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A Mechatronics-aided Light Reflection Experiment for Pre-College Students

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ABSTRACT: *Mechatronics*—increasingly recognized as a contemporary, integrative design methodology—is an interdisciplinary field of engineering with numerous applications such as medical, defense, manufacturing, robotics, and automotive systems and *smart* consumer products. Given the diverse range of engineering products and process benefiting from mechatronics, it is not surprising that the contemporary engineering students at the collegiate level receive exposure to the underlying principles and technologies of mechatronics. Unfortunately, mechatronics technology remains to percolate into the pre-college level laboratories and classrooms. Thus, the pre-college students have not yet benefited from this exciting technology. This omission is a disservice to the pre-college students. The educational experience of pre-college students can be enhanced through the use of mechatronics-aided laboratory experiments. In this paper, we illustrate the use of modern sensor, actuator, and microcontroller technologies to develop a prototype mechatronics-enabled light reflection experiment, which demonstrates the efficacy of integrating modern technology in pre-college science education.

1. INTRODUCTION

In the closing decades of 20th century, as the semiconductor and information technology industries experienced explosive growths, computing hardware became ubiquitous and cheap. A momentous transformation in the design and operation of mechanical devices and systems began to unfold, with information technology emerging as a technology enabler imparting intelligence to numerous products, processes, and machines. Microprocessors began replacing precision mechanical components, e.g., precision-machined camshaft that in many applications functions as a timing device. Thus, in recent years, engineers began developing highly efficient products and processes by judicious selection and integration of sensors, actuators, signal conditioning, power electronics, decision and control algorithms, and computer hardware and software—frequently termed as *mechatronics*.

Mechatronics brings to bear various engineering disciplines simultaneously on the problem of intelligent product design to provide efficient, cost-effective solutions. Thus, in recent years, technology applications of mechatronics have been in such far ranging fields as medical (e.g., implant-devices, assisted surgery, haptic, etc.), defense (e.g., unmanned air, ground, and underwater vehicles, smart munitions, jet engines, etc.), manufacturing (e.g., robotics, machines, processes, etc.), and automotive systems (e.g., climate control, antilock brake, active suspension, cruise control, air bags, engine management, safety, etc.) and smart consumer products (e.g., home security, camera, microwave oven, toaster, dish washer, laundry washer-dryer, climate control units, etc.). In fact, recently, *Technology Review: MIT's Magazine of Innovation* identified mechatronics as one of the "10 Emerging Technologies that will Change the World," [1].

A key aspect of any intelligent system is its ability to make smart decisions. A central processing unit (CPU) typically serves as the brain of the intelligent system. Microcontrollers are inexpensive, scaled-down CPUs that are designed to be embedded in end-user applications to impart embedded computing and smart decision-making capabilities to machines, products, and processes. Microcontrollers are designed to interface to and interact with electrical/electronic devices, sensors, actuators, and high-tech gadgets to automate systems. Recent emergence of mechatronics as a growth industry is primarily due to rapid advancements in low-cost microcontroller technology. A wide variety of low-cost microcontrollers are commercially available of which, in this paper, we focus on the Basic Stamp 2 (BS2) microcontroller [2].

Although principles and technologies of mechatronics have been widely used in consumer and industrial products, their usage as an aid for teachers in laboratories and classrooms remains to be explored. We contend that mechatronics can aid in the design, development, and operation of exciting experimental tools for pre-college science laboratories. To tap this potential of mechatronics, under National Science Foundation's Research Experience for Teachers (RET) program, the Department of Mechanical Engineering at Polytechnic University held its first annual **S**cience and **M**echatronics **A**ided **R**esearch for **T**eachers (SMART) project during summer 2003 [3]. The SMART project is designed to expose pre-college science and mathematics teachers (10 teachers/year for 3 years) to basic principles of mechatronics via hands-on activities involving sensor, actuator, instrumentation, and microcontroller technologies. During the project, the teachers learn to develop pre-college level science experiments using mechatronics tools thus gaining an appreciation for the potential of mechatronics as a laboratory aid. In preparation for the inaugural SMART project, our project team designed and developed five mechatronics-enabled physics experiments relevant for pre-college laboratories. In this paper, we focus on one of these experiments, namely, the light reflection experiment.

2. BACKGROUND

2.1. LIGHT

Light is essential to our survival. It is the driving force behind photosynthesis, the process by which various organisms, most notably plants and trees, convert carbon dioxide (CO_2) into organic material. Through photosynthesis plants release oxygen, the necessary ingredient in the air that we breathe, into the atmosphere. Because it is such a vital component of our existence, the nature of light is a subject that is generally covered extensively in pre-college science courses. However, light is also an intangible quantity in that we can sense light without actually being able to touch it. This often leads to confusion and complications for pre-college students. As an example, we will focus on reflection of light. When light hits an object some of the light bounces off the surface, while the remainder is absorbed by the object. We call the light that bounces off the surface the reflected light. To determine the angle at which the light reflects, point a flashlight at a mirror and draw a line, normal to the mirror, from the point where light hits it. Next, we define the *angle of incidence* as the angle between the normal line and the light hitting the surface. Similarly, we define the *angle of reflection* as the angle between the normal line and the reflected light. It can be shown that the angle of reflection is the same as the angle of incidence. See [4] for more details. In typical pre-college physics laboratories, the principle of light reflection is verified by tediously sighting the paths of the incident and reflected light. While this procedure does demonstrate the principle of light reflection, it shifts the focus of the student away from the subject at hand. It forces the student to concentrate on the experimental procedure rather than the underlying physical concept. The prototype mechatronics-enabled light reflection experiment of this paper automates the data collection process, freeing the student to investigate the physics behind the phenomenon.

2.2. MECHATRONICS COMPONENTS

As previously stated, the microcontroller used in this paper is a BS2. Specifically, we use the BS2 embedded in a Board of Education (BOE) development platform. These two devices are manufactured by Parallax, Inc. [5] and provide an environment that facilitates the development of mechatronics products. The BS2 is a 24-pin Dual Inline Package (DIP) integrated circuit (IC) [2, 6]. It is based on Microchip Inc.'s PIC 16C57 microcontroller. The BS2 is powered by a 6-14V direct current (VDC) power supply. A voltage regulator on the BS2 provides a steady 5VDC supply to the BS2. The BS2 comes with ROM, 2KB Electronically Erasable Programmable ROM (EEPROM), and a small amount of RAM. The BS2 is programmed in PBasic language; the instruction set that is permanently stored on the BS2 ROM. The user-defined program is downloaded into the EEPROM from a PC through a DB-9 serial cable connection between the PC and BOE. The excess EEPROM can be used for long-term data storage. The BS2 has 16 general-purpose digital input/output (I/O) pins that are user defined. The high position on a digital I/O pin refers to a 5VDC and a low position on a digital I/O pin refers to a 0VDC (ground potential). Each pin can source (supply) a maximum current of 20mA and sink (draw) a maximum current of 25mA. The 16 I/O pins on the BS2 at any given time can source/sink a maximum of 40mA/50mA. See [2, 5, 6] for more details on BS2 hardware features. We will now discuss the sensors and actuators used in the light reflection experiment along with the PBasic commands used to operate them.

As humans, we sense light with our eyes. Specifically, we recognize the presence of light when retina in the eye is stimulated by a narrow band of frequencies of electromagnetic radiation, which we call light. There are a variety of materials whose electric properties change in the presence of light. A photoresistor is a semi-conductor whose resistance is very high in dark conditions (on the order of mega-ohms), and very low in light conditions (a few hundred ohms). The light reflection experiment uses a photoresistor in a series RC circuit to measure the intensity of light. Using the *rctime* PBasic command, the BS2 measures the amount of time it takes to charge/discharge the capacitor in the circuit to a specified level. The charge/discharge time is dependent on the resistance and capacitance present in the circuit. Since the capacitor value is constant, the charge/discharge time is a direct measure of the resistance of the photoresistor. The angle of reflection is determined by the angle at which the charge/discharge time is a minimum. See [6, 7] for more details.

The light reflection experiment uses servomotors, commonly called servos, to control the angular position of the light source and sensor. A servo is a DC motor with built-in position control. In this experiment, the servos direct the light source/sensor to any specific angle using the *pulsout* PBasic command. This command directs the BS2 to send a high signal to the servo for a duration of time between 1 to 2 ms in units of 2μs. The duration of the high signal controls the position of the servo. The minimum and maximum positions correspond to 1ms and 2ms pulse durations, respectively. A linear relationship exists between the pulse duration and the angular position of the servo. This relationship is used to direct the light source/sensor to specific angles. See [6, 7] for more details.

3. EXPERIMENTAL PROCEDURE

The reflection experiment test bed consists of a light source and light sensor that can each be rotated independently in the horizontal plane. A common laser pointer is used as the light source. A photoresistor is used as the light sensor. The test bed was built so that the source and sensor have a common center and axis of rotation. The light source emits light directed at this common center of rotation. Figure 1 is an overhead view of the reflection experiment test bed. The left hand of the Figure 1, labeled *incidence*, houses the light source. The right hand side, labeled *reflection*, houses the light sensor.

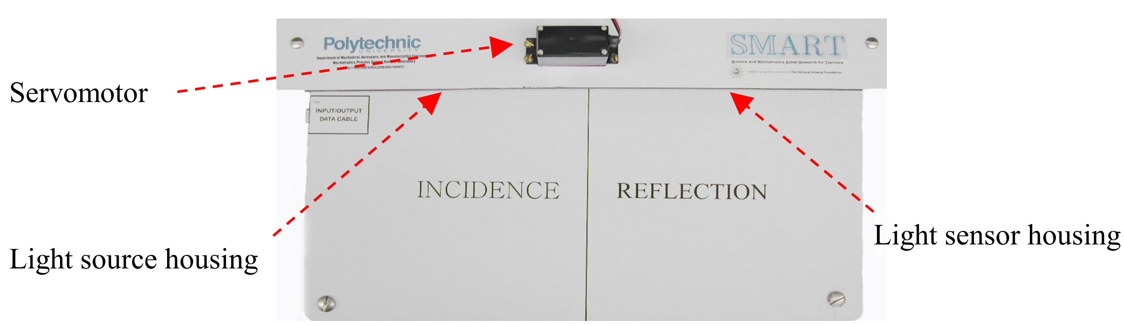

Figure 1: Top view of the reflection test bed

Figure 2 is a head on, frontal view of the test bed showing the light source/sensor arms. The light source/sensor each rotates, independently, in the plane coming out of the figure. The light source is located on the left hand side of the figure, and the light sensor is on the right hand side of the figure. In the center of the figure is the experimental material used to reflect the light. The black box at the top of Figures 1 and 2 is the servomotor used to control the rotation of the light sensor. The servo that is used to control the light source is below the test bed, hidden from sight in these two figures.

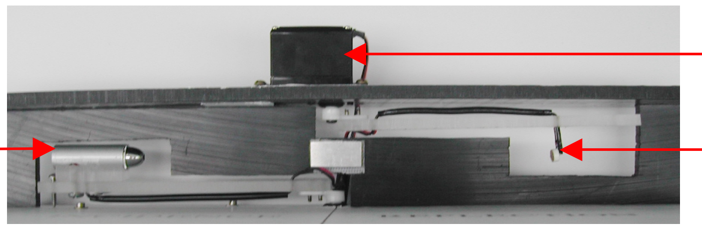

Figure 2: A view of the reflection test bed

The light reflection experiment has been designed to facilitate data communication between the BS2 and a personal computer hosting Matlab/Simulink software [8, 9]. A Matlab/Simulink-based graphical user interface (GUI) has been developed to allow the user to control the light reflection experiment and to visualize system response. For example, the servos were experimentally found to be accurate to a 2˚ step size. Thus, using a Matlab/Simulink-based control, the user-defined angle of incidence is restricted to even angles. This input data is transmitted over the serial link to the BS2, which then sets the angle of incidence accordingly. The BS2 then rotates the light sensor through 90˚ in 2˚ increments. After each 2˚ rotation of the light sensor, the BS2 uses the rctime command to monitor the light intensity as seen by the sensor. This data is then imported into the Simulink program over the serial link. The Simulink-based GUI includes an X-Y plot window in which the imported sensor data is plotted. This allows the user to view the rctime value plotted against the angle of the arm carrying the light sensor. See [10] for more details.

4. EXPERIMENTAL RESULTS

The light reflection experiment is quite accurate and yields experimental results that are consistent with theoretical projections developed using basic principles of light. Each experiment conducted clearly demonstrates that the angle of reflection is indeed the same as the angle of incidence.

Figure 3 is a plot of rctime versus the angle of the light sensor. This plot corresponds to a 40˚ angle of incidence. The angle of reflection corresponds to the angle with highest intensity of light, yielding lowest rctime value. Figure 4 is another plot of rctime versus the angle of the light sensor. This plot corresponds to a 20˚ angle of incidence.

The prototype experimental setup eliminates the drudgery of manually collecting and recording precise data by automating data collection. Real-time graphical representation of data being collected enables the student to immediately correlate with the underlying physical phenomenon. Furthermore, it provides the student an opportunity to explore, construct, and validate concepts by interpreting and analyzing the graph. Finally, through the GUI, the student can analyze the effect of varying experimental parameters (e.g., angle of incidence) by studying the resulting graph of rctime vs. angle of light sensor.

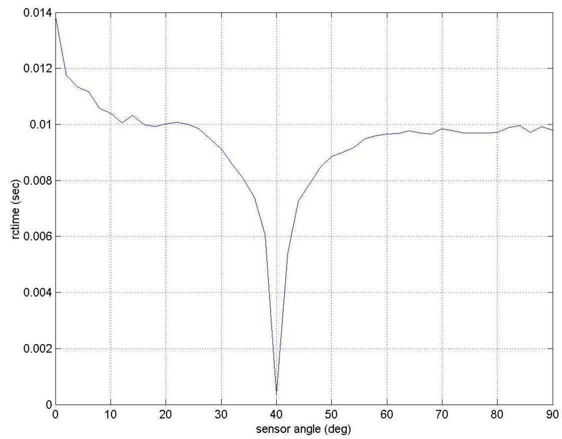

Figure 3: Plot of rctime vs. angle of light sensor for a 40˚ angle of incidence

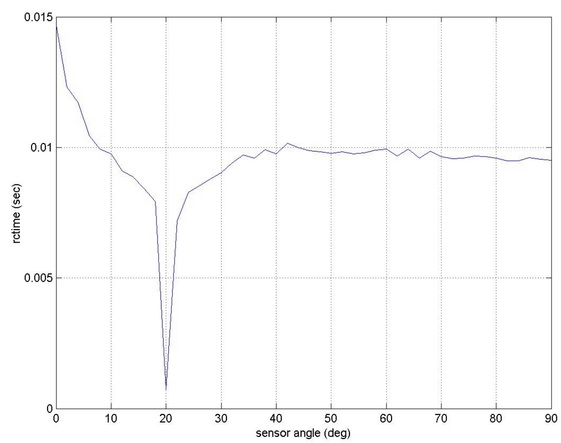

Figure 4: Plot of rctime vs. angle of light sensor for a 20˚ angle of incidence

5. CONCLUSION

The light reflection experiment is but one of many pre-college relevant science laboratories that can be enhanced through the use of mechatronics. We have similarly developed mechatronics-enabled prototype experiments that demonstrate refraction of light, thermal conductivity, static coefficient of friction, and the periodic motion of a simple pendulum. In summer 2003, the inaugural class of SMART teachers was exposed to these prototype experiments. The teachers thoroughly explored these prototype science experiments to investigate the utility of mechatronics-enabled laboratories. Over the course of the SMART program, the participating teachers also built their own prototype mechatronics-enabled experiments demonstrating principles of projectile motion, speed, time, static balance, mobile robotics, etc. These experiments will enhance the learning environment of pre-college students by serving as tangible demonstrations pertaining to classroom lectures and as laboratory activities. More importantly, the teachers are now equipped to thoroughly modernize their curricula by adopting mechatronics technology. Furthermore, the experiments and teachers' enthusiasm towards mechatronics will stimulate interest amongst pre-college students in the fields of science, technology, engineering and mathematics (STEM). We cannot underestimate the appeal of technologically advanced devices and tools to teenagers, and these experiments will utilize this appeal to interest them in pursuing STEM careers.

Acknowledgement

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6. REFERENCES

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