Developing a Massive Open Online Lab Course for Learning Principles of Communications

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***Abstract*—The course of Principles of Communications involves a wide range of knowledge and is both theoretical and practical. It is difficult for beginners to closely link theory with practice. Therefore, it is necessary to consolidate theoretical teaching results through experiments. The traditional experimental teaching of Principles of Communications is to let students go to the laboratory and carry out experiments by programming on software radio hardware. However, during the COVID-19 pandemic period, students are unable to conduct experiments in the laboratory, so online experiments become the only feasible scheme. This paper introduces an online experiment scheme, compares the online scheme with lab experiments. The online experiment system has been used in one class of 28 students and the positive rate of the system from the students is 86%.**

Keywords—principles of communications, software defined radio, online experimental teaching

I. Introduction

Principles of Communications is an important professional basic course for electronic information specialty, which plays a role of connecting the past with the future in the whole curriculum system. The course involves a wide range of knowledge and is both theoretical and practical. Theoretical researchers are not familiar with the application of relevant theories in practice, and practitioners have difficulty in understanding its theoretical basis. It is even more challenging for beginners to learn Principles of Communications well. Generally speaking, the more abstract the curriculum theory is, the more it depends on the simulation experiment teaching method to verify the theory.

In the past 30 years, with the development of software defined radio (SDR) technology, filtering, modulation and demodulation and other signal processing circuits in communication systems have begun to be replaced by software algorithms [1]. Especially in the past 10 years, with the reduction of hardware cost of software defined radio [2], the construction cost of communication system based on software radio is also getting lower and lower. Many schools begin to introduce software defined radio technology into undergraduate courses and use this technology to reform traditional courses [3][4]. It turns out that the SDR technology has played a very important role in the experimental teaching of Radio Engineering, Principles of Communications, Digital Signal Processing, Embedded Systems and other courses [5].

From 2016 onwards, the School of Electronic Information and Communications of Huazhong University of Science and Technology began to introduce the SDR technology into the experimental teaching of Principles of Communications. The open programming experiment based on SDR hardware replaced the traditional verification observation experiment based on the test box, and achieved good teaching results [6][7]. At present, the experiment of Principles of Communications based on the SDR technology has become an important link in training students' practical ability, and has been written into the training scheme of professional engineering certification in the School of Electronic Information and Communications [8].

In 2020, with the spread of the COVID-19 pandemic, students are not able to enter the laboratory for experiments, so a new demand arises: how can students complete the experiment of Principles of Communications online through the network in their own houses? In fact, massive open online courses are among the latest e-learning initiative to attain widespread popularity among many universities [9]. The massive open online course on industrial electronics circuits is also designed and implemented in [10] and [11], where the remote laboratory for electronic circuits' practices VISIR (Virtual Instrument Systems in Reality) is proposed within the MOOC to allow online and real time delivery of such practices. In recent years, the PILAR (Platform Integration of Laboratories based on the Architecture of VISIR) Erasmus Plus project is proposed for the federation of five of the existing VISIR nodes, for sharing analog electronics experiments and empowering capacity and resources of each partner [12]. However, the available online experiments are based on electronic circuits, not on communication systems. Considering that the experiment of Principles of Communications based on the SDR technology is essentially realized on the basis of programming, although SDR hardware is required to verify the programming effect, students are not required to carry out hands-on operation on hardware equipment. Therefore, theoretically, it is completely feasible to establish an online experimental system of Principles of Communications. This paper will

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introduce an online experiment system based on the available SDR hardware, and compare the differences between online experiments and lab experiments, so as to better evaluate the teaching effect of the online experiment system.

II. Design Scheme of Online Experimental System for Principles of Communications

This online system is based on Browser/Server (B/S) architecture, connecting teacher servers, student clients, hardware devices and other functional units through the network. Students can visit all the resources by network, and do not have to go to the laboratory. The system architecture is shown in Fig. 1.

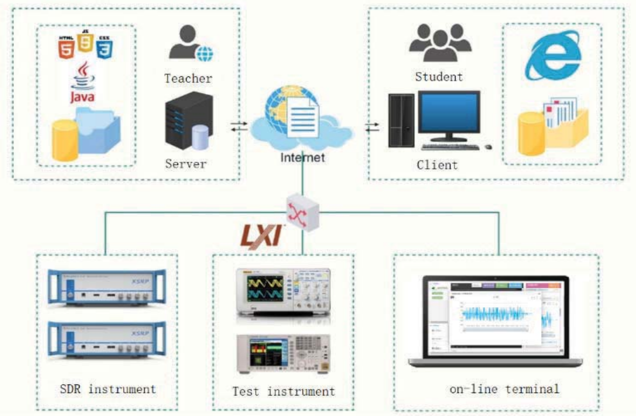

Fig. 1. Architecture of Online Experiment System for Principles of Communications

The online experimental software and the experimental management software required by the system are deployed on the teacher servers to realize the main experimental functions and the management functions of the whole system. The student clients visit the whole experimental system through the webpage, and the students complete the experimental steps such as programming and debugging on the webpage, and finally upload the experimental reports through the webpage. The experimental equipment includes a software radio platform, an online test instrument (selected according to requirements) and an online experimental terminal to realize the experimental functions of the online experiment. The system is jointly established by Huazhong University of Science and Technology and Wuhan Easy Start Technology Company limited.

Since the B/S architecture is adopted, the client only needs to access the network where the teacher server and experimental equipment are located, and the student can conduct experiments through the browser on the client. The experiment includes two modes: virtual simulation and online real-world experiment.

A. *Simulation Experiment*

The virtual simulation experiment is a pure virtual experiment and does not need the support of hardware equipment in the laboratory. The student can start the experiment at any time after selecting the experiment. Relevant requests initiated by the student on the experiment page of the client are sent to the teacher server through the network. The server calls the operation software module of the experiment through the pre-deployed Web service, and returns the experiment output result to the client after processing, and displays the result to the student.

Fig. 2 shows an example of a virtual simulation experiment: the student accesses the virtual simulation server through a browser to obtain the experimental interface of the DPSK modulation system shown in Fig. 2. Visiting the online experimental software by network, the student writes the modulation and demodulation programs, sets the parameters of DPSK modulation system, and after clicking on the running button, the experimental waveform and data are displayed on the right side of the experimental interface. The teacher can see the codes written by the student in the experimental management software. Therefore, the teacher can see the programming progress of each student if he wishes.

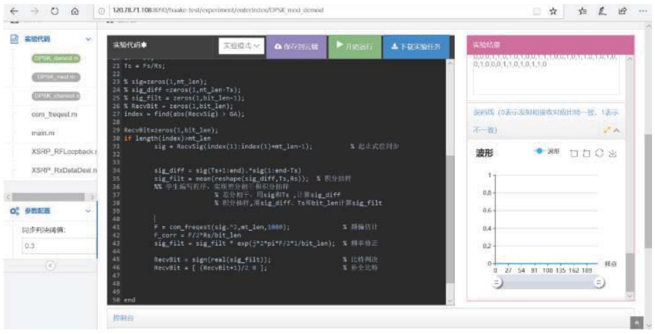

Fig. 2. Example of Virtual Simulation Experiment

B. *Online Real-world Experiment*

Online experiment needs the support of corresponding experimental equipment. The system administrator needs to set the corresponding time period when the equipment is open, and the student needs to reserve the experiment time and equipment in advance in the system, and complete the experiment by logging into the experiment system remotely during the reserved time period. In online experiments, Web services are deployed in online experiment terminals in the laboratory, and one online experiment terminal corresponds to one set of experiment equipment. When the student conducts the experiment at the client, the server transmits the experiment input data and parameters to the Web service of the online experiment terminal after receiving the experiment request, and the Web service transmits the relevant data and parameters to the hardware device for processing, and finally returns the experiment output result to the client in reverse direction, so that the client can display the experiment result and the measurement data and images of the instrument. At the same time, the student can also observe the experimental phenomena through the webcam.

Fig. 3 shows a typical application scenario of an online real-world experiment: the system remotely loads the DPSK modulation algorithm onto one SDR device to operate and transmits the DPSK modulated signal through wireless signals, while another SDR device receives the DPSK modulated signal and operates the remotely loaded DPSK demodulation algorithm to demodulate the modulated signal. The two oscilloscopes measure the modulated signal of the transmitting part and the demodulated signal of the receiving part respectively. The operation results and measurement results can be returned to the client for display. The student can also observe real-time experimental images through a camera.

The simulation technology is used in the stage of theoretical verification and algorithm simulation, so that most of the functions of the experiment can be completed in the simulation mode, and the codes submitted by the student can be verified in the simulation system, thus reducing or even eliminating errors, shortening the duration of the hardware experiment and improving the use efficiency of the experimental hardware.

Fig. 3. Typical Application Scenarios of Online Experiment

The online technology is used in the stage of system realization and hardware/software co-debugging, so that the student can access the experimental hardware in the laboratory through the network in any place with network connection, and the remote online real-world experiment is convenient to carry out. On the one hand, this scheme can make the experiment effect completely consistent with the engineering practice, on the other hand, it can also allow the student to freely use the extra-curricular time to stagger the peak period for experiments, thus improving the utilization rate of limited experimental equipment.

The online experiment enables the student to remotely access the software and hardware resources required by the experiment locally through terminal equipment (personal computers, smart phones, etc.), send the experimental data and parameters to the remote experimental equipment, and receive and display the experimental results processed by the experimental equipment in real time, so that the teaching effect of the online experiment for the student is not different from that of the lab experiment.

III. Procedures of Online Experiment

The experimental steps of this system are divided into the following four levels as shown in Fig. 4. Now we explain the four levels one by one.

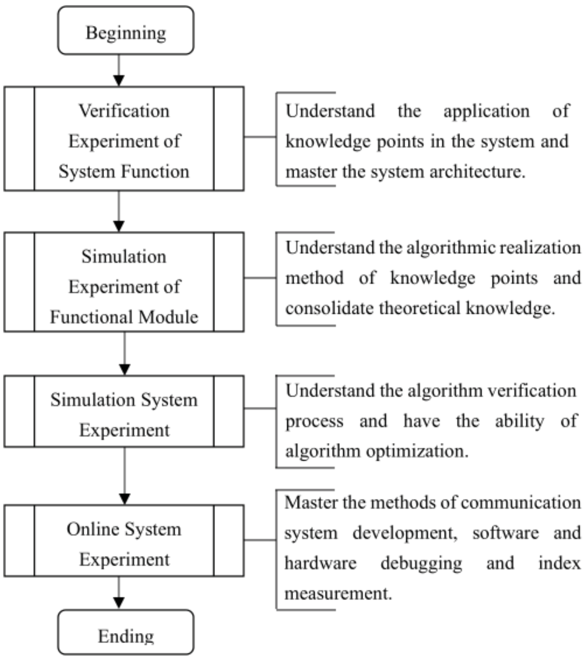

Fig. 4. Online Experimental Procedures

A. Verification Experiment of System Function

The student selects different configuration parameters in the communication system constructed in this experiment, and observes the changes of the results processed by each functional module and the influence on the key indexes of the system, so as to understand the function of each functional module in the communication system and the mutual influence of relevant parameters. For example, changing the modulation method and signal-to-noise ratio can verify that increasing the modulation order increases the transmission bandwidth, but the anti-noise performance will decrease. For another example, under the same modulation order and signal-to-noise ratio, channel coding can be used to correct errors. However, due to redundant data brought by channel coding, the transmission rate of effective data will decrease.

These experimental phenomena can verify the corresponding conclusions in the teaching materials of Principles of Communications. At the same time, the student can also understand the similarities and differences of corresponding knowledge between different communication systems and textbooks through verification experiments: the purpose and function are the same, and the realization techniques and methods are different.

B. Simulation Experiment of Single Module Algorithm

The student opens the M language (MATLAB programming language) code of a functional block diagram in the communication system experiment, and simulates the algorithm of a single functional module (to reduce the design difficulty, only part of the code functions can be selected for the student to realize), thus deepening the student's understanding of the theoretical knowledge of Principles of Communications and enabling the student to initially master the engineering realization method of the functional module.

C. Systematic Experiment in Simulation Mode

The student uploads the M language code of a functional module independently designed by himself to the virtual simulation server of the system to run jointly with other modules of the system, masters the method of communication module algorithm simulation, software debugging and testing, and at the same time, deeply understands how a single module is applied to a complete communication system. The step is more difficult than last step for student since the student should program more codes.

D. Systematic Experiment in Online Mode

The student loads the M language code that passes the test in the previous step of software debugging to the SDR platform for operation by remotely connecting the hardware. The student remotely connects the instrument to observe the operation results, and masters the methods of communication system development, software and hardware debugging and index measurement.

The above four levels completely correspond to the implementation stages of scientific research and engineering application of electronic information related disciplines from overall design to unit design, and then to unit test and system test. Therefore, this system not only enables the student to better learn and master the relevant knowledge of Principles of Communications, but also enables the student to be familiar with the research and development methods of communication system, thus laying a solid theoretical and practical foundation for future scientific research and engineering application.

IV. Comparison of Online Experiment and Lab Experiment

Compared with the lab experiment, although the online experiment has no change in the experimental content, it has changed greatly in the experimental form. Therefore, the following issues should be noticed when implementing the experiment.

1) The guidance of students' experimental problems: During the lab experiment, both teachers and students are in the laboratory, and students can consult teachers whenever they have experimental questions, so the questions can generally be answered. However, in online experiments, students' experimental time is arbitrary, and teachers are unlikely to be online all the time, so an additional set of communication mechanism between teachers and students needs to be established. In this system, students can ask teachers questions through the system's private message function. Teachers can extract students' programming codes to reproduce the problems according to students' problems, and then provide answers to students through the system's private message after finding out the problems.

2) The failure of experimental hardware: During the lab experiment, the SDR hardware may sometimes appear unresponsive, and the problem can be solved simply by shutting down and restarting. However, in the online experiment, students cannot directly contact SDR hardware, so students cannot solve this problem immediately. Therefore, the scheme for replacing the experimental hardware is designed in this system. Students can apply for replacing the SDR hardware, and the system redistributes the SDR hardware to continue the experiment. At the same time, students leave a message to the teacher in the system, and the teacher handles the failure of software radio hardware.

3) The examination of experimental results: In the lab experiment, the students' experimental results are evaluated by the teachers through checking the result of the experiment, but in the online experiment, the teachers are not present and cannot give the students the evaluation results immediately. Therefore, an automatic evaluation mechanism is designed in this system. For example, in the digital modulation experiment, the BER of the receiver is usually used to measure the performance of the communication system. The online experiment system can automatically measure the BER performance of the communication system designed by the students, thus indicating whether the students have reached the experimental requirements. The adoption of this automatic evaluation mechanism can greatly reduce the workload for teachers to check and accept the students' experimental results, and also enable students to check the experimental results at any time.

4) Plagiarism of experimental codes: For programming experiments, the most headache for teachers is the plagiarism of students' experimental codes. In the lab experiment, teachers can only see the experimental results, but cannot observe the experimental process. If the students' codes are the same, they cannot judge which students are plagiarizing. Therefore, an automatic duplicate checking function is adopted in the online experiment system to avoid plagiarism. When a student submits a code, the system will automatically compare it with the code that has already been submitted. When the similarity ratio of the code is more than 60%, the system will judge that the code is suspected of plagiarism, and then reject the submission of the code so that students can revise the code again. This measure can reduce students' plagiarism to a certain extent.

V. Usage of the Experiment System

The online experiment system is used in the School of Electronic Information and Communications, Huazhong University of Science and Technology. In the second semester of year 2019-2020, 28 students from Seed Class, which is established for undergraduate program for advanced project-based information science education, have used the online experiment system in the course of Principle of Communications.

There are two online experiments in our class: Differential Phase Shift Keying (DPSK) modulation and Frequency shift keying (FSK) modulation. The students are asked to program the modulation and demodulation codes for the two formats, which are the typical digital modulation schemes.

After the experiments, a survey is performed to assess the effect of the online experiment system, and 24 students give the positive comments. In the future, more students will utilize the online experiment system and more feedback data will be collected.

VI. Conclusion

In order to solve the problem that students cannot enter the laboratory to complete the experiment of Principles of Communications during the pandemic, this paper proposes a design scheme for the online experiment system of Principles of Communications, upgrading the original lab experiment content to the online experiment content, which not only solves the problem of students completing the experiment remotely, but also realizes the all-weather opening of the online laboratory, greatly improves the use efficiency of SDR equipment. The scheme increases the time for students to participate in the experiment, increases the interest of students in participating in the experiment, and provides a new direction for the teaching practice reform of Principles of Communications.

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