Construction of a computer simulation platform for optical experiments

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Abstract

With the rapid development of computer technology, computer-assisted instruction for complex and vulnerable optical experiments has become possible. Computer simulation technique has become an important branch in computer application and a new means in science research and engineering design. People have done a lot of research on optical experiment simulation. But there are still many defects, such as no friendly graphical user interface and the parameters cannot be freely adjusted. We design and develop a well extensible and portable simulation platform for optical experiments including basic optics experiments, information optics experiments and laser experiments and realize flexibility in setting the experimental parameters. Young's double-slit interference experiment, Fraunhofer diffraction experiment and grating diffraction experiment are conducted to show the effectiveness, efficiency and correctness of our simulation platform. The abstract and difficult optical concepts and rules are vividly manifested through the simulation experiments and become easier to understand for the students. The simulation platform will break through the limitation of teaching space, experimental equipment and various other factors and enable students to preview experiment, understand experiment, complete experiment and review experiment much better.

Keywords: optical experiment, simulation platform, interference and diffraction

1 Introduction

The optical experiment instruments are generally sophisticated and expensive. With the expansion of the scale of the university's enrolment students, laboratory equipment is difficult to meet the requirements. Because of the relative shortage of funds, schools are difficult to purchase a large number of laboratory equipment. The students usually carry out experiments in small group. At the same time, there is a certain limit in experimental class, so there are not conducive to students' understanding of the experiment in time and space. Optical experiments have the features of complex operation, difficult understanding of phenomenon, and stringent requirements of experimental data. These factors tend to limit the students to set up the experimental parameters and repeatedly adjust the instrument to observe different phenomena in order to achieve full understanding of the purpose of the experiments [1-4]. The teachers and the students can be freed from the limitations of the experimental apparatus and experimental sites by the use of computer simulation of optical experiments, which will reduce the experimental loss, make accurate simulation of the experiments and help the students to intuitively and easily observe the experiment phenomenon.

In the experimental teaching, the theoretical knowledge involved in the optical experiments is more esoteric than mechanics and electrics. For example, in the experimental teaching of ray diffraction and light interference, the students cannot see the experimental phenomena, so they will think that the experimental principles are arcane. Some teachers draw the light intensity distribution curve on the blackboard and hand-painted the interference fringe pattern of light and dark. They hope the students will get a better understanding of graphics. However, the teachers' hand drawings are unmatched real phenomena, so the students find it boring, abstract and difficult to be understood, which will even result in the theory and experiment out of touch.

Teachers are also hard-pressed to express the experimental phenomena to the students; therefore, they think that this teaching method is of many deficiencies. In order to enable the students to witness the experimental phenomenon, some teachers personally carry out the experiments to help the students directly to observe the experimental results. But this teaching method is also deficient. It will not only waste the time and will deprive the students to explore their own experiments and the opportunity to exercise experimental ability. This experimental teaching become a repeated mechanical labour of the students from the teachers' experimental procedure and is not conducive to improve the students' ability to experiment.

With the continuous development of computer technology, computer-aided teaching is introduced into the modern education system and becomes an interesting teaching subject from theory to practice [5-14]. Computers have powerful computing, graphics and image processing ability. The use of computer is very useful in

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the simulation of difficult experiments in the actual operation. The use of computer simulation in the experiments is to break the traditional physical experiments. It will enable the students to better understanding and completion of the experiments and is a very good teaching method for the optical experiments.

Therefore, the use of computer simulation is no doubt an effective experimental teaching adjunct. However, the traditional computer software involves a lot of repetitive and complex programming work. There is a certain degree of difficulty to master. Matlab has powerful symbolic computation and numerical calculation function. The language used in Matlab is intuitive and easy to understand. It will automatically determine the required number of points, the location of the axes, and automatically draw the graphics. The programming is simple, easy to operate and easy to grasp.

2 Computer simulation of optical experiments

In the field of engineering design, through the study of object model, a computer program system run and get the results to find out the optimal solution. The solution will be implemented physically. This is the computer simulation science. In the growing popularity of the computer, the computer simulation technology as a means of virtual experiment has become an important branch of computer applications. It is a new means of understanding the objective world.

The computer simulation is achieved by the running of the simulation programs. Simulation programs firstly set certain parameter values of model to describe the system characteristics. Some of the variables in the model are to be changed in the specified range [8]. The specific circumstances and results of the system movements can be obtained by calculating the variables. The simulation program has a variety of functions.

The computer can display the entire process of the system movements and the various phenomena and status arising in this process. In order to facilitate the observation, the process can be effectively controlled. By changing the external conditions of the system and setting of different parameters of the system, a variety of different characteristics of the system movement can be studied and found. Since computer is of high-speed operation, the simulation system can quickly respond accordingly when the entering experimental conditions and data changed [9]. Using the random number given by the computer system, probabilistic characteristics and the corresponding state of phenomena can be given by certain calculation of the values.

Therefore, the computer simulation has good controllability. The parameters can be adjusted wantonly. The simulation is non-destructive. It will not cause damage to the device or accidents because of unreasonable designs. It is reproducibility, that is, it can exclude a variety of random factor effects, such as temperature, humidity, etc. Also, it is easy to observe the

phenomenon which are difficult to be observed in practical experiments.

The computer simulation of optical experiments includes theoretical experiment and application experiment [15-18]. Theoretical experiment is to move the optical experiments into the computer. The main purpose is to increase students' understanding of the basic theory and to grasp and predict the experimental results. This theory simulation method is very important in scientific research. With the development of computer technology and photovoltaic technology, many of the traditional optical experiments have gradually broken away from the experimental platform and get into the computer simulation environment, such as digital holography [16].

The hologram recording and reproducing can be all digitalized, which makes it easier to measure and analyse quantitatively. In some areas, it has entered the practical use. In addition, the combination of optics and computer is the development trend of optics and optical experiments. Application experiment is to fully develop students' potential and initiative. It starts from a practical engineering problem to discuss the optical applications, so that students will cogitate gradually from the ideal assumptions to the interpretation, analysis and exploration of solutions of practical engineering problems, which will inspire and nurture the students' learning and development capabilities and creativity to solve practical engineering problems. The students can not only master the traditional knowledge but also learn new technology and broaden their horizons. By the optical experiment teaching with computer simulation, the students will really integrate theory with practice and improve their practical ability and innovative ability.

3 The framework of the optical simulation platform

The optical simulation experiment platform includes basic optical experiments, information optics experiment, and the laser experiments, as shown in Figure 1. To improve the scalability of the platform, it used modular design. Each specific experiment is taken as a module for system maintenance, so it is very convenient for adding new experimental simulation.

To allow users to better understand and think about the experiments, the interface in each experiment was added the purpose of the experiment, the experimental principles, experimental steps, thinking questions and other information. Students can enter the corresponding interface for the learning of basic theory. Every window of each experiment was divided into three areas: parameter settings area, the command control area, the simulation results area. Experimental parameters of every experiment are adjustable. The experimental parameters can be set flexibly, and the results can be visualized. The users can observe the different phenomenon under a variety of experimental parameters.
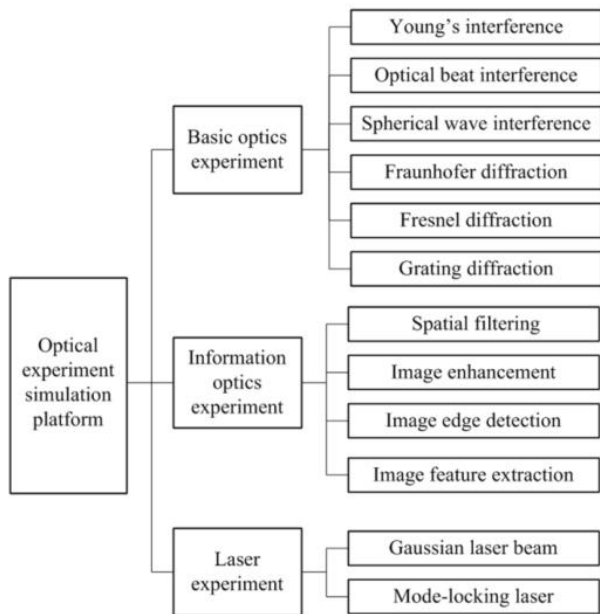
FIGURE 1 Simulation platform of optical experiment

The simulation platform constructed by the above method has friendly interface, simple operation, high portability, scalability and good security. This method makes a breakthrough on teaching space, equipment and various other factors' limitation. The difficult abstract concepts, rules are manifested through vivid simulation experiments and made easier to understand for the students.

MATLAB is a set of computer simulation software which has been widely used in optical experiment simulation. It allows the users to program in mathematical form and has powerful graphics capabilities. It has many graphics library functions, which can be used to draw all kinds of complex two dimensional and multi-dimensional graphics. Users can create a graphical user interface to achieve communication between users and computers. However, the powerful capabilities of MATLAB need the installation of MATLAB system in computer, which gives a big inconvenience to engineering calculations. At the same time, the MATLAB program can be seen directly, which is not conducive to software security and maintenance.

With the development of computer technology, people use MATLAB simulation system for the implementation of optical experiments and conduct a lot of research, but still there are many defects such as no graphical user interface, hence the user must master the language MATLAB and then can adjust the parameters in the experiments program. It is lack of laser experiment simulation. The program cannot run from the MATLAB environment. In response to these shortcomings, we will conduct a comprehensive simulation of the optical experiments and produce a simulation experiment platform including basic optical simulation experiments, information optics simulation experiment and the laser simulation experiments. The platform is of great

scalability, portability of optical experiments. It can really be applied to optical theory and experimental teaching to enhance students' interest in learning. The students can better understand, complete and grasp the experiments.

4 Simulation of Young's interference experiments

In the normal Young's double-slit interference experiment, the interference fringes will change insignificantly by changing the experimental parameter. It is difficult to observe and demonstrate all the characteristics of the experiment. In addition, the experiment requires specific equipment and places which will bring the teaching and research a lot of inconvenience. The experiment can be easily done with our simulation platform based on the theory of Young's double-slit interference. Emulator can display the interference pattern and the light intensity distribution curve whenever the monochromatic or non-monochromatic lights incidence, and will calculate the corresponding fringes spacing and contrast of specific points. We had designed friendly graphical user interface. Users can set different experimental parameters and qualitatively and quantitatively analyse the experimental results of various parameters.

Set the double-slit distance of the experiment apparatus is d, and the distance between the screen and the slit is D. The origin point of the coordinates on the screen is O and is symmetrical with the two slits. The two light source slits meet the interference condition of same vibration direction, same frequency and constant phase difference. When two lights meet in space, interference phenomenon will appear [18]. Bright and dark interference fringes will appear on the screen. Let OP = y, then we can know from the geometric relation that the distance between two interference sources and any point of the screen P is:

$$r_1 = \sqrt{D^2 + (y - \frac{d}{2})^2}$$
$$r_2 = \sqrt{D^2 + (y + \frac{d}{2})^2} \qquad (1)$$

The optical path difference of the two interference lights is $\Delta r = r2 - r1$; the phase difference is $\Delta\varphi = \frac{2\pi\Delta r}{\lambda}$. λ is the wavelength of light. Set the amplitudes at point P on the screen of the two light waves are E_1 and E_2 respectively, and the light intensities are I_1 and I_2. The amplitude of the superimposed waves is:

$$E = \sqrt{E_1^2 + E_2^2 + 2E_1E_2\cos\Delta\varphi}. \qquad (2)$$

The light intensity is:

$$I = I_1 + I_2 + 2I_1I_2\cos\Delta\varphi. \qquad (3)$$

Let the amplitudes of the two light waves are equal when they meet at the point on the screen, then the light intensity of the point P is:

$$I = 4I_0\cos^2(\frac{\Delta\varphi}{2}). \tag{4}$$

Interference bright stripes will meet the condition:

$$\Delta\varphi = \pm 2k\pi, k = 0,1,2,3, ... \tag{5}$$

Interference dark stripes will meet the condition:

$$\Delta\varphi = \pm(2k + 1)\pi, k = 0,1,2,3, ... \tag{6}$$

Figure 2 is the interference pattern and the interference intensity distribution curve of monochromatic light and Figure 3 is that of non-monochromatic lights.
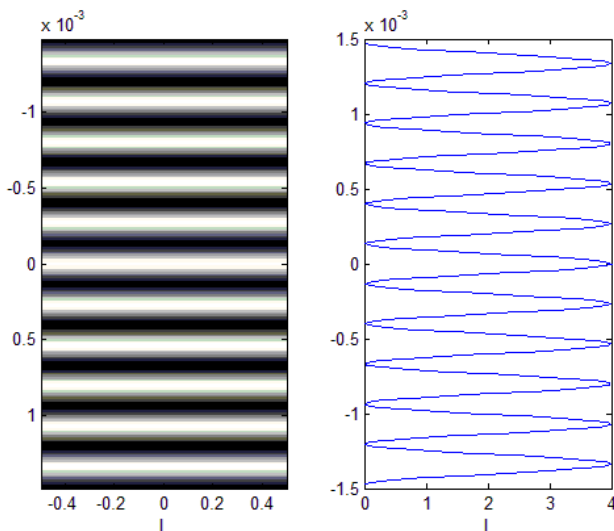
FIGURE 2 Young's double-slit interference pattern and the interference intensity distribution curve of monochromatic light
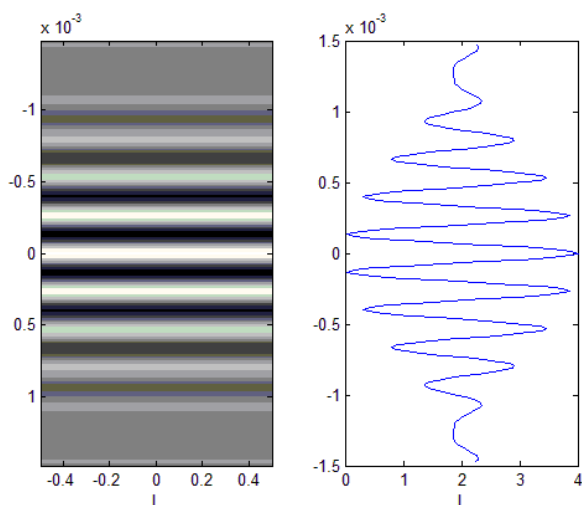

FIGURE 3 Young's double-slit interference pattern and the interference intensity distribution curve of non-monochromatic light

The results show that our simulation platform can draw directly two cases of monochromatic and non-monochromatic light conditions of Young's double-slit interference pattern and the light intensity distribution curve, and can simultaneously calculate the corresponding fringe distance of spacing and degree of contrast. The simulation results and the theoretical calculation are completely consistent. When the incidence light is monochromatic or non-monochromatic, the simulation results and the theoretical derivation are completely consistent. The drawings are delicate, realistic and distinct, which can help to observe and analyse the experiments. In addition, the users can visually analyse the interference results with different parameters. The simulation makes the whole physical process objective and offers a new effective supplementary means for optical theory analysis and experiment teaching.

5 Simulation of light diffraction

Diffraction is a fundamental phenomenon in the light wave propagation. Usually it is divided into two types: Fresnel diffraction and Fraunhofer diffraction. These two diffractions are also called the near-field and far-field diffraction. In optical diffraction experiments, the instruments should be with extremely high precision [19]. During the experiment, it is vulnerable to a number of factors, so the operation is very difficult. People have been conducted a lot of research on the Fraunhofer diffraction simulation experiments, but still there are many defects such as no flexible emulation interface to set parameters and the impact of the changes of wavelength and lens focal length on the diffraction results cannot be easily observed. The use of our simulation platform to do the optical experiments will allow users to intuitively and easily simulate and observe the experimental phenomena.

The Fraunhofer single slit diffraction intensity formula is

$$I = I_0(\frac{\sin(u)}{u})^2, \tag{7}$$

where $u = \frac{\pi a\sin\theta}{\lambda}$, and   is the slit width,   is the diffraction angle,   is the wavelength of the incident light.

The centres of the dark stripes meet the condition:

$$a\sin\theta = \pm 2k\frac{\lambda}{2}, k = 1,2,3, ... \tag{8}$$

The approximate centres of the bright stripes meet the condition:

$$a\sin\theta = \pm(2k + 1)\frac{\lambda}{2}, k = 1,2,3, ... \tag{9}$$

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Set the single-slit width is a. We use the Huygens–Fresnel principle to calculate the diffraction light intensity distribution on the screen. Huygens postulated that every point on a primary wave front acts as a source of spherical secondary wavelets and the sum of these secondary waves determines the form of the wave at any subsequent time. Fresnel developed an equation using the Huygens wavelets together with the principle of superposition of waves, which models these diffraction effects quite well [19]. The wave front is divided equally into N parts, that is, N sub-bands. The amplitude E_0 of every sub-band on the point P of the screen can be regarded approximately equal. As for diffraction angle, the optical path difference of any two adjacent sub-band is $\Delta = \frac{a}{N}\sin\theta$, then the phase difference is:

$$\Delta\varphi = \frac{2\pi}{\lambda}\frac{a}{N}\sin\theta. \tag{10}$$

The combination amplitude of the point P on the screen is equivalent to the overlay of N same direction, same frequency simple harmonic vibrations. So the amplitude at point P on the screen is:

$$E = E_0 \frac{\sin(\frac{N\Delta\varphi}{2})}{\sin(\frac{\Delta\varphi}{2})} = E_0 \frac{\sin(\frac{\pi a}{\lambda}\sin\theta)}{\sin(\frac{\pi a}{\lambda N}\sin\theta)}. \tag{11}$$

Because $I = E_0^2$, the light intensity is:

$$I = I_0 \frac{\sin^2(\frac{\pi a}{\lambda}\sin\theta)}{\sin^2(\frac{\pi a}{\lambda N}\sin\theta)}. \tag{12}$$

Figure 4 is the diffraction pattern and light intensity distribution curve with the wavelength close to the slit width, and Figure 5 is the diffraction pattern and light intensity distribution curve with the wavelength greatly less than the slit width.
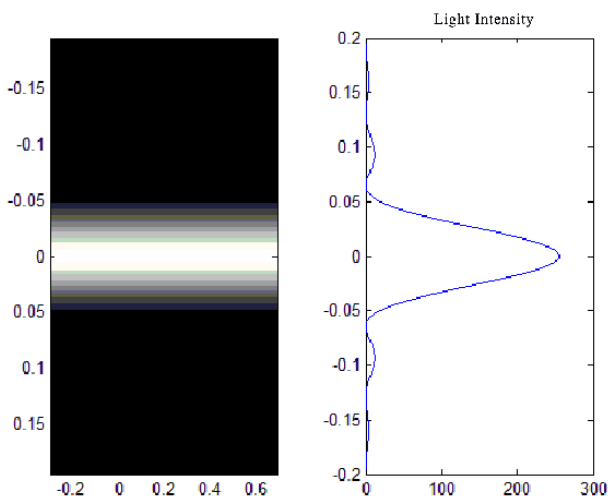

FIGURE 4 Diffraction pattern and light intensity distribution curve with the wavelength close to the slit width
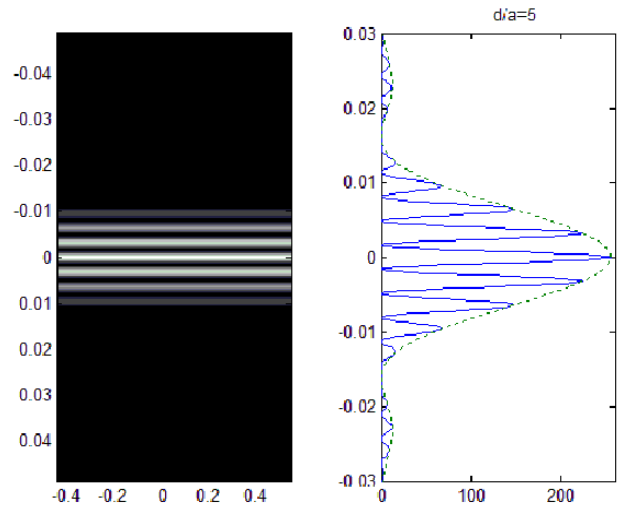

FIGURE 5 Diffraction pattern and light intensity distribution curve with the wavelength greatly less than the slit width

The Fraunhofer grating diffraction intensity formula is:

$$I = I_0 \left(\frac{\sin(u)}{u}\right)^2 \left(\frac{\sin(Nv)}{\sin(v)}\right)^2, \tag{13}$$

where N is the grating number, $u = \frac{\pi a \sin\theta}{\lambda}$, $v = \frac{\pi(a+b)\sin\theta}{\lambda}$, and a is the slit width of the transmittance part; b is the slit width of the opaque part; d=a+b is called the grating constant.

Figure 6 is the grating diffraction pattern and light intensity distribution curve with different slit number and d/a value. The results show that our simulation platform can turn the light intensity distribution to luminance simulation, which will facilitate the computer simulation of relevant diffraction problems, provide multimedia understanding for the students and improve the teaching quality. The parameters can be changed to get different results for the experimental operation, which will save the time and energy for the students and teachers and improve learning efficiency and interest.
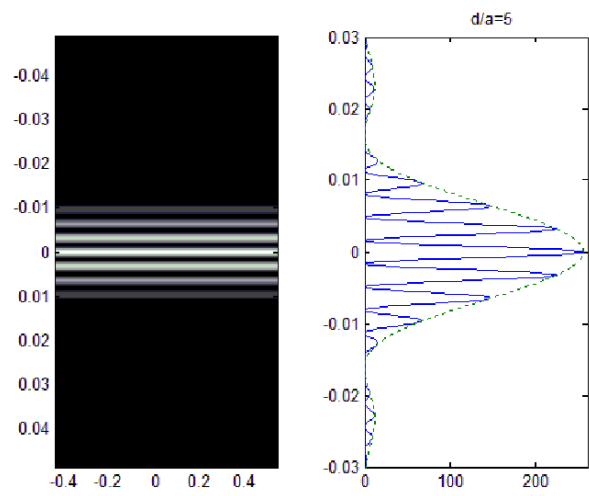

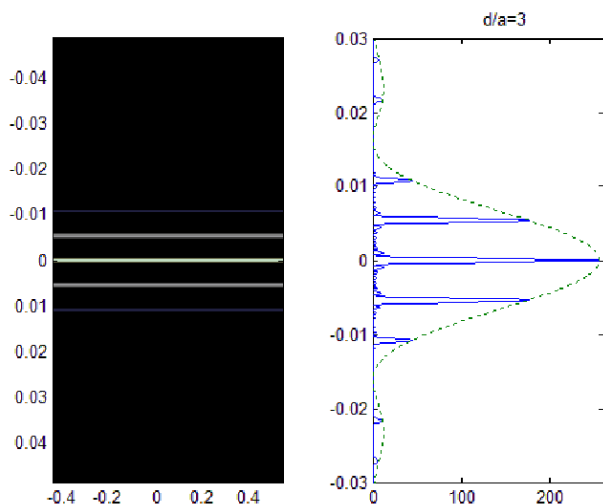FIGURE 6 Grating diffraction pattern and light intensity distribution curve with 2 slits and d/a=5

FIGURE 7 Grating diffraction pattern and light intensity distribution curve with 8 slits and d/a=3

experiments and laser experiments and realize friendly flexibility in setting the experimental parameters. The optics and computer technology are organically integrated in our simulation platform. The optical experiment lab can be moved into the computer. The simulation platform will facilitate the optical theoretical analysis, quantitative measurement and optical experiments. Thus, traditional demonstration experiments are turned into simulation experiments in the computer, which will improve the students' understanding of optical experiments and the learning initiative and enthusiasm. The case study shows the effectiveness, efficiency and correctness of our simulation platform. Meanwhile, it will bring the experiment time a lot of flexibility.

6   Conclusions

Computer simulation technology is introduced into the optical experiments. According to the basic theory of optical information, we build a computer simulation platform for basic optics experiments, information optics

Acknowledgments

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