DIGITAL SUNDIALS ON THE INTERNET, A NEW WAY OF USING ANCIENT TECHNOLOGY

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The sundial is one of the oldest scientific instruments; its principle is simple: a gnomon casts a shadow based on the Sun's position. By recording the position of the gnomon's shadow, one can track the motion of the Sun across the sky. While sundials have typically been used as a way to gauge the passage of time, they remain a useful pedagogical tool since it shows unexpected (to the student) details about the Sun's motion across the sky. We have built a sundial and put it on the internet. By storing pictures on a website of the gnomon's [1] shadow taken at regular intervals, teachers can present data about the Sun's motion across the sky so fast that it can match any student's attention span (Figure 1). Students all the way from the University and College level to the Elementary School level can learn aspects of space and astronomy, from the comfort of the classroom and without having to monitor home-made apparatus out of doors from dawn till dusk.

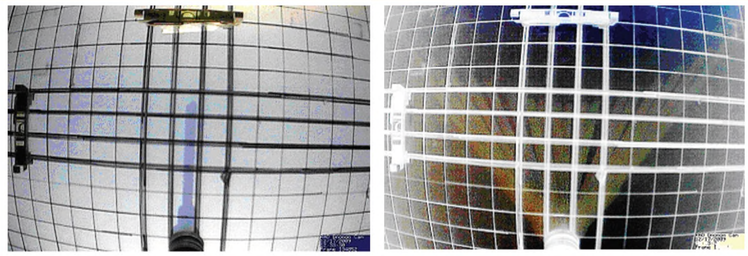

Fig.1 (left) A single image of the gnomon's shadow and (right) a composite image of many shadows by the gnomon over the course of a day (December 17th, 2009). The image is taken from a digital camera placed inside the box and looking up at the glass surface. The lines are 2 cm apart for easy measurement. The digital camera provides some distortion to the image; further advances in this project will hopefully include a way of manipulating the image to compensate for this distortion.

Since the Sun's motion across the sky changes from day to day, and month to month, and clouds frequently obscure the Sun, data from several years are often necessary to really explore and understand how the Earth's elliptical orbit and tilt affect the passage of the Sun across the sky. This web-based data collection and storage system will enable students to make such studies. We are hopeful that other institutions will set up similar systems at their locations. With this type of Sun shadow data coming from different positions on the Earth, one can see firsthand why man-made time zones are so convenient, and even attempt to measure the actual size of the Earth.

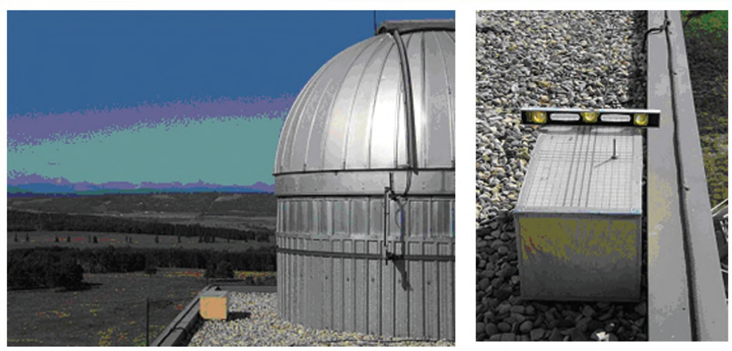

Fig. 2 Our digital sundial box in its position atop the roof of the Rothney Astronomical Observatory. The grid has 2 cm graduations. The gnomon is 6.5 cm tall in this picture, but was later reduced to 3 cm in order to maximize the usefulness of the shadow.

Our new advance to the sundial is located at the University of Calgary's Rothney Astrophysical Observatory [2]. It was constructed and implemented as part of International Year of Astronomy activities at the RAO [3]; the device is shown in Figure 2. An example of the images and data obtained via a webcam inside the wooden box are shown in Figures 1 and 3, and are discussed below.

Students have many misconceptions about the Sun's motion across the sky and a sundial system can be a fun and interactive way for students to re-think their model of the Earth-Sun system. The major disadvantage has been the amount of time needed for students to collect data. Long before interesting conclusions can be reached most students become bored and want to go surf the web. Here is a preliminary list of possible concepts that this system can help the students explore relatively quickly:

1. Does the Sun really rise exactly east and set exactly west?
2. At what time of the day is the Sun due south in the sky?
3. Why are the days longer in the summer than in the winter?
4. Where is the Sun in the sky during the colder time of year compared to the warmer time of year?
5. Why does Santa ride a sleigh in Canada and a surfboard in Australia?
6. Why is Canada colder than the tropics? Is it because the tropics are closer to the Sun?
7. What's the significance of the five special latitudes on a standard classroom globe: the equator, the tropics of Cancer and

1. A gnomon is "A pillar, rod, or other object which serves to indicate the time of day by casting its shadow upon a marked surface; esp. the pin or triangular plate used for this purpose in an ordinary sun-dial." According to the second edition of the Oxford English Dictionary.
2. The website that links to the data and more information www.ucalgary.ca/rao/skywatch
3. The precise position of the RAO is +50° 52.10' Latitude -114° 17.30' Longitude.

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Capricorn and the Arctic and Antarctic circles?

As simple as most of these concepts may seem to an instructor, students are inclined to hold on to their preconceived notions unless they carefully trod their own path to understanding. As has been shown in many papers [1], simply telling students that they are wrong has little to no effect on their model for understanding the universe. This system will allow students to actively play with real, and comprehensible, data and even have fun with it. Excellent inquiry based teaching modules have already been developed [2,3] which could be modified to use this data. Personal experience from some of the authors is that many of these misconceptions persist at various grade levels, through college, despite instruction to the contrary. Students seem to place information for tests into a different bin in their mind than information about the real world. Careful observation by the student and careful questioning by the instructor are needed to reformulate these models of the world.

Our setup has a box with a grid on the top surface (Figure 2b). The grid is on a translucent piece of plexiglass, with 2 cm gradations. The grid lines are carefully oriented N-S and E-W, and bubble-levels verify that the grid sits horizontally. There is a 3.0 cm tall bolt sticking through the grid to act as the gnomon. The web camera sits safely inside of the box looking up at the gnomon's shadow. An example of what the webcam sees is shown in Figure 1a. Since web cameras are somewhat susceptible to weather, it was felt that hiding the camera in the box was optimal. With this system, the computer takes a picture of the underside of the grid and the shadow usually has a distinct tip. This picture is then time stamped so that the user can tell both the local date and time that this picture was acquired. A series of these pictures over the course of the day can show the Sun's relative motion across the sky. An example from Dec. 17th, 2009 is shown in Figure 1b.

By allowing students to use real data to generate shadow plots (Figure 3), it's possible for the students to reconstruct the Sun's apparent motion for themselves. Unlike many activities in teaching science, students can understand almost all of the nuances for the data collection, which gives the instructors more room to allow the students to explore their own questions in addition to the questions of the instructor.

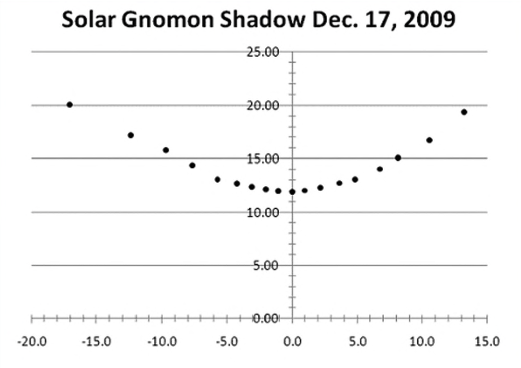

Fig. 3 Here's an example of a typical shadow plot. The dots represent the position of the tip of the gnomon's shadow. The units of the axes are cm, and the gnomon is at (0,0). East is to the left, West to the right, and North is up. Chronologically, time runs from the upper right corner (NW) to the upper left (NE). Uncertainty in determining the position of the shadow tip increases as the shadow length grows. The uncertainty also increases when the Sun is veiled by clouds. The Sun's shadow is shortest when it is pointing straight north (the Sun is due south) and occurred between 12:33 and 12:34 local time on this day.

The RAO's computers can store months or even years of webcam images which can easily be retrieved. It is thus possible to compare shadow plot data on the same day from different years and see if there are any differences. Instructors know that the path of the Sun across the sky will be the same, but the timing of that path could be a bit different because of the leap-year effects (and that things repeat over a 4 year cycle). Students could be invited to make predictions before examining the data to see if their ideas are correct. An important concept to emphasize to students is that the Sun's yearly motion is not random, but is repeatable.

An archive of retrievable images also allows students to explore many other concepts. Seasonal effects like how the Sun's maximum altitude is related to the length of day can be explored. The unique features of the Sun's path across the sky on the days of the solstices and equinox can also be explored. Best of all, this can be done from the comfort of the classroom.

Another key advantage of using technology is that information can be shared over a wide area. If other digital sundials can be set up at different latitudes and longitudes, the Sun's apparent position as a function of geography can be explored. By comparing sundials at exactly the same time students will hopefully be able to start thinking about the Earth as a large spherical object that has different shadows at different times of the day and different locations. Also, the climate at different latitudes can be discussed by seeing the Sun's relative position in the sky.

While it is beyond the scope of what has been done so far by this group, it is hoped that instruction using the digital gnomon would commence with instructors showing an actual sundial to the students. Perhaps this could be done in a darkened room with a flashlight, to show how moving the flashlight in a particular way could lead to particular shadows. Perhaps also students could collect a day's worth of data themselves, as a group, so they get a feel first-hand for how the process goes. This would possibly help understand the data more personally.

We feel that this project is off to an exciting start. Image archiving and web retrieval tools are in place but will be expanded. The project will be more exciting as data is collected and more sundials are set up. Please contact the authors of this paper if you are interested in discussing building your own digital sundial, to make sure that we have some consistency in design. It is also hoped that future papers will discuss in deeper detail what numerical data can be extracted from the Sun's shadow data collected using this new twist on ancient technology.

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