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Original Paper

An Intelligent Experimental Aid System Taking Sound Velocity Measurement Experiment as an Example

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Abstract

With the continuous progress of educational technology, laboratory teaching is facing the important task of enhancing students' active learning and understanding. The study aims to develop a set of this intelligent experimental assistance system to solve the "black box" phenomenon that prevails in university physics experimental teaching. The system adopts video recognition technology and deep learning algorithms to monitor and optimize students' operations in the sound velocity measurement experiment in real time. The results show that the system significantly improves students' experimental ability, reduces the instructor's burden, and opens up a new way of thinking for physics experiment teaching.

Keywords

Intelligent, Experimental, Image recognition

1. Introduction

In modern science education, especially in university physics courses, experimental teaching is not only an important part of knowledge transfer, but also a key way for students to understand physical principles and methods. However, in the actual classroom, many students tend to take the attitude of mechanical repetition of the experimental process, ignoring the deep physical principles and connotations behind the experiment. The existence of this "black box" phenomenon limits students' independent learning and in-depth understanding, and it is urgent for the educational community to take effective measures to solve this problem. Therefore, this study develops an intelligent experimental aid system, which aims to provide an innovative solution with the speed of sound measurement experiment as the main application scenario.

The core objectives of the intelligent experiment assistance system mainly include real-time feedback and error correction, deepening knowledge understanding and improving efficiency. Deepen understanding mainly by relying on video real-time feedback and error correction: recognition technology monitors students' operations in real time, identifies potential errors, and provides timely feedback to correct inappropriate behavior and enhance the learning effect; by gradually displaying the error analysis and principle hints, it helps students to deeply understand the physical theories behind the experiments, with a view to promoting the effective combination of theory and practice; by alleviating the burden of teachers' guidance to individual students, it enables them to By reducing the teacher's burden of instructing individual students, it enables them to focus more on the in-depth discussion of the teaching content, and at the same time enhances the students' independent learning ability and spirit of inquiry.

2. System Working Principle and Application Scenarios

2.1 System Working Principle

The system integrates video recognition technology, user interaction interface and data processing module. The video recognition technology can analyze the experimental video stream in real time through deep learning algorithms, identify the key operation steps and possible errors, and improve the students' operation standardization; the user interaction interface can design an intuitive user interface to display the experimental steps, real-time operation status, error hints, and principle explanations, which can help the students to obtain information at any time. The data processing module can collect experimental data, conduct preliminary analysis and compare with theoretical values to assess the accuracy of experimental results and provide data support for subsequent error analysis.

2.2 System Work Program

In order to test the enhancement of the intelligent experimental aid system on the practical work of students in the actual university physics experimental courses, the experiment of “sound speed measurement” is taken as an example, which aims to understand the working process of piezoelectric transducer, and to be able to measure the propagation speed of sound waves in different media through the method of standing wave resonance, the method of Li Saju graphics and other measurement methods. The system is deployed in the laboratory, using high-definition cameras to fully monitor the experimental process and analyze the key aspects of the students' operations.

In the laboratory, HD cameras are set up for monitoring the experimental operation process. The HD camera is installed about 2 meters above the experimental bench to ensure that the lens is vertically downward, can completely cover the entire operating area of the experimental bench, and clearly capture the connection of the experimental equipment (e.g., signal generators, transducers and oscilloscopes), the student's hand movements in operating the instruments, the content of the screen display of the oscilloscope, and other key areas. The field of view of the camera should ensure that it can capture the details of students' operations in each step of the experimental process, such as the action of the transducer distance adjustment, signal generator parameter setting and other operations, so that the system can carry out accurate analysis and monitoring.

2.3 Experimental Procedure

Lissajous figure method in the sound speed measurement experiment was selected as a real case for testing. The specific experimental process is as follows:

Prepare experimental equipment including signal generator, sound speed meter and oscilloscope, and ensure the completeness and correctness of the experimental equipment. Start the Intelligent Assist System, the system starts to record and analyze the real-time video. Connect the signal generator with the ultrasonic transmitting transducer to ensure that the signal transmission is correct. Set up the receiver transducer to be connected to an oscilloscope in preparation for receiving and displaying the acoustic signal. Transmit ultrasonic waves by outputting a sinusoidal voltage signal from the signal generator to the transmitter transducer. The receiver transducer captures the ultrasonic wave and converts it back to a voltage signal for input to the oscilloscope.

The distance between the transmitter and receiver is gradually changed to observe and record the change in phase difference with distance, thus enabling the observation and recording of data. When the Lissajous graph forms a straight line, the corresponding distance change is recorded to calculate the wavelength. Combine the known sound wave frequency with the calculated wavelength, and use the corresponding formula to calculate the speed of sound. Finally, the experimentally measured sound speed is compared with the theoretical value, and a detailed report is generated, which includes operational errors, explanation of the principle and analysis of the experimental data.

3. Research Methodology and Development Process

3.1 Demand Analysis and Design

On the basis of fully investigating the needs of experimental teaching, it was clarified that the system should have the core functions of real-time feedback and error correction, deepening understanding and improving teaching efficiency. The design framework of the system adopts a layered architecture, which is divided into data acquisition layer, data processing layer and user interaction layer. The data acquisition layer is responsible for collecting video data of experimental operations through high-definition cameras; the data processing layer analyzes and processes the collected data using deep learning algorithms to identify students' operation steps and errors; the user interaction layer provides students and teachers with an intuitive interface for displaying information on experimental steps, real-time operation status, error hints, and principle explanations, etc. This design framework ensures that all the functions of the system are available to the students and teachers. This design framework can ensure a clear division of labor between the functional modules of the system and work together to meet the actual needs of students and teachers in the process of experimental teaching.

3.2 Video Recognition Model Training

In this study, a large amount of video data from sound speed measurement experiments are integrated to train deep learning models using the TensorFlow framework. The model used is Convolutional

Neural Network (CNN), which has the characteristics of local connectivity and weight sharing, and can automatically extract the features in the image, which is very suitable for processing video image data. In the sound speed measurement experiment, the CNN model is mainly used to identify the key operation steps and possible errors in the experiment.

The specific use of the process is as follows: first, a large number of sound speed measurement experiment videos are labeled with key frames, the labeling content includes the category and location of correct and incorrect operations and other information. Then, the labeled key frame data are divided into training set, validation set and test set. In the training phase, the training set data are input into the CNN model, and the model continuously adjusts the network parameters through the back-propagation algorithm to minimize the error between the prediction results and the labeled results. In the validation phase, the validation set data is utilized to evaluate the performance of the model and prevent model overfitting. When the performance of the model on the validation set reaches a certain standard, the test set data is used to conduct a final test of the model to ensure the generalization ability of the model. After several rounds of training and optimization, the model is able to efficiently monitor and correct students' operations in real applications.

3.3 System Development and Integration Testing

The back-end system is developed based on the Python framework, which is mainly responsible for the tasks of data processing, model computing, and interaction with the database, etc. Python has rich scientific computing libraries and machine learning frameworks, such as TensorFlow, NumPy, etc., which are convenient for realizing the core functions of the system. In the front-end, JavaScript is used to create an interactive interface to provide users with an intuitive and convenient operation experience. JavaScript's cross-platform characteristics and powerful DOM operation capability make it able to meet the front-end interaction needs.

4. Experimental Data and Performance Indicators

4.1 Typical Experimental Data

Experimental purpose: calculate the speed of sound by measuring the wavelength.

Experimental materials: signal generator, speed of sound meter, oscilloscope.

Frequency: 37.397 kHz.

Theoretical speed of sound (in dry air at 18.5 ℃): 343 m/s.

The experimental data are shown in Table 1 and Table 2, of which Table 1 is the data without using the intelligent experimental aid system and Table 2 is the data after using the intelligent experimental aid system.

Table 1. The Data without Using the Intelligent Experimental Aid System

	measured wavelength(mm)	Calculating the speed of sound(m/s)	Theoretical speed of sound (m/s)	Error (m/s)	relative error
A	9.28	347.0	342.4	4.6	1.4%
B	9.42	352.3	342.4	9.9	2.9%
C	9.37	350.4	342.4	8.0	2.3%
D	9.33	348.9	342.4	6.5	1.9%

Table 2. The Data after Using the Intelligent Experimental Aid System

	measured wavelength(mm)	Calculating the speed of sound(m/s)	Theoretical speed of sound (m/s)	Error (m/s)	relative error
A	9.01	336.9	342.4	-5.5	-1.6%
B	9.10	340.3	342.4	-2.1	-0.6%
C	9.12	341.1	342.4	-1.3	-0.4%
D	9.08	339.6	342.4	-2.8	-0.8%

The average relative error is 2.1% without using the intelligent experimental aid system, which is large and unstable; after using the intelligent experimental aid system, the average relative error is -0.9%, which significantly improves the accuracy of the measurement. By comparing the experimental data, it can be seen that the accuracy of calculating the speed of sound is significantly improved after using the intelligent experimental aid system, and the average relative error is within 1%, which greatly reduces the errors that may occur in the experiment. This proves that the system effectively promotes students' understanding of physical principles in experimental teaching and improves the reliability of experimental data.

4.2 Performance Index Evaluation

The sound wave propagation distance in the sound speed measurement experiment ranges from 50 meters to 500 meters, and the time measurement accuracy reaches 0.001 seconds. The time measurement error is less than ±0.002 seconds, and the sound speed calculation error is controlled within ±1% to ensure the reliability of the experimental results. The response time from the beginning of the operation to the real-time feedback of the system is no more than 0.5 seconds, which ensures that students can get fast and effective guidance.

4.3 Limitation Analysis

The accuracy of this system may be affected under different environmental conditions, such as temperature changes and air movement. In addition, the stability of the system relies on high-quality camera equipment and stable network connection, and the selection and configuration of hardware is crucial.

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5. Discussion

This project has successfully developed an intelligent experimental assistance system for sound velocity measurement experiments. The real-time operation monitoring and error correction realized by video recognition technology not only effectively improves students' experimental comprehension, but also significantly enhances the teaching efficiency. In the future, we will continue to optimize the performance of the system and expand the application scope to provide more comprehensive and intelligent support for physics experiment teaching. Through persistent research and development, we want to modernize and intelligentize physics experiment teaching, and ultimately promote students' active learning and deep understanding.

In future research, it is planned to introduce environmental monitoring algorithms and dynamically adjust recognition parameters to enhance the stability of the system under different administrative conditions. And more physics experiment modules are developed as needed to expand the scope of application of the system so as to serve a wider range of experimental teaching needs. Continuously optimize the operation process based on user feedback to improve user experience and ensure that students can easily understand and apply the system. Continuously collect experimental data, optimize the deep learning model, improve recognition accuracy and adaptability, and ensure that the system can flexibly respond to different experiments. Thus further optimizing the performance and adaptability of the system.

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