Title: Remotely-Controlled Browser-Based Apparatus Enabling Low-Cost Elementary Optics Experimentation

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Abstract:

A remotely-controlled apparatus enables students to conduct experiments on the polarization of light and thereby demonstrates the sensitivity of photons to mechanical intervention. The experiment investigates how a laser beam is impacted by the angle between two linear polarizers. Each experimental component is connected via the internet to a web-based platform making the apparatus universally accessible to instructors and students. Ultimately, the apparatus may be improved/revised to include more sophisticated photonics experiments.

Construction:

A budget and comprehensive list of the equipment pieces used in the apparatus can be found in Appendix A. A detailed bird's eye drawing of the apparatus can be found in Appendix B. Our apparatus is composed of both hardware and software elements. The hardware consists of a base, mounting, laser source, light-dependent resistor (LDR), optics, and stabilization equipment. Our base is constructed with two 27" x 12" plywood boards which are screwed together using four ⅝" wood screws to provide "top" (of 0.25" depth) and "bottom" (of 0.75" depth) parts of the base. Within the top base only, we cut small plots into which the mounts are inserted. This allows for any needed modifications/exchanges of mounting while also supplying stable support for each mount.

For the laser mount, a 0.75" by 1.25" plot is cut from the top base, centered along the width of the base, and starting 3.75" in from the left most side of the base. The laser mount is made of a rectangular strip of plywood 3" in height. A hole is drilled using a 0.5" drill bit to a 2" depth. A factory-made MTO-laser steel mount, which consists of a cylindrical (13.55mm inner diameter) shell atop a thin 2" rod, is inserted into this 0.5" diameter aperture. A 1" bolt is then fastened into the side of the wood mount 2.25" from the bottom until contact is made between it and the steel MTO rod. This helps to secure the MTO-laser mount in the wooden component of the laser mount. Similar to all mounts in the apparatus, this wood and steel mount is then inserted into its 0.25" deep plot in the top base where it stands securely and may be removed for later alterations. The laser can then be placed inside the metal shell to be at a 3.5" height.

Two 0.25" by 3.5" plots are cut from the top base 7.5" and 18" in from the leftmost side of the base to host the polarizer mounts. Both polarizer mounts are made of 5.5" tall plywood boards in which a 1.5" diameter aperture is drilled in each. The center of these apertures are 3.5" above the surface of the top base and centered laterally (1.75" in from either side of the board).

The LDR mount is made of a block of plywood, which is screwed into the top base using two 2” wood screws, and a plastic cover screwed to the side of this block with a 0.5” wood screw. The LDR can easily attach and detach from this cover through two small 0.25” machine screws on the top and bottom of the cover. The target for the laser beam on the LDR stands 3.5” above the top base as well.

The optics equipment pieces and secondary components are attached to these wooden mounts. The secondary components are utilized to decrease the chance of damage to polarization and electronics equipment and increase their maneuverability for remote control.

For Polarizer #1 a 58mm to 55mm step-down ring adapter was centered and glued on the wooden mount using epoxy. Polarizer #1 can then be fastened onto this ring adapter by utilizing its built-in screwing/rotation mechanism.

A 55mm to 58mm step-up ring adapter is epoxyed in this same way to polarizer mount #2. Polarizer #2 can then be screwed onto its mount. To allow rotation of Polarizer #2, we screw a 58mm to 55mm step-down ring adapter to the open side of the polarizer and glue a 58mm diameter, 56 tooth, plastic gear to the adapter. Implementing this additional ring adapter ensures that no glue remaining on the back of the gear will block the manufactured rotation mechanism in the polarizer.

We fasten a second gear (a replica of the polarizer gear) on the servo using two small screws. To fasten the servo on the second polarizer mount, we first laser cut a plastic holster which surrounds the left, bottom and top sides of the servo. The holster is cut from a 3.75” by 1.75” plastic board. A 2.25” by 0.75” rectangle is cut out from the board’s top right corner. A 1.5” by 0.75” rectangle is then cut out starting from the left side of the previous cut and 0.25” from the top of the board. The servo is able to rest securely inside this cut crevice. A 0.2” diameter hole is then drilled 0.5” from the bottom and 0.1” from the right side of the board. We then drill a 0.2” diameter hole into the second polarizer mount ⅞” above the top base and ⅝” from the right side of the mount. We insert a 2” bolt through this drilled hole and the 0.2” hole in the plastic servo holster. The plastic holster should now be fastened on the same side of the mount as the polarizer as shown in Appendix B. A 0.25” nut is used from the opposite side of the mount to secure the holster and servo on the side of the polarizer mount. The gear on the servo should now interlock with the second polarizer gear. This also allows the option to “detach” the servo from the mount by loosening the nut around the 2” bolt and rotating it away. Thus, the polarizers, gears, and servo are all mounted securely with little risk of damage to the equipment, diligent attention to safety, and increased mobility.

Our apparatus construction has a software aspect as well. The primary goal of our software is to enable certain components of the apparatus to be remotely controllable or accessible over the web. There are three components which are accessible online: the laser, the servo, and the LDR. Each component is centrally connected to a Raspberry Pi which is an essential element in allowing the exchange of information or commands from remote instructors or students online. It is powered by an electrical outlet and USB cord.

Users are able to turn the laser “on” and “off”. This mechanism works by connecting the laser diode’s anode and cathode pins to a breadboard which can provide the laser with the required 5V. The power to this breadboard is controllable from the Raspberry Pi through a connection to its GPIO pins.

Users are able to control the rotation of the servo. The servo's ground and control signal pins are connected directly to the Raspberry Pi-breadboard system. The servo requires more voltage then the laser. We draw power directly from an outlet by using a socket to 12V DC power converter, plugging this DC power cable into a DC power to pin converter which can connect easily to the power pin on the servo.

Users can also read an output value from the LDR, which displays measurements of light in lux (a unit from which luminous intensity can be derived). The LDR is a type of photoresistor and contains two legs which can be connected to pins on the Raspberry Pi. We apply a constant voltage to one leg through the Raspberry Pi and insert an analog to digital signal converter on the other output leg. We connect this converter to a digital input pin on the Raspberry Pi. This enables us to read the lux value resulting from the LDR based on the incoming intensity of the laser beam.

The Raspberry Pi can connect to the internet through a wireless connection to a modem-router system. We have constructed a web server through Digital Ocean (a cloud infrastructure provider) that hosts an online platform where users can access the apparatus remotely. Users can send commands to and receive updates/values from each component through a websocket, written in python (code available upon request), established between the server and Raspberry Pi. This allows users to control power to the laser and rotation of the servo (and thus rotation of the second polarizer through the gears system). Users can also view information on the "on" or "off" state of the laser, the current position of the servo given as an angle, and real-time LDR values.

In addition, web cameras are positioned at strategic areas on the apparatus. We establish a live feed of the set-up from three different angles on our online platform so users may view their alterations made to the servo and laser in real-time. Using a web camera mount attached to the base of the experiment users have a bird's eye view of their experiment. Two smaller mounts are clipped to the top and left side of the second polarizer mount to provide views of the servo-gear system and the "dot", created by the resulting laser beam, on the target of the LDR. Users can therefore observe how their rotation of the servo (and thus the second polarizer), affects the intensity of the laser beam hitting the LDR. These web cameras are connected to the Raspberry Pi's USB ports. With internet connection we can then establish a live stream with the visual information being inputted to the Raspberry Pi.

Use of Apparatus:

The apparatus enables instructors to run experiments with a class or group of students which demonstrate fundamental concepts of polarization and photonics. Components of the apparatus were designed to be interchangeable such that instructors may create different lesson plans on optical physics using the same basic set-up and remote control technology. Students may also design their own apparatus, with similar size and number of parts and mounts as the current design, to explore the entire process of creating a hypothesis, constructing an experiment to test that hypothesis, and recording the appropriate data to analyze these tests. An example of a lesson plan one can utilize with this set-up can be found in Appendix C.

While the cost to construct the entire apparatus is just under $300, instructors and students may conduct trials and demonstrations for very little to no cost because our software platform enables the remote manipulation of apparatus components using a web browser. This makes the apparatus universally accessible for instructors and students across the country (and around the world) who can connect to the internet. This was a primary goal for our apparatus: to not only demonstrate optical phenomenon, but to make these demonstrations easily accessible and free to use.