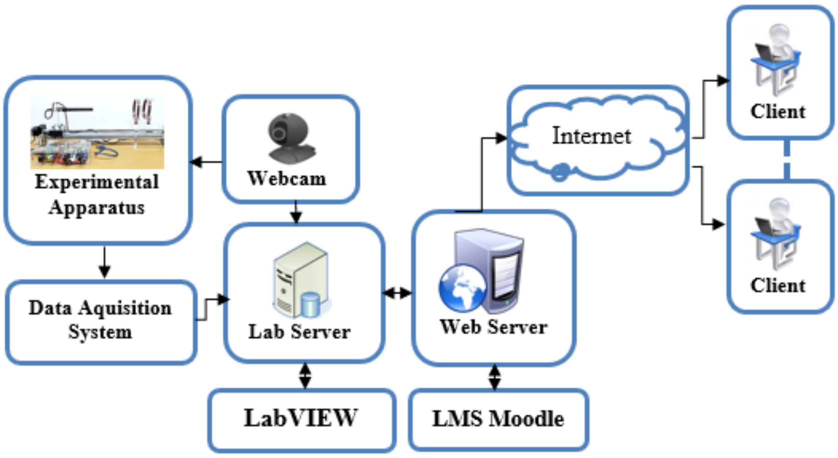

Figure 1. Remote Laboratory Hardware System Design Diagram

Atomic Spectroscopy Experiment Apparatus and Graphical User Interface

The atomic spectroscopy experimental apparatus (Figure 2) used a Vernier Spectrometer, Optical Fiber, and Spectrum Tubes to support the measurement of emission spectra. The learner-centred GUI makes it easy for all levels of learners and educators to integrate spectroscopy into the teaching and learning of physics (Figure 3).

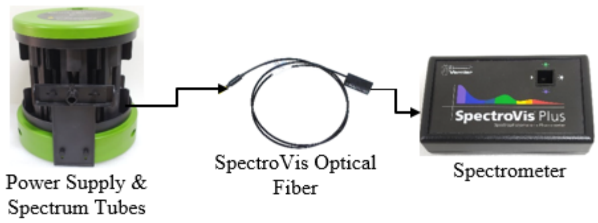

Figure 2. Atomic Spectroscopy Experimental Apparatus

The measurement results of the hydrogen atomic emission spectrum, as displayed in Figure 3, show a good agreement with the theoretical predictions based on the Bohr atomic theory. It can be concluded that the remote physics laboratory apparatus for atomic spectroscopy experiments is feasible for use in physics learning.

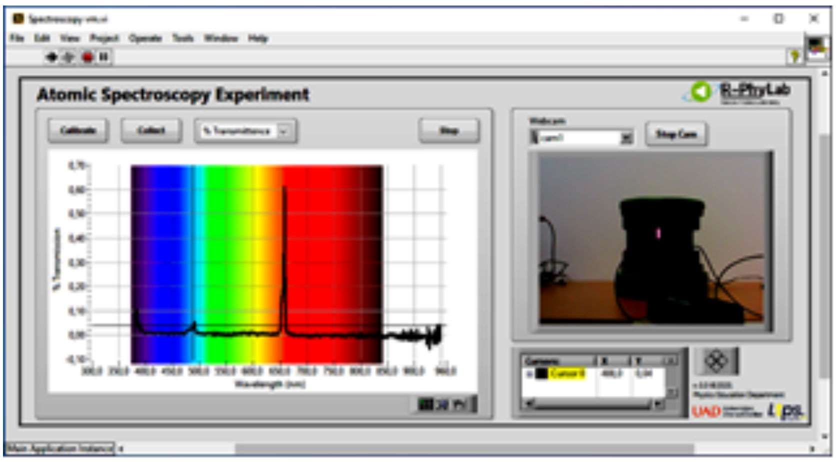

Figure 3. Remote Experiment Results of Hydrogen Atom Spectroscopy

Apparatus and Graphical User Interface for Radiation Enumeration Experiments

The radiation enumeration experimental apparatus used the Vernier Radiation Monitor and SensorDAQ Interface to describe radiation statistics, measure nuclear decay rates, and monitor radon decay. This easy-to-use sensor is a Geiger-Mueller tube housed in a small, sturdy plastic case. A thin window protected by a metal screen allows alpha radiation to be detected, along with beta and gamma (Figure 4). The process of measuring radiation was done through the GUI (Figure 5).

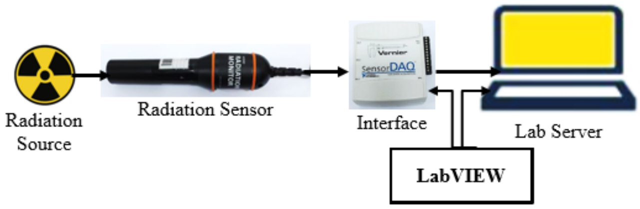

Figure 4. Radiation Enumeration Experimental Apparatus

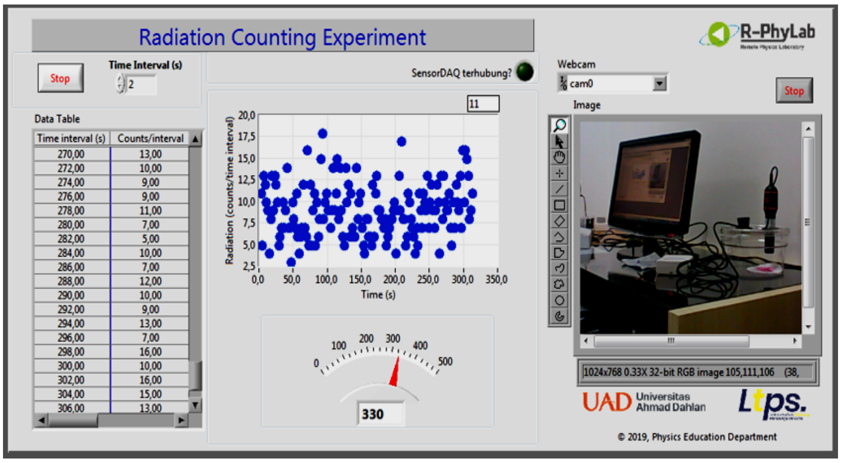

Figure 5. Results of the Remote Experiment for Radiation Enumeration

If the count is large, more than ten counts/time interval, the distribution of the count follows a Gaussian distribution (Figures 6 and 7). The experimental values aligned with their theoretical predicted values based on the results of radiation enumeration experiment trials for small radiation count (less than ten counts/time interval) and large count (more than ten counts/time interval). It was concluded that the remote physics laboratory apparatus for radiation counting experiments worked well and was suitable for learning physics experiments.

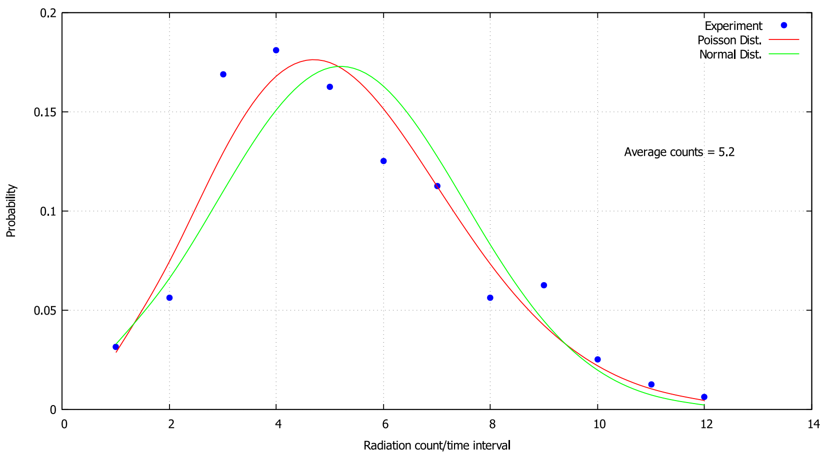

Figure 6. The distribution of Count Scores for an Average of Fewer Than 10 Counts

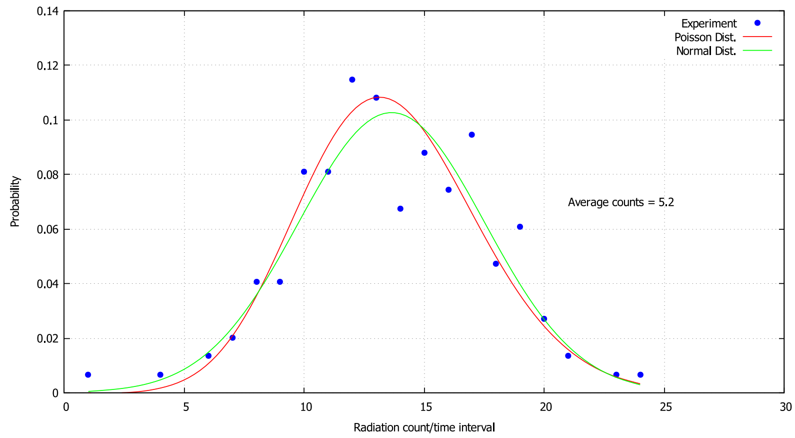

Figure 7. The distribution of count scores for an average of more than ten counts

Remote Laboratory Learning Management System

A remote laboratory requires three main components: the Learning Management System (LMS), the remote laboratory (software and hardware), and the interface between the LMS and the remote laboratory, which must be fully developed. LMS is needed to realize greater stimulation in using a remote laboratory-based online learning environment that allows the creation and storage of learning materials and media in electronic form, as well as student assessments. To monitor and analyze the learning process, all learning outcomes were documented for each participant online and stored in a database. Communication between students and educators, exchange of opinions, and collaboration with all students in groups were carried out through email, chat, forum, and video meeting features. LMS enables users to create courses, enroll, store, manage, and publish learning content on the web. Remote Laboratory Learning Management System

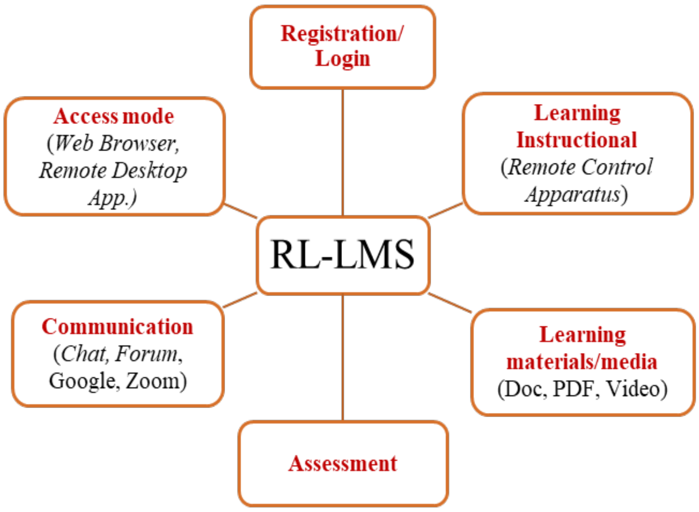

Figure 8. Remote Laboratory Learning Management System

The LMS used to manage the learning using a remote laboratory was Moodle. This LMS was structured as a set of modules providing various possibilities for monitoring the learning process and managing learning content. This LMS is based on constructivist learning theory and a constructionist approach to education where learners can contribute educational experiences by acquiring and testing their knowledge through mutual collaboration. Because Moodle is open source, this leaves room for creating new modules for specific application requirements. The developed remote laboratory application is integrated into Moodle, called the Remote Laboratory Learning Management System (RL-LMS), as shown in Figure 8. The website of this RL-LMS can be accessed at the address http://rphylab.pf.uad.ac.id/sistem/. The management of laboratory activities included the following activities: scheduling experiments, remote experiments, sending pre-lab and post-lab assignments, interactive discussions between students and educators, and assessment.

The feasibility testing of e-learning devices to support using a remote physics laboratory was undertaken on e-learning objects and designs. The feasibility test of e-learning objects covered eight aspects: functionality, accessibility, technical support, mobile design, privacy-protection of data and rights, social support, teaching support, and cognitive support. At the same time, the feasibility test for e-learning design included student support and resources, online design and organization, teaching delivery and design, student assessment and learning, innovative teaching with technology, and the use of feedback by the teacher.

The evaluation test results for e-learning tools by experts indicated that the developed e-learning tools were feasible to use in online physics learning. The validators suggested adding a user feedback menu to measure the usability aspect of the RL-LMS device by the user.

IV. Conclusions

From the results of the development and testing of the products, it was concluded that the remote laboratory system for online experimental learning of modern physics was of good quality. Especially the performance results of measuring the apparatus and its data acquisition system. The results of validation tests of e-learning at the Remote Laboratory Learning Management System (RLMS) indicate that the learning tools are feasible for physics experiments.

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