AC 2012-4634: THE IMPACT OF BUILDING A ROBOTIC OBSERVATORY ON ENGINEERING STUDENTS

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Introduction – Observatory Mission

Small robotic observatories are enhancing educational programs and generating excitement around science and engineering at an increasing number of institutions. The University of Iowa, a pioneer in this area, has been successfully using a remotely operated telescope in their undergraduate curriculum for over a decade[1]. Middle and high school students throughout the United States have shown significant gains in conceptual understanding of math and science topics through use of the MicroObservatory[2], a distributed network of automated small telescopes. Access to such facilities is becoming more common as the hardware and software required to build them becomes less expensive and more readily available.

Dedicated to the mission of education, the University of St. Thomas (UST) observatory is a fully robotic facility capable of remote control through a web browser as well as unattended queue based operation. With the support of a grant from the National Science Foundation (TUES award #1140385), we are actively developing inquiry based observational exercises for undergraduate introductory astronomy courses that incorporate the robotic observatory. These exercises will be implemented at the University of St. Thomas as well as five other local schools including The University of Minnesota, North Hennepin Community College, Normandale Community College, Metro State University, and Cretin-Derham Hall High School.

A significant additional component of our educational mission is the training of future scientists and engineers. Through an ongoing collaborative relationship with the UST School of Engineering, UST engineering students have assisted with various aspects of the design, construction, and operation of the observatory. In some instances, the engineering students brought knowledge and experience to the task that did not exist among the physics faculty. In other instances, the students learned new skills and acquired the knowledge needed to perform the task. In all cases, the experience was rewarding and educational to both students and faculty as we engaged in the creative process of problem solving. In this paper, we provide a brief description of the observatory, describe several key projects undertaken by engineering students along with their educational impact, and provide a brief overview of how we are integrating the finished observatory into our curriculum.

Observatory Description

The observatory was designed to emulate a professional facility. Observers control the telescope and associated instruments through a computer from a climate controlled control room. A large wall mounted flat screen monitor displays the most recent images from the telescope. A desktop to ceiling window in the control room looks out into the dome where the telescope and associated instrumentation reside. From their vantage point in the control room, visitors and observers can watch the telescope and the dome move under computer control.

The primary components of the observatory are the telescope, the telescope mount, the imaging camera, the filter wheel, and the dome. The telescope, a PlaneWave[3] CDK 17, is a 17" F/6.8 corrected Dahl-Kirkham. The CDK line of telescopes have flat focal planes and excellent imaging performance over a wide field of view. Attached to the CDK 17 is the Santa-Barbara Instrument Group's[4] STL 11000M which provides a large 0.75° x 0.50° field of view with a spatial resolution of 0.67 arcseconds per pixel. In-line with the camera is an 8 position filter wheel containing color balanced LRBG imaging filters for astrophotography, and a subset of UBVRI[5] (standard bandpasses for astronomical research) filters for photometry. Also available are narrow band Hα, O III, and S II filters for imaging and photometry. The telescope is mounted on the GTO 3600 German equatorial mount from Astro-Physics[6]. Like many German equatorial mounts, the GTO 3600 employs worm gears on the two control axis. The right ascension axis, the one responsible for countering the Earth's rotation, contains a high resolution encoder that reduces the tracking error to under one second of arc providing a very stable imaging platform.

The software system is designed to provide maximum flexibility. At the lowest level, the ASCOM platform[7] provides a driver based programming interface to the observatory hardware. This driver model allows developers to create device independent observatory control software. On top of the ASCOM platform is the centerpiece of the control system, ACP Observatory Control from DC3-Dreams[8], which provides telescope/dome synchronization, acquires and plate solves images from the camera through MaximDL[9], auto-focuses the telescope through FocusMax[10], and performs automatic pointing corrections. Additionally, it has a full featured scripting interface for observatory automation and provides a web browser interface that allows remote control over a network connection. When coupled with ACP Scheduler, a queue based observation dispatcher, the observatory can run unattended, waking up at dusk, making observations all night, and shutting down at dawn. Thus, the observatory can be controlled locally from the control room, remotely in real time through a web browser, or unattended through the observing queue. The multiple observing modes make the observatory extremely flexible and available for a variety of uses.

Project #1: Finding Celestial North

Telescopes are essentially big cameras designed to take images of objects in space. Because the targets are often dim, the exposure times are long enough that the Earth's rotation must be countered to keep the telescope pointed at a fixed location in the sky. The UST observatory employs an equatorial mount in which one of the two control axis is positioned parallel to the Earth's polar axis. Once the mount is precisely aligned, rotations about this single axis at the right rate effectively counter the Earth's rotation. To facilitate precision alignment, we had to locate celestial north to within one or two degrees prior to installation. Simply using a magnetic compass to locate celestial north does not work because celestial north and magnetic north are offset from one another. Although the offset, known as magnetic declination, for our geographic location can be determined, the presence of re-bar and steel cable in the surrounding structure distorts the Earth's field lines giving an inaccurate reading.

An engineering student was hired as a summer research assistant to find a way to accurately locate celestial north, among other tasks. He ultimately located celestial north using the shadow cast by a pole placed perpendicular to the ground. Because we are in the Northern Hemisphere, the Sun traces an arc across the southern sky. At solar noon, the exact moment when the Sun is halfway across the sky, the shadow cast by the pole will be aligned exactly north to south. The trick lies in determining exactly when the Sun crosses the Meridian. Because time zones have width, solar noon coincides with civil noon at only one longitude per time zone. The student realized that, because the Sun is at its greatest elevation above the horizon at solar noon, the pole's shadow will be shortest then. By marking the location of the shadow tip every five minutes for an hour surrounding solar noon, he was able to sketch an arc and precisely locate the point where the pole's shadow was the smallest and thereby locate celestial north.

Because he initially had little astronomy experience, he had to learn the basics of celestial motion in order to understand why the mount must be aligned with its principal axis pointed north. Then, upon realizing that magnetic north and celestial north were different, he had to think carefully about the relative positions of the Sun and Earth to understand the difference between solar time and civil time. He was then able to synthesize that information into a working solution for the problem. Much more important than the acquired technical knowledge, he gained practice gathering, organizing, and synthesizing information, which is at the heart of problem solving. He also gained a great deal of confidence in his own ability to approach a foreign topic, gather the required information, and develop a working solution, a critical skill in any engineering discipline.

Project #2: Precision Polar Alignment

Locating celestial north with the solar shadow provides a rough alignment of the telescope mount to within several degrees of the Earth's polar axis. In practice, to avoid tracking errors, we wanted the alignment to be under one minute of arc. During the fall semester of 2009, four engineering students enrolled in our introductory astronomy course developed and implemented a precision polar alignment procedure. This project was performed for course credit as an alternative to the regular astronomy laboratory. While many such alignment procedures already exist, we wanted these students to develop an understanding of the general problem through independent research and then apply that knowledge to the UST observatory.

They were asked to prepare a final report describing the polar alignment problem, presenting a working alignment procedure, and explaining why the procedure works on the UST observatory.

These students had no prior astronomy experience, so they had to begin by learning the basics of astronomical imaging and observatory operation. They researched various telescope mounting systems and learned how the mount in the UST observatory addresses the tracking issue. Then, turning to the specific problem of polar alignment, they explored several popular alignment techniques listing their strengths, weaknesses, and precision. Given the precision required for our imaging tasks, they went on to develop and test a polar alignment procedure tailored to the UST telescope. In their final report, they presented their procedure, explained in detail how and why it works, and also provided a detailed set of telescope operating procedures.

Their alignment procedure employs the drift method, which exploits the fact that a misalignment of the polar axis will cause a star to drift in the frame. As a result, stars in a long exposure image will appear elongated rather than symmetric. The difficulty lies in knowing whether to adjust the mount's azimuth or elevation for a given drift. However, as Figures 1 and 2 illustrate, drift due to misalignment in azimuth is minimized when pointed at the Eastern or Western horizon and misalignment in elevation is minimized when pointed South. The degree of misalignment is revealed by measuring the drift rate. The procedure is iterative. First, point the telescope East, measure the drift rate, and make a corrective a adjustment to the elevation. Next, point the telescope South, measure the drift rate, and make a corrective adjustment to the azimuth. Repeat these two steps until the drift rate is within the desired tolerance.

This project had a multi-faceted impact on the students involved. First, they gained knowledge and experience in an area completely new to them. More significantly, however, they learned how to independently research a new topic and develop a detailed understanding of the problem that they were asked to solve. Leveraging this understanding, they went beyond mere implementation of a stock procedure and instead developed a procedure tailored to the specific equipment and requirements of our observatory. In addition to performing research and synthesis in problem solving, these students gained valuable experience distilling and communicating the results of their research in the form of a written document. Finally, they were given great latitude to work without direct supervision. They gained confidence that they could work on a fairly complex project, take responsibility for its completion, and take proper care of the equipment.

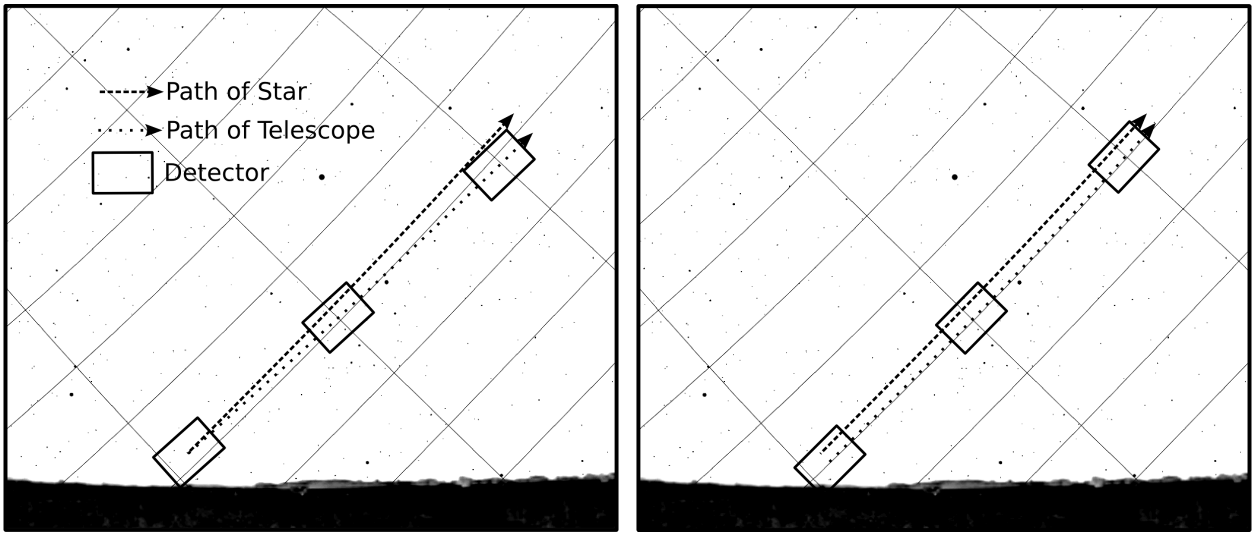

Figure 1: Illustration of the effect of a misalignment in elevation (left panel) and azimuth (right panel) of an equatorial telescope when pointed East. If there is a misalignment in elevation, the paths of a star and the telescope detector will not be parallel and the star will drift out of the frame over time. A small misalignment in azimuth will not cause drift.

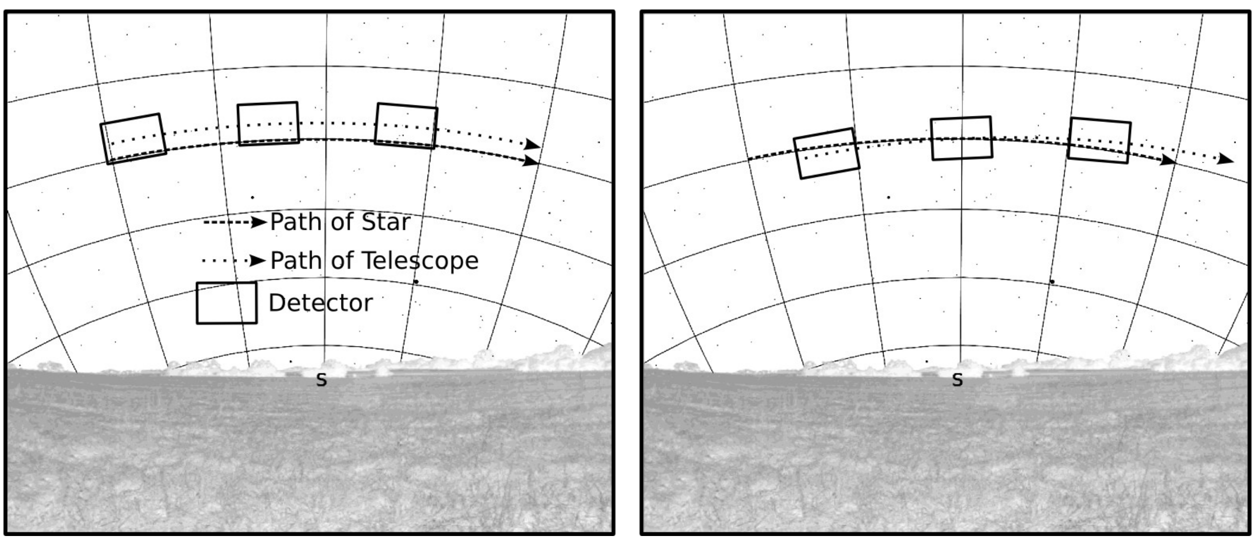

Figure 2: Illustration of the effect of a misalignment in elevation (left panel) and azimuth (right panel) of an equatorial telescope when pointed South. If there is a misalignment in azimuth, the paths of a star and the telescope detector will not be parallel and the star will drift out of the frame over time. A small misalignment in elevation will not cause drift.

Project #3: Establishing Communication

Because the computer that runs the observatory is located in a different room than the equipment that it controls, some communication issues had to be resolved. Several pieces of equipment communicate via RS-232, but the control computer is a stock desktop computer with only two dedicated RS-232 ports. Other pieces of equipment communicate via USB, but the distance between the control computer and the equipment is greater than the maximum distance allowed for a standard USB cable. An engineering student was hired as a research assistant to develop a communications solution.

After researching variety of products including RS-232 to USB adapters, expansion cards to provide the computer with additional RS-232 ports, and USB extenders, our student settled on a combination of RS-232 to USB adapters and a USB extender. The extender consists of a local unit that connects to the computer and a remote unit that presents several USB ports. The two units communicate via a cat-5 cable. The plan was to have all communications travel on the single cat-5 cable. The equipment communicating via RS-232 would connected to the remote unit via an RS-232 to USB converter.

During initial testing, the setup worked well. During production, however, communication between the control computer and the telescope mount would occasionally fail. The failure manifested in loss of control of the telescope mount and garbled information in the telescope status window on the control computer. Control could be re-established by resetting the communications link in the telescope control software.

After extensive testing, the student determined that the problem was dropped communications packets between the telescope mount and the computer. The telescope control software continually polls the mount for status information. But, the data coming from the telescope is not framed with start and stop characters, so the receiving computer must rely on the byte count in the incoming data stream to properly parse the data. If a packet is dropped, the data stream is parsed incorrectly and the control software becomes hopelessly confused. The student tried a variety of fixes including ground straps on the equipment in case the issue was noise related and replacing the USB extender with a different model. Ultimately, he constructed a dedicated heavily shielded serial cable connecting the control computer and the telescope mount through one of the two RS-232 ports on the computer, thereby removing the highest traffic connection from the USB extender. No further communication difficulties were seen.

Our student learned that even the most carefully researched and well thought out plans often don't work as intended. A system that looks good on paper and works during testing sometimes fails in production under heavy load. However, because the planned solution failed, he had the opportunity to practice his troubleshooting skills and was ultimately able to determine the exact nature of the problem and devise a solution. During his research and troubleshooting, he learned a lot about serial communications from both a hardware and software standpoint, particularly the importance of employing error checking techniques when transmitting and receiving data.

Project #4: Embedded Lighting Controller

The observatory is located on the upper deck of a parking ramp; and, like most parking ramps, there are security lights mounted on top of tall light poles. When the lights are on, they shine directly into the observatory dome making observations impossible. A bank of switches installed in the observatory control room provide control of the security lights, but because the observatory is automated, the control computer must be able to turn them off. An engineering student was hired as a research assistant to develop a controller allowing the main telescope computer to control the parking deck security lights.

The switches themselves are low voltage control boards that contain a momentary contact switch and an LED. Pressing the switch toggles the state of the lights, which is indicated by the LED. Our student built a controller consisting of an embedded processor, responsible for light control logic and communication with the control computer, and associated circuits responsible for "pressing" the switches and sensing the state of the lights. He designed all of the circuits and wrote the embedded control software. When the controller is active, it watches the state of the lights and, if they turn on, turns them off. The software also listens to the serial port for commands from the control computer. The controller can be commanded to hold the lights off, turn the lights on, or to stop monitoring. Everything worked well in testing but failed when installed in the observatory. After additional troubleshooting of the circuit and some design changes, the system functioned as required.

The student had a fair amount of electrical design experience prior to the project but little experience in embedded control and software design, particularly in serial communications. He successfully learned the details of the software design and developed the software quickly. He also gained experience acquiring new skills and synthesizing them with existing skills to produce a final project. He also learned that projects do not always go as planned and how to handle the frustration that comes when a project passes initial tests but fails in the production environment.

Continuing Student Impact: Observatory Staff

Beyond its design and construction, the observatory continues to have an impact on students both inside and outside of the classroom. To handle day to day operations and general maintenance, we employ students to work as observatory staff. The observatory staff act as teaching assistants in our introductory astronomy course, assist with public events, and help faculty and other students obtain observations for various projects. During their first semester, observatory staff are trainees. While in training, they work closely with experienced staff learning to operate the facility, guide student observations, and assist on public nights. The training period ends when they are able to demonstrate proficiency in a list of critical skills. Thus, the population of observatory workers is self propagating, with each generation training the next.

The observatory staff gain technical knowledge and skills in observational astronomy, experience that facilitates their transition into collaborative research with a faculty member. But their experience adds up to much more. As a group, they take ownership of the observatory as they are largely responsible for its care and maintenance, a fact in which they take great pride. They gain valuable leaderships skills by guiding other students through observations and training incoming observatory workers. The process is transformative and, while they many never use the specific technical knowledge after leaving college, the sense of responsibility, leadership, and camaraderie that they acquire will remain with them long after graduation.

Continuing Student Impact: Undergraduate Curriculum

One of our primary goals in building the observatory was to add hands on inquiry based observational experiments to our introductory astronomy course. Before the introduction of the observatory, our laboratory experiments involved either pencil and paper exercises or simulated observations using a computer. Student response to these experiments were mostly negative as they complained about doing "worksheets" for two hours. With the observatory, they actually control the telescope and have ownership of the resulting data, both of which motivate the students, and their response has been very positive. Engineering students in particular benefit from seeing and using remote controlled robotic equipment, experience that they will find useful in their careers.

The new laboratory exercises are designed to mimic professional observational astronomy by leading the student through the design, data acquisition, and data analysis phases of an investigation. Each exercise takes place over two lab periods. Period one is dedicated to exploring the principles underlying the experiment and developing an observing plan. Period two is dedicated to performing the data analysis and reporting the results.

During the first period, the students engage in a series of interactive exercises that explore the fundamental physical relationships used in the experiment. They then apply those relationships to the specific experimental situation to develop a scientific question that can be answered using images from the telescope. Finally, they complete an observing plan that will be executed at the observatory at a later time. Between the first and second lab periods, the students can either visit the observatory to execute the observing plan themselves or submit the plan to the observing queue for execution at a later time.

At least one experiment per semester involves a visit to the observatory where groups of four students operate the telescope in real time and learn how an observatory functions. Group members assume the roles of telescope operator, camera operator, recorder, and staff scientist. The staff scientist leads the group through the observing plan, the telescope operator points the telescope and acquires a target, the camera operator takes images, and the recorder writes the details in the observing log. After taking a few images of a given target, the roles rotate allowing everyone to perform each task.

We are also actively integrating the observatory into local schools. Cretin-Derham Hall a local high school, uses a lab that we co-developed in their science curriculum. With the support of a National Science Foundation Grant (TUES award #1140385), we are also developing additional laboratory exercises with UST and a group of local schools. Taking advantage of the robotic nature of our observatory, our partner schools can implement curriculum using either queued or live observing over the Internet. The curricular projects are still in the early development stages, so no formal assessments have been done. As the project progresses, we will perform formal assessments using student feedback, the results of which will be reported in future publications.

Conclusion

The UST Observatory is a highly successful robotic observatory located on our St. Paul campus It is integrated into the undergraduate curriculum at UST as well as other local area schools and is providing exciting public events for the surrounding community. The observatory would not have been as successful were it not for the engineering students who helped put it together, continue to assist in its day to day operation, and benefit from its use in the classroom. The authors welcome requests for information and questions regarding the observatory and its programs.

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