

Distance Learning and Remote Controlled Laboratories for Photonics Technology

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Abstract

Most colleges cannot develop technology programs in photonics or related areas due to the large start-up costs involved. One solution is to use distance learning to access specialized technology from another college. A major roadblock to the development of science and technology courses for distance learning is the laboratory. Among the concerns is that a “real” laboratory experience is an important part of many such classes and difficult to achieve through distance learning. At Queensborough Community College, with the support of the National Science Foundation (Advanced Technological Education grant award #DUE – 9752061), we have addressed the issues of distance learning and laboratories and are adapting courses for our Laser and Fiber-Optics Technology Program for distance learning. The “problem” of the laboratory is solved by remote-controlled laboratory equipment. We have completed the work on course materials in physical optics, lasers and fiber optics. Course materials include interactive multimedia textbooks and laboratory manuals along with the remote-controlled laboratory exercises. Remote-controlled laboratory exercises include interferometry, diffraction, polarization, acousto-optics, electro-optics, second harmonic generation, Q-switching, modelocking, thermal lensing, diode laser characteristics, laser principles, optical time domain reflectometry, coupling losses, wave division multiplexing and characteristics of fiber optic switches and couplers. As course materials were developed they were tested at a remote site, Suffolk County Community College.

I. Introduction

Recently, institutions of higher learning are trying to be more accessible to students. For students who may have difficulty attending courses on campus, distance learning modalities, such as those based on using television, videotapes and the web, are actively being pursued. In this regard, all colleges are competing with one another. The case is quite different when it comes to technology programs. Most colleges can not develop courses and programs in certain areas of technology. In particular, programs in photonics and related technologies require substantial start-up costs. These costs are prohibitive for many institutions especially in light of the relatively small number of students these programs would serve. Another factor is the requirement for laboratories in many science and technology courses. Laboratory exercises involving real equipment in real

situations are an important aspect of any laboratory course. For engineering technology students there is the additional requirement they gain some “hands-on” experience.

At Queensborough Community College (QCC), with the support of the National Science Foundation (Advanced Technological Education grant award #DUE – 9752061), we developed and implemented a plan to make technology education more accessible. We have adapted courses in our Laser and Fiber-Optics Technology Program (LFOT) for distance learning. The “problem” of the laboratory is solved by remote-controlled laboratory equipment.

There are three specialized courses in our LFOT curriculum which require extensive instrumentation in the laboratory. The subject areas of the courses are; lasers and detectors, fiber optics and physical optics including modulators and a brief introduction to non-linear optics. Each course has lecture and laboratory components both of which are addressed in conversion to distance learning. Course materials include interactive multimedia textbooks and laboratory manuals along with the remote-controlled laboratory exercises. Remote-controlled laboratory exercises include interferometry, diffraction, polarization, acousto-optics, electro-optics, second harmonic generation, Q-switching, modelocking, thermal lensing, diode laser characteristics, laser principles, optical time domain reflectometry, coupling losses, wave division multiplexing, dispersion and distortion in fibers and characteristics of fiber optic switches and couplers. As materials were developed they were tested on QCC students and then tested at a remote site, Suffolk County Community College (SCCC).

II. Lecture

Classes in the LFOT at QCC are small. Lectures and recitations are generally limited to twenty-four students and laboratories to sixteen. The small class sizes provided for a great deal of interaction between students and instructors. One method to provide lectures and recitations to distant learners is through video-conferencing. QCC has a complete multimedia classroom with video-conferencing capabilities. But there will be instances where distant learners can not fit a QCC course into their schedules or a semester when a course is not available at QCC. For those situations, we have produced a complete set of videotaped lectures. Although students do not have interaction with the instructor, they can view the tapes at their own pace and review any sections as often as they wish. Remote students will be provided with individual office/recitation hours. By internet connection and the use of conferencing software with whiteboard capability, we are using Microsoft’s Netmeeting because it is available to everyone at no cost, students have their own individual time with their instructor. A private office hour so to speak.

Another adaptation we made is in the textbook. We have developed our own multimedia, interactive textbook. By making animations and video clips part of the text, students get information from the text in a way normally reserved for lecture. By adding inactivity, such as a button students must click for each diagram to appear, requires students to be active while reading the text. Where example problems are provided, each step is accompanied by its own figure, which appears as the students click on buttons. The sequential building of a complicated

figure reduces confusion. When students attempt to solve homework problems, they can get hints at each step in the process and check their solutions. Simulations are provided to help students get a feel for certain situations. For example, when discussing polarization and polarizing optics, typically one wants to know how a particular device changes the polarization and irradiance of the light. Given a specific input to a specific device, what is the output? What is the effect as the input is varied or the device is changed? Since each situation requires a calculation, it takes too much time for students to see trends in that manner. Providing some kind of analytic solution is not much better. In this case, the inputs are; what kind of device (linear polarizer, phase retarder or polarization rotator), the eccentricity of the ellipse, e , the angle the major axis of the ellipse makes with the fast axis of the retarder or the transmission axis of the polarizer, θ , the handedness and the retardation, ϕ . The results in the case of left-handed light incident on a phase retarder are:

$$E_1 = E_0 \left(\frac{1}{2-e} \right)^{1/2} \quad E_2 = E_0 \left(\frac{1-e}{2-e} \right)^{1/2}$$

where $E_0 = (I_0)^{1/2}$ and I_0 is the incident irradiance

$$E'_F = E_1 \cos\theta \cos\phi - E_2 \sin\theta \sin\phi + i[E_1 \cos\theta \sin\phi + E_2 \sin\theta \cos\phi]$$

$$E'_S = E_1 \sin\theta + iE_2 \cos\theta$$

$$\phi_F = \tan^{-1} \left(\frac{E_1 \cos\theta \sin\phi + E_2 \sin\theta \cos\phi}{E_1 \cos\theta \cos\phi + E_2 \sin\theta \sin\phi} \right)$$

$$\phi_S = \tan^{-1} \left(\frac{E_2 \cos\theta}{E_1 \sin\theta} \right)$$

$$\tan(2\theta') = \frac{2|E'_F||E'_S|\cos(\phi_F - \phi_S)}{(E'_F)^2 - (E'_S)^2}$$

$$(E'_1)^2 = [|E'_F| \cos\theta' + |E'_S| \cos(\phi_F - \phi_S) \sin\theta']^2 + [|E'_S| \sin(\phi_F - \phi_S) \sin\theta']^2$$

$$(E'_2)^2 = [|E'_F| \sin\theta' + |E'_S| \cos(\phi_F - \phi_S) \cos\theta']^2 + [|E'_S| \sin(\phi_F - \phi_S) \cos\theta']^2$$

$$\text{if } E'_1 > E'_2 \text{ then } e = \frac{(E'_1)^2 - (E'_2)^2}{(E'_1)^2}$$

$$\text{if } E'_2 > E'_1 \text{ then } e = \frac{(E'_2)^2 - (E'_1)^2}{(E'_2)^2}$$

if $\phi_F > \phi_S$ then the light is right elliptically polarized

if $\phi_F < \phi_S$ then the light is left elliptically polarized

As can be seen the analytic results are not very illustrative. But a simulation, which gives the

output for a specific situation, can be repeated over and over with varied inputs and help develop insight. The student enters the input parameters and clicks on a button (figure 1a), the simulation supplies the resulting polarization with an animation of the resulting electric field vector. When the animation is completed a plot of the vector is displayed (figure 1b).

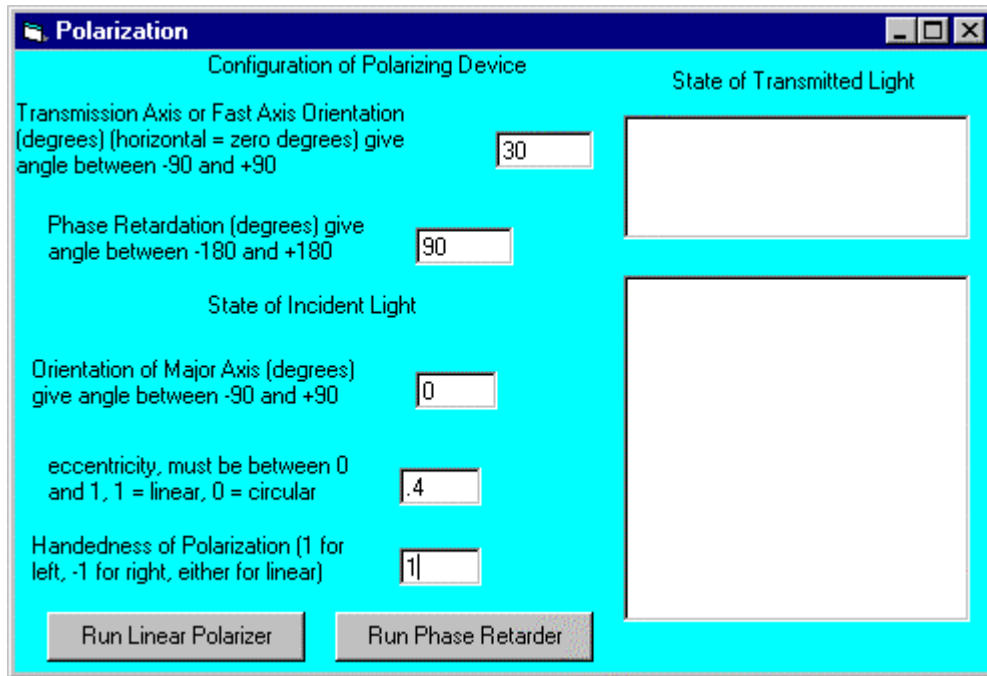


Figure 1a Polarization Simulation with input values

The interactive textbooks were written with ToolbookTM and the simulations were written in Visual Basic and LabVIEWTM

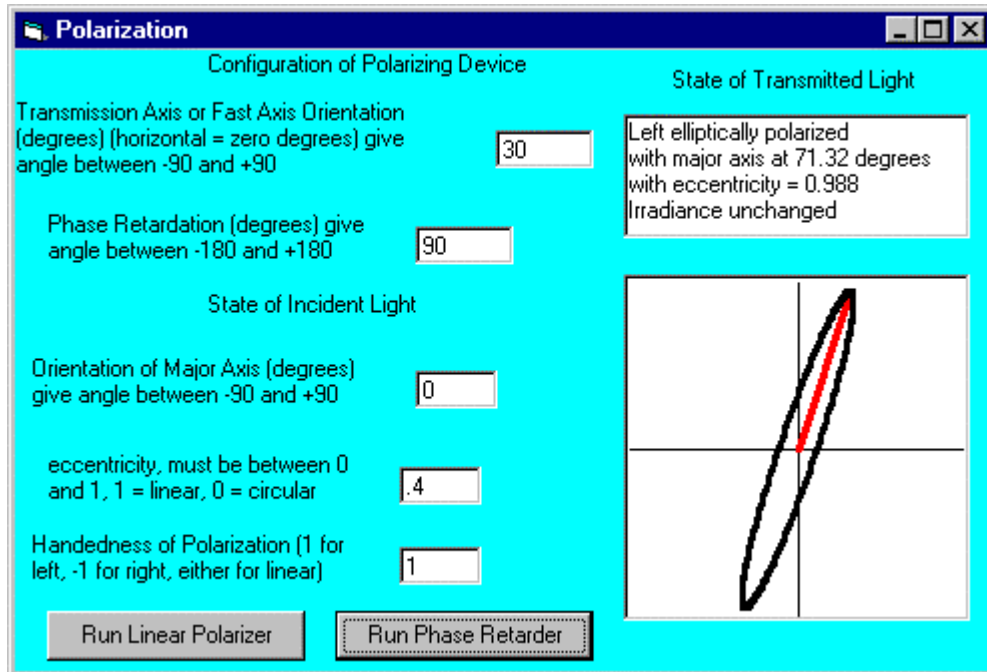


Figure 1b Results of polarization calculation after animation is complete

III. Laboratory

The laboratory required much more development. A set of laboratory exercises had to be converted or developed for remote control and instructions written. The laboratory is accessed by remote sites through the internet, with the remote user sharing control of software running on the computer in the QCC lab, which is interfaced to all the equipment. The control of QCC equipment and software is limited in a number of ways. Only those applications chosen at QCC can be shared by the remote users. When using National Instruments LabVIEW™ control of instruments can be limited by running front panels without diagrams. This is equivalent to running an executable without the source code. The program only allows for specific inputs but the program can not be altered. In LabVIEW™ a front panel without the diagrams allows only specified controls. For instance, the front panel controlling a Nd:YAG laser only contains a switch to turn the flashlamps on or off and a control for the flashlamp current. Without the ability to change the current limit, the student can not exceed preset maximum current value protecting the laser.

Laboratory exercises fit within two categories. Those that require the movement of objects of some sort such as mirrors (Michelson interferometry) and those that only require the control of instrumentation (optical time domain reflectometry). All movements of sensors, detectors, polarizers, etc. are controlled by motorized mounts. These mounts are in turn controlled by an AutoOptics™ controller box which is interfaced with the computer. Integrated Photonics Systems supplies the AutoOptics™ controller, the motorized mounts and software, both

Windows and LabVIEWTM versions.

The laboratory manual must provide instructions for students who will be working without an instructor present. We have written an interactive lab manual, which includes simulated experiments as well as simulated instruments. Write-ups contain video clips, still photos and diagrams of the experimental set-up along with simulations of the experiment. Included are simulations where the student works through the use of the software controls, step-by-step. In this way, the student becomes familiar with the “equipment” before performing the actual laboratory exercise.

Additionally, there are certain “hands-on” exercises required in each course. Since these exercises must be performed in person, students must come to QCC once per semester. Typically, students will perform three exercises while at QCC, which can be accomplished on one Saturday.

IV. Examples of Remote Laboratory Exercises

The first set of exercises students perform in the physical optics course involve the use of a Michelson interferometer (figure 2). The interferometer is aligned remotely by controlling the horizontal and vertical tilt on one mirror.

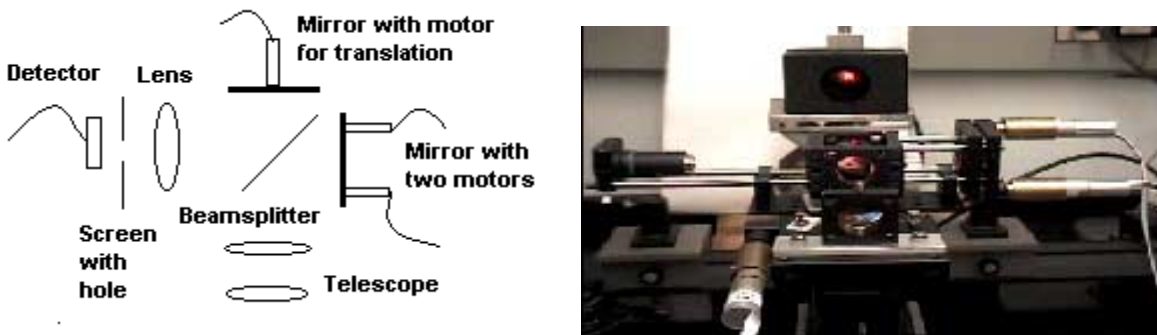


Figure 2 Schematic of Michelson interferometer with photograph.

In order to align the interferometer, fringes must be observed. A video camera allows the fringes to be seen at the remote location. The student has controls for the camera and the motors along with the video image on his/her monitor (figure 3). In one exercise the wavelength of the emission from a tunable Helium-Neon laser is measured.

The emission wavelength of the laser is selected by remote control and then measured by scanning (moving) one of the mirrors. As the mirror translates the fringes move across the detector producing a scan from which the wavelength can be determined (figures 4 and 5).

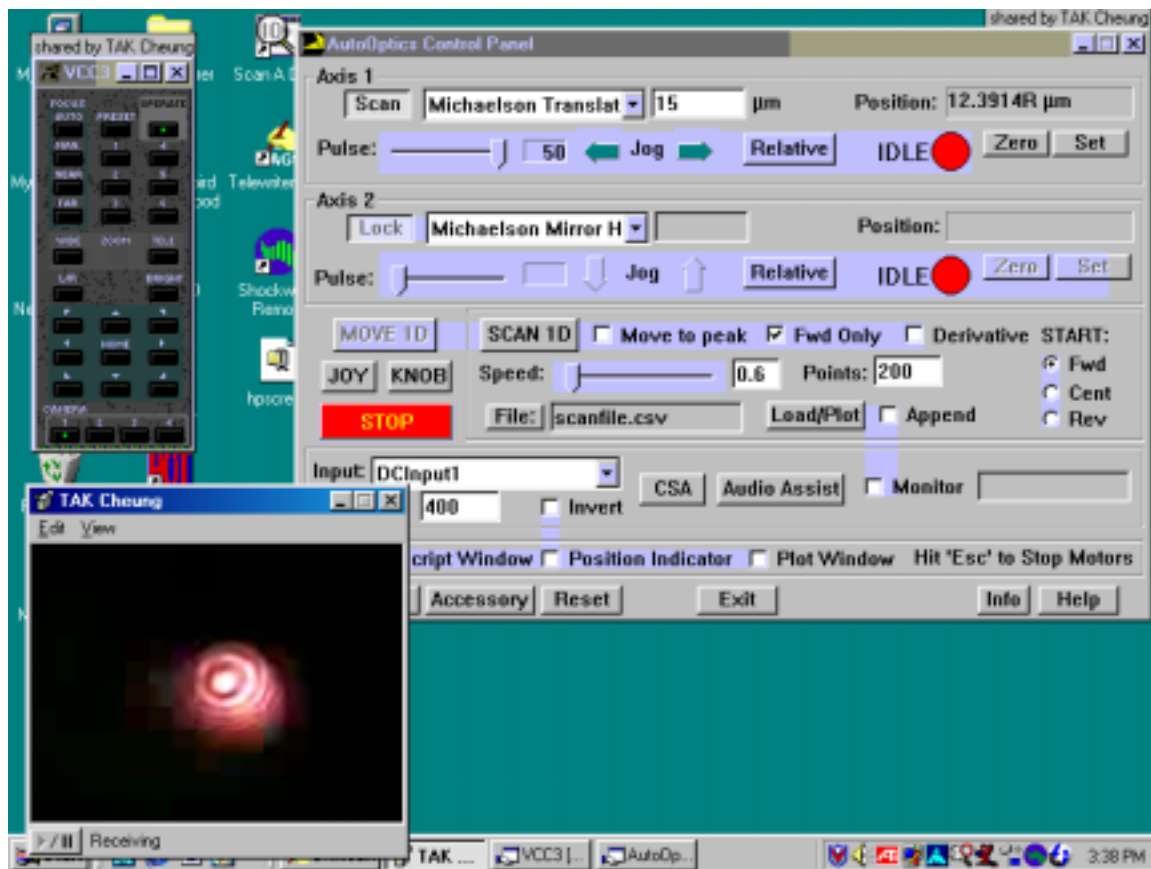


Figure 3 Computer screen with controls and video of fringes.

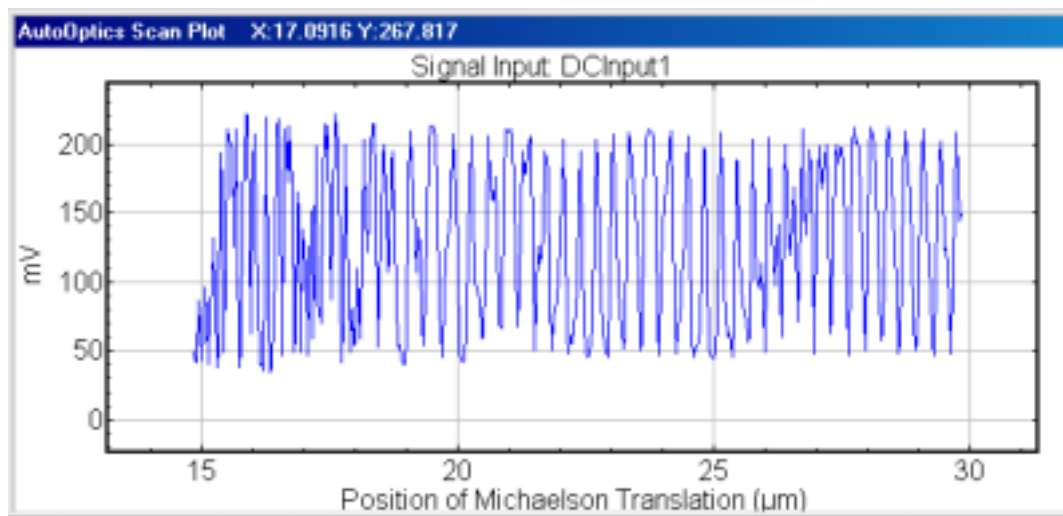


Figure 4 Actual scan for red (632.8nm) HeNe light.

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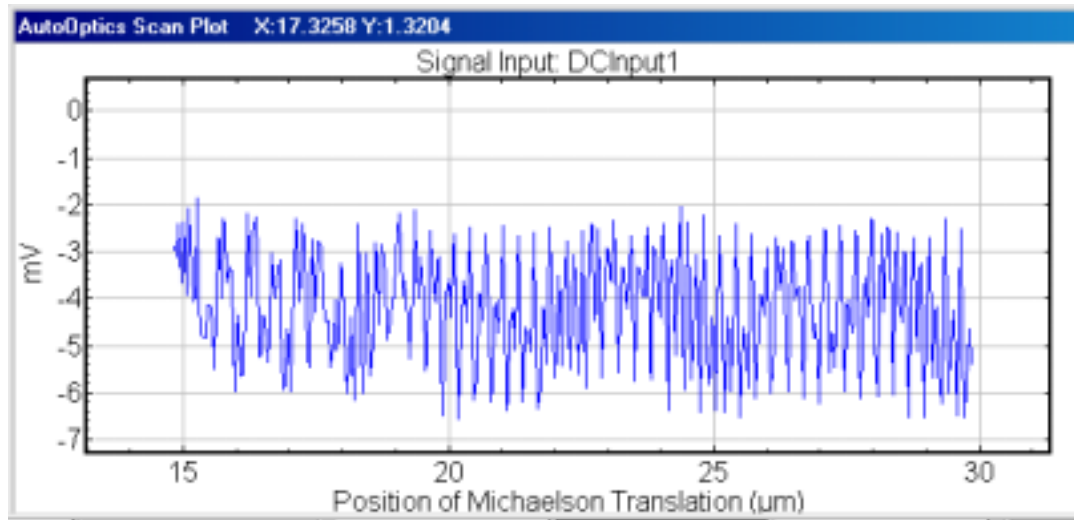


Figure 5 Actual scan fore green (543nm) HeNe light.

In the past when a micrometer was turned and fringes counted as they moved, the random errors were so large (10%-20%), there was no possibility of looking for systematic errors. In the case of remote control, the results are reproducible, the random errors are small (1%-2%) and systematics can be analyzed. For instance, it is very noticeable that on all scans the fringe spacing is larger at the start of the scan. This is caused by the “taking up of slack” in the mounts and motors.

Determination of unknown polarizations is a new laboratory exercise that was developed for the remote laboratory. It is important for two reasons; the propagation of light through and the interaction of light with materials depends on the polarization of the light and certain devices, such as electro-optic modulators, work by changing the polarization of light. Thus, before students can study electro-optic devices, they must first learn how to determine unknown polarizations. The experimental set-up (figure 6) consists of a source (laser with wave-plate) whose polarization state can be varied, and two analyzing components (a quarter-wave plate and a linear polarizer).

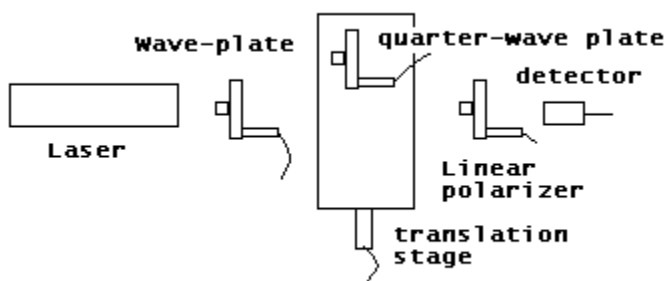


Figure 6 Schematic and photograph of polarization experiment.

The analysis is done by first measuring the transmittance through a linear polarizer as a function of angle (figure 7).

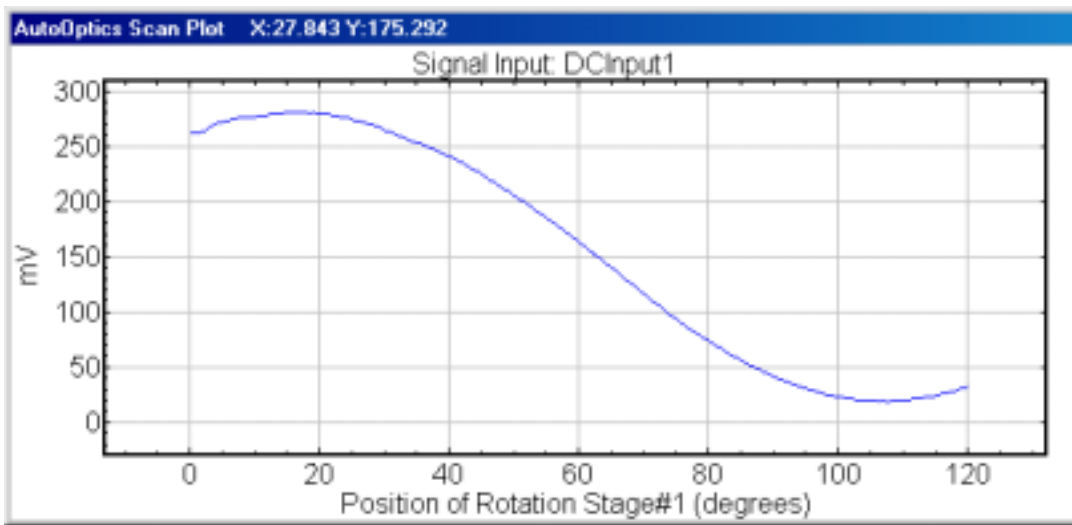


Figure 7 Transmittance through linear polarizer alone.

A quarter-wave plate is then moved into the beam such that the light must pass through it. The fast axis of the plate is aligned with the direction of maximum transmittance of the linear polarizer in the first step. The linear polarizer is then rotated and the transmittance as a function of angle measured (figure 8). Using the data in the example represented here, the analysis indicates the light was elliptically polarized with the major axis at 15 degrees.

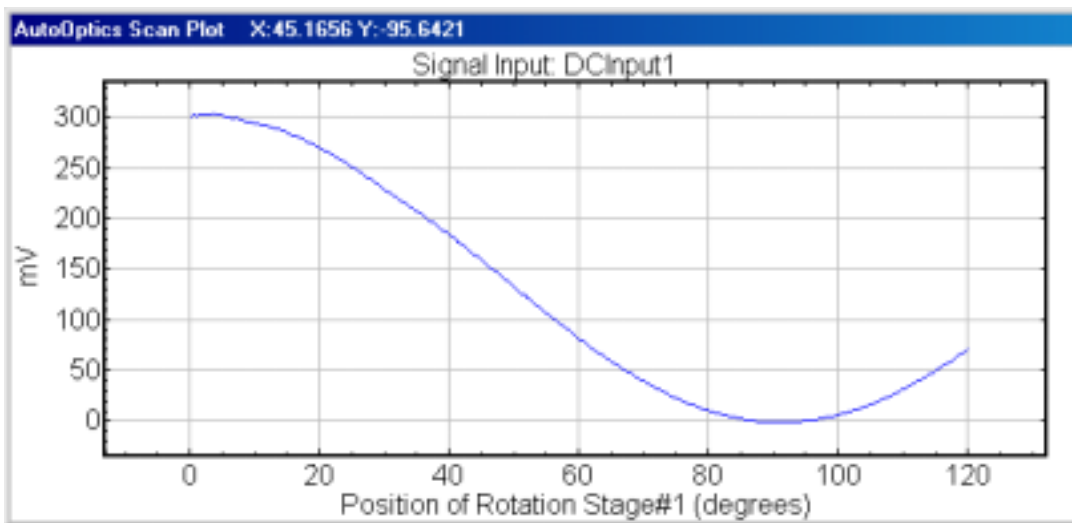


Figure 8 Transmittance through linear polarizer after quarter-wave plate is inserted.

After students perform this experiment they are prepared for the exercise on electro-optics. In

the second part of the electro-optics experiment the students determine how the electro-optic modulator works by measuring the polarization of the light transmitted by the e-o cell as a function of voltage. The exercise is the same as described above except with the e-o cell replacing the quarter-wave plate in front of the laser (figure 9).

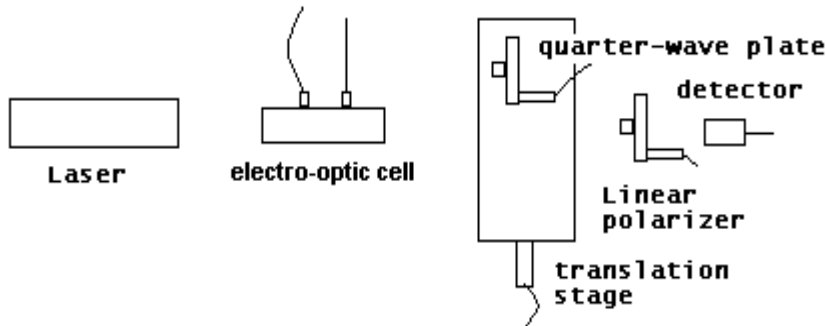


Figure 9 Schematic of Electro-optics experiment

V. Lessons from Development

As the materials were developed they underwent testing and modification. Initially, we thought we would not need to modify our original drafts very much because when tested on QCC students there were few problems. We were wrong. Once we started to test the materials with SCCC students many problems became apparent. We realized that when we tested the materials with our own students, we were around to answer their questions and help them out. The distant learners did not have that advantage. A poor laboratory write-up is not much of a problem when an instructor is in the room. In the worst case, the instructor describes the complete apparatus and procedure to the student. Distant learners require much better materials. A passable write-up is not good enough.

One example of a problem that arose with the distant learners had to do with the naming of the motors controlling the motion of different devices (refer to the AutoOptics controller panel in figure 3). In the beginning of each write-up we assigned different generic names and numbers to each motor, such as, translation stage 1 and indicated what device that motor controlled, such as an analyzer. Later the write-up would instruct the student to move the analyzer. The students tended not to remember the assignments and it was inconvenient for them to keep going back to the beginning of the write-up where the assignments were made. As a result, we needed to modify the instructions. Our first thought was to include both the motor name and what it controlled, but the students thought instructions such as “move the analyzer by moving translation stage 1” was a bit cumbersome. They suggested changing the names of the motors for each experiment such that the name was transparent. If translation stage 1 was used to translate an analyzer in one experiment and to translate a power meter in another, then the name in the first case would be “analyzer translator” and in the second case, “power meter translator”. We went with the students’ suggestion. The problem was that when the students were using the AutoOptics controller, they were selecting a motor from a pull down list and needed to remember

which name on that list was the motor they wanted. With transparent naming the choices become obvious.

Using our experience to make all the write-ups more “distant learner friendly”, we tested the laboratory exercises with SCCC students. The results of the tests were favorable. The SCCC students wrote lab reports as good as or better (their average grade was approximately 5% higher) than those of the QCC students and when quizzed on the lab material scored higher (on average approximately 10%) than their QCC counterparts. Considering that the sample is small and the distant learners may be self-selecting, it is not clear which mode of laboratory instruction is better. It is likely that the extra preparation required in order to perform the remote-controlled experiments leads to better understanding.

VI. Conclusion

Distance learning can be applied to technology courses with careful planning. These courses can be used to increase access to capital intensive technology programs. SCCC is in the process of establishing a Laser and Fiber Optics Technology program where students will take the specialized courses at QCC via distance learning and remote-controlled laboratories.

Remote-controlled laboratories can be an effective way to have students perform laboratory experiments. The development of materials not only makes courses more accessible but improves them for in-house students and enhances teaching as well. In our case QCC students benefit from improved texts, videotapes to review lectures and improved laboratory exercises and data acquisition techniques.

VII. Acknowledgements

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