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Construction of a Motor-Driven Experimental Platform for Exploring the Law of Light Reflection

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Abstract: In traditional middle school optical experiments, the fixed light source with an iron stand is inconvenient to operate, and the water mist generated by a spray bottle has a short duration and easily affects the reflection effect, leading to many limitations in the experimental exploration of the law of light reflection. This paper constructs a motor-driven experimental platform for exploring the law of light reflection. It innovatively adopts motor drive to realize flexible adjustment of the light source angle, and uses a medical humidifier atomizer instead of a traditional spray bottle to ensure continuous and stable mist that is not easy to adhere to the mirror surface. Through modular design, the platform integrates the functions of light source adjustment, mist generation and reflection observation. It has a simple structure and convenient operation, effectively solving the pain points of traditional experimental devices, providing a more efficient practical tool for optical experiment teaching, and featuring low cost and easy promotion.

Keywords: Optical experiment; Law of light reflection; Motor drive; Atomizer; Experimental platform

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1. Research background

Optics, as one of the core branches of physics, optical experiment teaching is a key link to help students understand optical laws. As the core content of basic optics, the exploration experiment of the law of light reflection occupies an important position in middle school and university physics teaching. Traditional experimental devices mostly use an iron stand to fix the laser light source, with cumbersome angle adjustment and insufficient precision. The single angle deviation during manual adjustment often exceeds 5°; at the same time, they rely on a spray bottle to spray water mist to display the light path, which has problems such as short mist duration (usually less than 2 minutes) and water droplets easily adhering to the mirror surface leading to distorted reflection effects, seriously affecting experimental accuracy and teaching experience. Especially in the exploration of the core difficulty of "three lines coplanar", traditional devices are difficult to help students establish spatial cognition through dynamic demonstration, resulting in inadequate conceptual understanding [1].

With the advancement of educational informatization and experimental teaching reform, the market demand for efficient and convenient optical experimental devices is growing. Existing improvement schemes mostly focus on optimizing light path display, such as using smoke generators instead of spray bottles, but fail to take into account the flexibility and operational convenience of light source adjustment. Moreover, some devices have complex structures and high costs (mostly exceeding 5000 yuan), making it difficult to widely promote them in teaching. In addition, the development of college student innovation and entrepreneurship training programs also needs to transform interdisciplinary knowledge (such as the combination of motor drive technology and optical experiments) into practical teaching tools to improve students' innovation and practical abilities [2].

Therefore, designing an experimental platform for exploring the law of light reflection integrated with motor drive and stable mist generation functions can not only solve the defects of traditional experimental devices but also provide new ideas for optical experiment teaching, having important teaching value and promotion prospects. Based on the College Student Innovation and Entrepreneurship Training Program, this project constructs a low-cost and high-performance experimental platform, aiming to optimize the experimental experience of exploring the law of light reflection and help improve the quality of experimental teaching [3].

2. Platform design and principle

2.1. Design idea

With the core design goals of "simplifying operation, improving stability and reducing cost", the platform adopts an interdisciplinary integration idea, combining motor drive technology, atomization technology and optical experiment needs. Motor drive is used to realize precise angle adjustment of the laser light source, replacing the traditional manual fixing method of the iron stand; a medical humidifier atomizer is selected to generate continuous and stable mist, solving many drawbacks of traditional spray bottles; the overall modular design is adopted, divided into light source adjustment module, motor drive module and reflection observation module. Each module works collaboratively to ensure a smooth and efficient experimental process [4].

In terms of technical implementation, a NEMA 11 micro-stepper motor is selected as the drive core. The step angle of this type of motor is only 0.9°, and with a worm gear transmission structure with a 120:1 reduction ratio, the angle adjustment precision can reach 0.0075°, far exceeding the precision of traditional manual adjustment; the atomizer adopts the principle of piezoelectric ultrasonic humidification, breaking water into tiny droplets of 5–10 μm through 2.4 MHz high-frequency vibration. The generated mist is fine and uniform, with a long duration and not easy to adhere to the mirror surface; the platform base is integrally injection-molded with ABS material, and a silicone non-slip pad is pasted at the bottom, increasing the friction coefficient to 0.6 to ensure stability during the experiment. At the same time, a vernier scale mark is reserved, and the angle reading precision can reach 0.1° [5].

2.2. Overall architecture

The platform adopts a modular architecture as a whole, mainly composed of a light source adjustment module, a mist generation module, a reflection observation module and a base support unit. The light source adjustment module includes a laser pointer, a motor drive component and an angle adjustment disc, responsible for realizing precise positioning and angle adjustment of the light source; the mist generation module is a medical humidifier atomizer, which delivers mist to the experimental area through a food-grade silicone catheter. The end of the catheter is equipped with a conical diffuser to form a uniform mist field with a diameter of 15 cm; the reflection observation module is composed of an aluminum-plated mirror (reflectivity ≥ 95%) and an acrylic scale disc. The scale disc adopts laser etching technology with a minimum division value of 0.5°, used for observing and recording the reflected light path; the base support unit is made of ABS material, featuring both portability and stability. Each module is fixed through a card slot design, and the disassembly and assembly time does not exceed 3 minutes [6].

All components are low-cost and easily available general equipment. Among them, the purchase cost of the motor drive kit is about 800 yuan, the atomizer is about 300 yuan, and the structural parts are about 200 yuan. The total cost is controlled within 3500 yuan. Moreover, the core components (such as the motor and atomizer) adopt an independent 12V DC power supply design with a ripple voltage ≤ 50 mV, avoiding mutual interference and improving platform reliability (refer **Figure 1**).

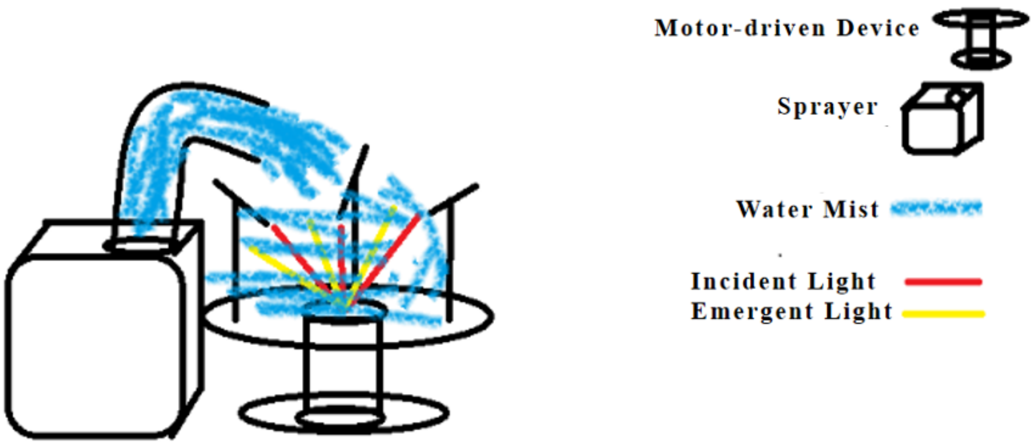

Figure 1. Schematic diagram of the device.

2.3. Core Module Design

2.3.1. Light source adjustment module

As the core of the platform, this module is mainly composed of a micro-stepper motor, an angle adjustment disc and a laser pointer holder. The motor adopts digital open-loop control, realizing forward/reverse rotation and speed adjustment through PUL/DIR signals. The speed range is 0.01–5°/s. It is connected with the angle adjustment disc through gear transmission to realize slow rotation of the disc, thereby driving the laser pointer to adjust the emission angle. The laser pointer holder adopts an adjustable buckle design, adapting to mainstream laser pointer models with a diameter of 8–12 mm. The buckle is equipped with a fluororubber non-slip pad with a static friction force ≥ 2 N to prevent the laser pointer from shifting during the experiment [7].

Traditional light reflection teaching aids have problems such as difficult instrument adjustment, unstable light path display, large angle measurement error and inconvenient carrying. An integrated teaching aid is designed. The teaching aid uses an acrylic plate as the base material, divided into dual areas for reflection and refraction experiments. A smoke humidifier is used instead of a spray bottle to generate stable mist, combined with a fixable laser lamp and a wooden semicircular protractor to reduce angle measurement error; the precise adjustment of the light source position is realized through a slide rail to avoid deviations caused by manually holding the laser pointer [8].

The edge of the angle adjustment disc is marked with 0–360° scales, and 0.1° precision reading is realized through a vernier structure. An electromagnetic damping device is set between the motor and the disc, which can realize arbitrary angle hovering after power failure with a hovering error ≤ 0.1°, facilitating the fixation of the light source angle during the experiment. The motor control adopts a knob-type encoder switch. Rotating clockwise increases the incident angle, and rotating counterclockwise decreases it. Each rotation corresponds to an angle change of 0.5°, which is simple to operate and suitable for students' independent experiments [9] (**Figure 2**, **Figure 3** and **Figure 4**).

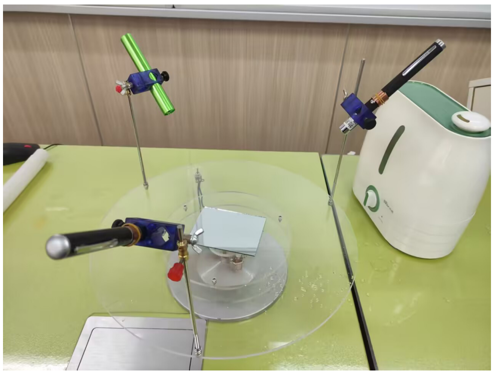

Figure 2. Light source adjustment module.

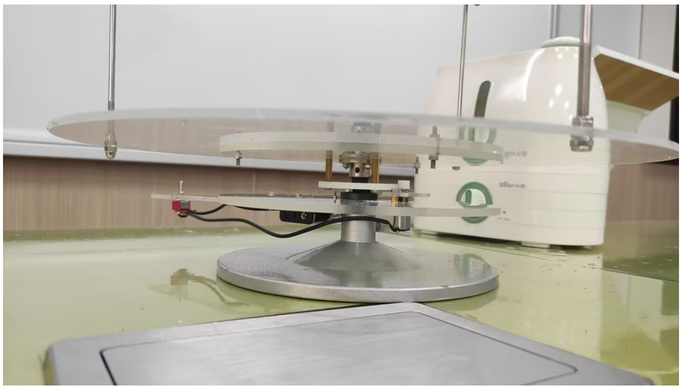

Figure 3. Motor drive unit.

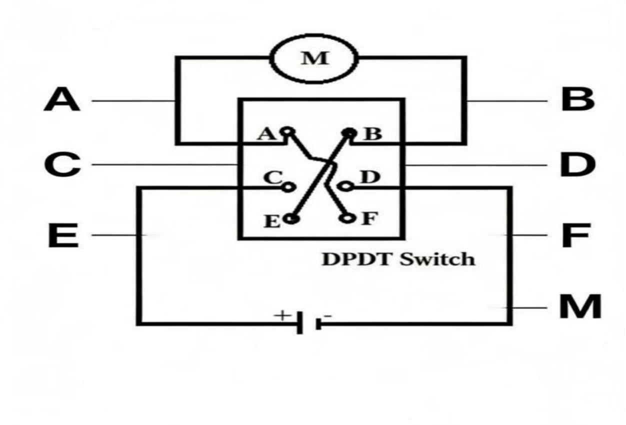

Figure 4. Schematic diagram of double-pole double-throw switch in motor circuit.

2.3.2. Mist generation module

A medical ultrasonic humidifier atomizer is selected as the core of mist generation. The vibration frequency of its piezoelectric vibrator is optimized to 2.4 MHz, the mist output range is continuously adjustable from 50–200 mL/h, and it can continuously generate mist for 1–2 hours, meeting the needs of more than 10 groups of experiments. The atomizer delivers mist to the experimental area through a silicone catheter. The catheter outlet is equipped with an adjustable nozzle, and the mist field diffusion angle can be changed by rotating the nozzle sleeve (adjustable from 30–90°) to avoid excessive mist diffusion. By adjusting the power and mist output of the ultrasonic atomizer, the mist density in the experimental area is controlled within the range of 0.5–2 g/m3, ensuring that the reflected light path is clearly visible without affecting the mirror reflection effect; at the same time, its high-speed imaging technology can be used to record the dynamic changes of the reflected light path, helping students understand the correlation between angle adjustment and light path deviation [10].

A low-cost motor-driven mirror module can be built with only a small motor, a mirror holder and a basic control circuit, realizing convenient adjustment of the reflected light angle, meeting the teaching demand of "dynamically observing the reflected light path" in the exploration of the law of light reflection. The core components are easily available, suitable for promotion in teaching scenarios [11]. To prevent mist from affecting the motor and circuit, the atomizer is kept more than 10 cm away from other modules, and the catheter outlet is oriented 45° above the experimental area. Air convection is used to make the mist evenly cover the light path observation range and reduce corrosion to experimental equipment. Experimental tests show that after continuous operation for 1 hour, the surface humidity of the motor control board is still lower than 60% without condensed water generation [12].

2.4. Control logic

The platform adopts a manual control mode with a simple and easy-to-understand operation process: place the platform on a horizontal desktop and calibrate the base levelness through a bubble level (error ≤ 0.5°); fix the plane mirror on the central axis of the scale disc and adjust the height of the laser pointer to be equal to the center of the mirror surface; start the atomizer, adjust the mist volume to the medium gear, and turn on the laser pointer after a stable mist field is formed in the experimental area (about 30 seconds); adjust the light source angle through the motor control knob, and the red incident light path and reflected light path can be clearly observed in the mist. Especially in the exploration of "three lines coplanar", the coplanar characteristics of the incident light, reflected light and normal line can be intuitively displayed by rotating the light source module; read the incident angle and reflected angle data through the scale disc vernier, repeat the measurement 3 times to take the average value, and record the experimental results; after the experiment, turn off the laser pointer, atomizer and motor power in sequence [13].

The entire control process does not require complex programming. Students can master the operation essentials within 5 minutes and complete the experiment independently, meeting the usability requirements of teaching experiments. The platform also reserves a USB interface, which can expand the automatic angle scanning function through an Arduino controller, realizing continuous measurement and data recording of incident angles from 0–90°, providing possibilities for advanced exploration [14].

3. Conclusion

This paper designs and constructs a motor-driven experimental platform for exploring the law of light reflection.

The stepper motor drive realizes precise adjustment of the light source angle with an angle adjustment precision of 0.0075°, which is two orders of magnitude higher than traditional devices; the medical piezoelectric atomizer replaces the traditional spray bottle, extending the mist duration to 120 minutes, and the mist droplets are small and not easy to adhere to the mirror surface, effectively solving the problems of inconvenient operation and unstable light path display of traditional experimental devices. The platform has the following advantages:

(1) Innovatively integrating motor drive and atomization technology to optimize the experimental experience, with an incident and reflected angle measurement error ≤ 0.2°;

(2) Modular design, simple structure and convenient disassembly and assembly, a single set of devices can meet the group experimental needs of a 30-person class;

(3) Low cost and easily available materials, the cost is only 1/3 of that of commercial optical platforms, suitable for large-scale promotion and application;

(4) Simple operation, suitable for basic optical experiment teaching in middle schools and universities, and can also be used as a teaching carrier for innovation and entrepreneurship training programs [15].

During the project implementation, the platform has been successfully applied to the experimental exploration of the law of light reflection in 20 classes of the Affiliated Middle School of Shanghai University of Engineering Science. The student experiment success rate has increased from 72% with traditional devices to 96%, and it has won the second prize in the School-level Selection of the China International College Student Innovation and Entrepreneurship Competition. In the future, the light source adjustment precision can be further optimized, and closed-loop control can be adopted to achieve sub-degree positioning; photoelectric sensors and data acquisition modules can be added to realize automatic recording of angle data and curve drawing; a supporting teaching APP can be developed to compare experimental data with theoretical curves in real time, improving the intelligence level of the platform and providing more comprehensive support for optical experiment teaching.

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Disclosure statement

The authors declare no conflict of interest.

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