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Remote Laboratory Based on the Internet of Things for E-Learning: A Development Model of Newton's Law Experiment

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***Abstract*—Remote laboratory is a development of digital technology to support the quality of learning in this digital era. However, scientific processes often cannot be accommodated in digital spaces such as e-learning. This research highlights a remote laboratory system that can accommodate scientific process improvement in e-learning. The research objective is to develop and determine the performance of the remote laboratory system of Newton's Law experiment based on IoT for e-learning as an experiment development model. Research methods can be classified into design and development, abbreviated as DDR. The remote laboratory system is designed and developed in six phases. This system is developed by five main components, namely, a photodiode sensor, MCU nodes, motor drivers, stepper motor, and ESP 32 CAM. The results indicate that the remote laboratory system of Newton's law experiment has demonstrated positive performance, and the accuracy and precision of measurement from the remote laboratory system are classified as high. Accordingly, the remote laboratory system of Newton's law experiment can be used as an alternative to support scientific processes in e-learning. It is expected to serve as a guide for virtual laboratory design, enlightening the audience on the potential of this system. It is used extensively for experimental teaching in modern physics education. The success in designing and developing an experimental model of Newton's law by implementing a remote laboratory based on IoT provides a good opportunity to develop various more sophisticated physics experimental systems to support the science process and e-learning.**

***Keywords*—Remote laboratory, Internet of things, E-learning, Physics experiment, Performance.**

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I. INTRODUCTION

The application of digital technology in learning has become trendy nowadays. Digital technology has created active, interactive, flexible, and distance learning. Learning with the assistance of digital technology is currently widely recognized as a suitable form of learning. This is evident from the increasing need to develop and utilize e-learning in education today. E-learning provides an opportunity to create distance learning that uses computer technology and internet networks [1], [2]. Besides that, e-learning can create flexible learning that does not depend on place and time [3]. The application of e-learning in learning can increase insight, overcome the shortage of education personnel, and increase the efficiency and effectiveness of learning [4].

E-learning is a good solution to solve various learning limitations during COVID-19 and in the era of digital technology. COVID-19 has created several obstacles in implementing classroom learning, such as face-to-face meetings, discussions, experimental activities, task-solving guidance, assessments, and others [5]. E-learning has been proven to exist and can overcome learning problems during COVID-19 [6]. E-learning can deliver information, provide learning materials, interact with teachers and students, perform experimental activities, give assignments, carry out assessments, and others [5]. This further emphasizes that digital learning is feasible in the current era.

However, several e-learning obstacles are often found, especially in science education, namely experimental activities. The experiment is an activity that should also be accommodated by e-learning. In science education, such as physics, experiments are essential in helping students carry out scientific processes [7], [8]. These activities can improve students' science process skills. Implementation of experimental activities can also develop students' motivation and scientific attitudes towards science. Experimental activities can generate motivation to learn, develop basic skills in the scientific method, provide direct and meaningful experiences, and support mastery of learning materials [9]. For this reason, physics experiment activities need to be carried out in the learning process, even during distance learning.

The preliminary study results indicate several problems related to science process activities. There are several problems regarding the experiments carried out remotely, such as the limitations of using experimental sets in groups, the limited number of experimental sets, and the need for more student mastery of the science process. In addition, from the student's point of view, it was found that the experiment implementation process was not carried out properly [10], there is not enough time allocation to experiment, tools to support experimental activities are still limited, room to carry out experimental activities is not available, and the experimental activities are troubled to carry out [11].

Based on these problems, it is necessary to carry out advanced development regarding implementing experiments for e-learning, one of which is by developing a remote laboratory to support IoT-based physics experiments. This solution provides an opportunity to carry out experimental activities remotely, provides flexibility in the time of carrying out experiments, carrying out experiments alternately, and carrying out experimental activities in groups or individually. This method provides opportunities for students to carry out real experimental activities remotely with the help of the Internet of Things.

Several other researchers have developed experiments with remote laboratories. Remote laboratories have been widely developed in engineering education. Azad designed and developed a remote laboratory with the Internet of Things settings in 2021 [12]. Jaya et al. [13] developed a remote laboratory for remote experiments in 2020. Limpraptono et al. [14] developed a remote laboratory architecture as a solution for learning in the era of the Industrial Revolution 4.0 in 2020. Rivera et al. [15] designed a remote laboratory for digital e-learning systems in 2017. Elvyanti [16] researched performance assessment from remote laboratories. This research was intended to complement and expand remote development laboratories to support physics experiment activities, especially Newton's laws of motion.

The application of remote laboratory in learning increasingly exists today. A remote laboratory is a laboratory that can be controlled and observed remotely using the internet [17], [18]. Another definition of a remote laboratory is a web-integrated system that allows students to carry out real experiments [13]. Users can directly interact with real experimental systems. The remote laboratory method is often known as the Remote Laboratory. Laboratory activities can also be interpreted as experimental activities carried out and controlled remotely via the Internet. In this case, the remote laboratory uses real instruments that users can use and control at different locations from the instruments [19], [20]. Remote laboratories deal with conducting real experiments remotely via the internet [21], [22].

Remote laboratories can be a key in education, allowing students to access and interact with remote laboratory equipment via the Internet [23]. The primary purpose of the remote laboratory is to expand the possibilities of remote experimentation [18]. Remote laboratory enables students to carry out practical experiments at any time and from anywhere, as long as an internet connection to laboratory equipment is available. In this case, the remote laboratory is used as a learning to set as a tool to provide students access to experiments [15]. By connecting to a unique application, students can access the right instrument attached to the server via a specific interface and carry out the desired measurements but not change the experimental set [24].

Remote laboratory work is often based on the Internet of Things (IoT). The term Internet of Things was first introduced by Kevin Ashton in 1999. Cisco stated that IoT involves people, processes, data, and things to create a more relevant and valuable network based on this digital technology [25]. IoT can be defined as a computing and communication paradigm where objects of everyday life are connected to the Internet [26]. Another understanding of IoT is that it is a system of interconnected physical devices that communicate through network connectivity using various types of communication [27]. The goal of IoT is to make everything connected [28].

Internet of Things (IoT) can assist in transferring data from sensors over wireless networks, achieving recognition and exchange of information in open computing networks. Things that are used in daily life are becoming smart with today's technology [29]. IoT has provided valuable opportunities for new applications to improve their performance and quality of life. In recent years, IoT has received much attention from researchers and practitioners from around the world [30], [31]. An application of IoT in learning activities is to support the performance of remote laboratories.

Experimental activities are an essential component in learning science and engineering [32]. Thoughts and actions to support this experimental activity should always be carried out. Therefore, it is necessary to develop IoT-based remote laboratory science experiments. The research aims to determine the performance and design specifications of the remote laboratory system of Newton's law based on the Internet of Things to support e-learning activities.

II. MATERIALS AND METHOD

This research can be classified into the design and development research method (DDR). DDR is a systematic study conducted to design, develop, and evaluate a product or tool. A tool designed and developed in this research was a remote laboratory system from a physics experiment based on the Internet of Things. In this research, Newton's law of motion is an experimental development model of physics as a product of the DDR method. The remote laboratory system is designed and developed in six phases. The phases in research activities include identifying problems, describing objectives, designing and developing systems, testing systems, evaluating test results, and communicating test results.

The remote laboratory system for Newton's law of motion has five main components: photodiode sensors, MCU nodes, motor drivers, stepper motors, and ESP 32 CAM—the photodiode sensor functions to read the travel time of objects on an inclined plane. NodeMCU, in the form of a Wi-Fi module, functions as the system's brain to process all received data. The TB6600 driver controls the stepper motor to move the inclined plane according to the angle entered by the user. ESP 32 CAM functions to record system movements that can be seen via the user's cell phone. To carry out all the main circuit functions in the Remote Laboratory System for Newton's Law Experiments, a 12 Volt 5A Power Supply is used. The design of the remote laboratory of Newton's law experiment of object motion can be seen in the block diagram in Figure 1.

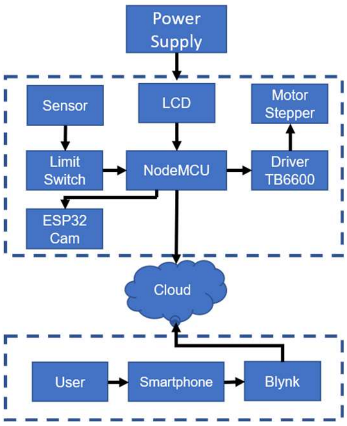

Fig. 1 Block diagram design of the remote laboratory system

Newton's law experiment's remote laboratory system design software serves as instructions for running NodeMCU. Instructions in the form of input tilt angle values are given to the system for further processing so that the output is in the form of a tilt angle. If the angle input value meets the conditions, the stepper motor will work, and the results will be displayed on the cell phone. On the other hand, if the angle value entered does not meet the requirements, the stepper motor will not work, and the results will not be displayed on the cell phone. The flow chart design of the remote laboratory system for Newton's law experiments can be seen in Figure 2.

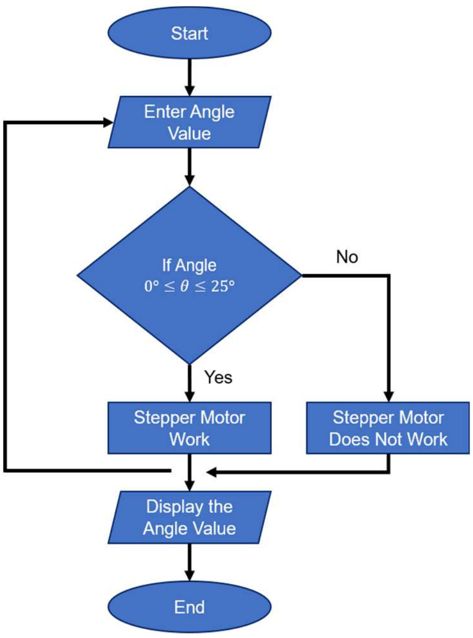

Fig. 2 Flowchart of remote laboratory system of Newton's law experiment

The hardware design of the remote laboratory system of Newton's law experiment consists of six main parts. The grounding board serves to place the system on a table or floor. An inclined plane with a changeable position is used to base a moving object from start to finish. The first object moves on an inclined plane, while the second object functions as a free-falling moving object. Pulleys are used to connect between the first object and the second object through a string. Two parallel metal rods are used to keep the inclined plane moving steadily. The cell phone controls the inclination angle and displays the measurement results in Newton's law experiment.

Data collection techniques in this research consisted of direct measurements and indirect measurements. Direct measurements include measuring travel time and slope angle. The standard instrument for measuring travel time is a digital stopwatch, while the standard measuring instrument for measuring slope angles is a bow. On the smartphone display from the remote laboratory of Newton's law experiment, read the angle of inclination, travel time, object speed, object acceleration, and string force. This means that direct measurements on this remote laboratory instrument are carried out on these four physical quantities. Indirect measurements include both the accuracy and precision of remote laboratory systems of Newton's law experiments.

III. Results and Discussion

A. *Performance Specification of Remote Laboratory System*

The remote laboratory system of Newton's law experiment is a tool made for long-distance measurements. This remote laboratory system generally consists of photodiode sensors, stepper motors, TB 6600 drivers, and NodeMCU. A power supply operates all active components in the remote laboratory. On the other hand, the mechanical part of the remote laboratory includes an inclined plane with adjustable positions, two objects, and a pulley to connect the two objects. The remote laboratory system of Newton's law experiment can be seen in Figure 3

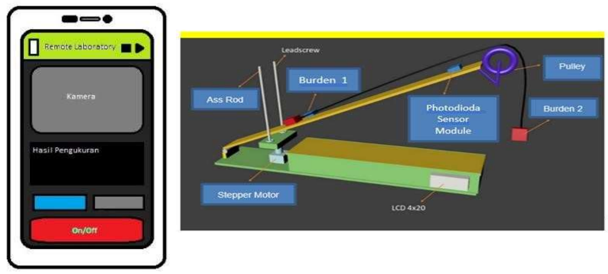

Fig. 3 Remote laboratory system of Newton's law experiment

A test of each part is carried out to determine the performance specifications of the remote laboratory system. The TB 6600 driver can control the stepper motor according to the angle value entered by the user. Stepper motors are capable of lifting inclined planes from 0° to 25°. Users can control the angle continuously from this range. The photodiode sensor detects objects up to the final terminal so that the object's travel time can be determined. The ESP 32 Cam camera can record the increase in the incline and the movement of the remote laboratory system, which moves according to the input value given by the user. Display A tool in the form of a mobile phone is capable of displaying the results of recordings of moving objects on an inclined plane, reading angle data, object travel time, object acceleration, and string force.

B. *Accuracy and Precision of Remote Laboratory System*

The accuracy of the remote laboratory system is determined by comparing the measurement results from this system with an expected value. The expected value of time is obtained from the measurement results with a stopwatch, while the expected value of the acceleration and force of the string is obtained from theoretical calculations. An accuracy test was carried out for three different angle values, namely 15, 20, and 25. Results of data analysis from the measured value, trusted value, and accuracy are shown in Table 1.

TABLE I
ACCURACY DATA OF THE REMOTE LABORATORY SYSTEM

Angle variation	Accuracy		
	t	a	T
15°	97.222	99.736	99.949
20°	99.379	99.706	99.955
25°	99.749	100.000	99.988
Average	98.783	99.814	99.964

From the results of the data analysis in Table 1, it can be stated that the accuracy of time measurements from remote laboratory systems varies from 97.222 to 99.749. The average value of time measurement accuracy is 98.783. The accuracy of measurements from remote laboratory systems varies from 99.706 to 100.00, with an average acceleration measurement value of 99.814. On the other hand, the accuracy of string force measurements from remote laboratory systems varies from 99.949 to 99.988. The average accuracy of string force measurements by remote laboratory systems is 99.964. This means that the measurement accuracy of time, acceleration, and string force from a remote laboratory system can be classified in the high category. The results of this analysis indicate that the measurements of time, acceleration, and string force from the remote laboratory system are close to the expected values.

Testing the precision of Newton's law experiment's remote laboratory system was conducted to determine the consistency of measurement results under the same conditions. In testing the accuracy of measurements carried out repeatedly ten times. The precision test was carried out for three angle conditions, namely 15°, 20°, and 25°. The results of data analysis from testing the precision of the remote laboratory system in measuring the speed, acceleration, and string force are displayed in Table 2.

TABLE II
PRECISION TESTING DATA OF REMOTE LABORATORY SYSTEM

Physics Quantities	Precision and Error	Angle		
		15^0	20^0	25^0
Velocity	P	98.81	98.24	99.03
	E	6.02	1.28	1.06
Acceleration	P	99.74	100.00	99.67
	E	0.26	0.00	0.33
String Force	P	99.96	99.96	99.99
	E	0.04	0.04	0.01

Based on the data analysis in Table 2, it can be explained that the speed measurement precision of the remote laboratory system of Newton's law experiment varies from 98.24 to 99.03. The precision average value of velocity measurement of remote laboratory systems is 98.69. The precision of acceleration measurements of remote laboratory systems varies from 99.67 to 100.00, with an average value of acceleration measurement precision of 99.80. Meanwhile, the accuracy of string force measurements of remote laboratory systems varied from 99.96 to 99.99, with an average string force measurement precision of 99.97. The results of this data analysis indicate that the precision of measuring velocity, acceleration, and string force of remote laboratory systems can be included in the high category. Thus, the remote laboratory of Newton's law experiment can display consistent results on repeated velocity, acceleration, and string force measurements.

C. Testing Result of Relationship between Physical Quantities

Remote laboratory system testing of Newton's law was also done to determine the relationship between physical quantities. An independent variable in this test is the tilt angle. On the other hand, the dependent variables in this test are travel time, velocity, acceleration, and string force. In this test, the tilt angle is varied, and the physical quantities of time, velocity, acceleration, and string force were measured for each change in tilt angle. The results of the data plot from the test results can be seen in Figure 4

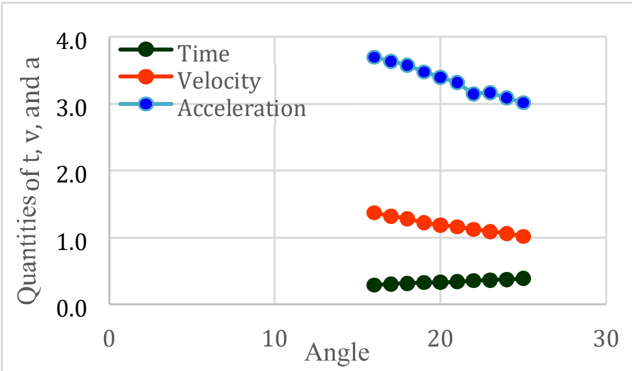

Fig. 4 Relationship of time, velocity, and acceleration with angle

The result of the data analysis in Figure 6 can be described as the travel time of objects increasing linearly with an increase in the tilt angle. This means that increasing the tilt angle will increase the travel time of objects. The object's velocity will decrease linearly as the tilt angle increases. These results indicate that increasing the tilt angle will reduce the object's speed. On the other hand, the object's acceleration will decrease linearly as the tilt angle increases. These results indicate that increasing the tilt angle will cause the object's acceleration to decrease.

From the results of the data analysis, it can be stated that the accuracy of remote laboratory experiments of Newton's law can be classified into the high category. Measurement accuracy shows the closeness of the value of the quantity measured by an instrument with the actual value of a standard instrument [28], [33], [34]. Accuracy is related to measurement uncertainty [33], [35]. High accuracy is caused by the instrument's reading value being close to the actual value. The closer the value read by the instrument to the actual value, the more accurate the instrument. The higher the accuracy of an instrument indicates the smaller the measurement error and vice versa [34]. Therefore, high accuracy of an instrument is essential in measurement and control.

The results of data analysis have also indicated that the accuracy of measurements from remote laboratories is included in the high category. This data was obtained from repeated measurements ten times. These results suggest that the remote laboratory system consistently displays measurement results under the same conditions. In other words, remote laboratory systems can show results for repeated measurements. Measurement accuracy relates to the closeness of agreement between the values of the measured quantities for repeated measurements under the same conditions [28], [33], [34]. Accuracy concerning the standard deviation of repeated measurements [33], [35]. This result is based on precision, namely, a measure of the repeatability of measurements that still displays the same results.

IV. Conclusion

Based on the results of the data analysis, three conclusions can be stated from this research. First, the components of the remote laboratory system of Newton's law experiment have been able to demonstrate good performance in the aspect of lifting an inclined plane according to the input tilt angle, returning it to its initial position, determining the travel time of an object, recording moving object, and displaying values on the display. Second, the accuracy and precision of measurements from Newton's law experiment's remote laboratory system can be classified into the high category. Third, time increases linearly with the tilt angle, while velocity and acceleration decrease linearly with an increase in the tilt angle. Thus, the remote laboratory system of Newton's law experiment can be used as an alternative to support scientific processes in the era of COVID-19 and the 4.0 industrial revolution. Therefore, the remote laboratory system of Newton's law experiment can be used as an alternative to support scientific processes in e-learning, whether applied with blended, hybrid, or complete in digital space. The results of this study will serve as a guide for future research and can be used widely, both in experimental teaching of physics education and in other fields of science.

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