AS 102 – Lab 4
Triangulation and Parallax

Barnard's Star – Perkins Telescope, September 4, 2005

The Problem

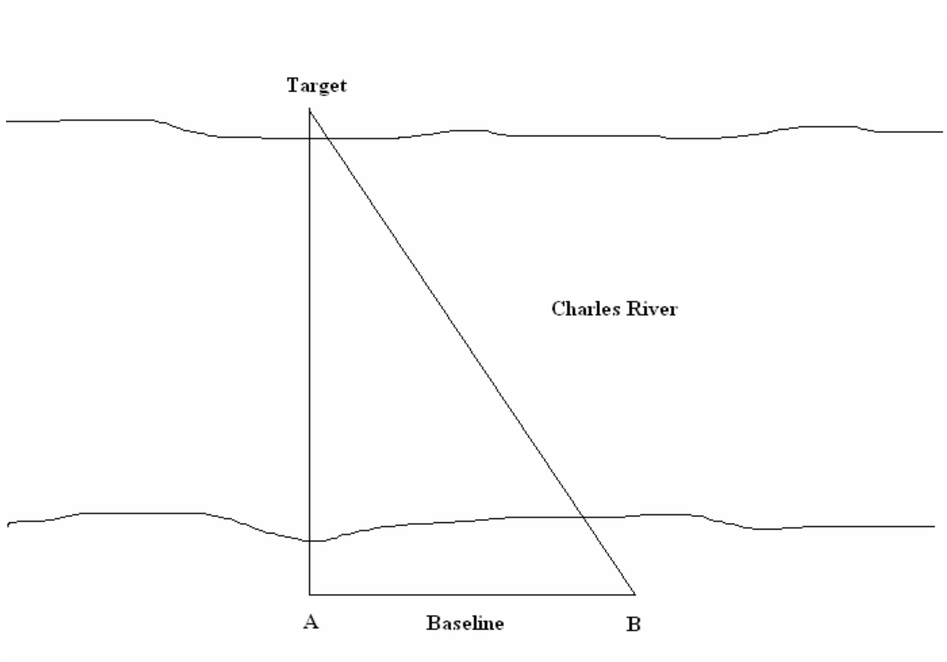
The principle of *surveying* -- measuring distances from one place to another -- has been known for a very long time. Using some very simple trigonometry, it is possible to measure the distances to inaccessible locations, such as the other side of a river or the distance to a star. The goal of this exercise is to demonstrate that it is possible to measure the distance to someplace without actually going there. You will start with measuring the width of the Charles River and move on to finding the distance to Barnard's star, one of the closest stars to the Sun.

Introduction

People have been using surveying techniques to measure distances on the Earth for thousands of years. We can now measure the distance from almost any spot on the Earth to any other spot with great accuracy. The techniques are more or less the same, whether we wish to lay out property boundaries or follow the motions of continents relative to one another. But how can we contemplate finding the distances to even the nearest stars? This question has occupied astronomers at least since the ancient Greek astronomer, Hipparchus, realized that if the Earth moves around the Sun, the stars should show the effects of **parallax**. But even for the nearest stars, the parallax is so small that extremely precise measurements are needed just to detect the effect. Nevertheless, it is the only way we can make direct measures of the distances to the stars. All of our other distance methods depend on the parallaxes of the nearby stars.

A. Width of the Charles River - Unfortunately, it is not possible to observe the parallax of a star in a single lab period. For this exercise, you will begin with a traditional surveying problem, finding the distance across a river to a target on the other side. (In this case, the river is the Charles, and the target will be a tree or building on the other side.) The goal will be the same – to measure the distance to some remote object using the parallax concept.

To measure the distance across the river, all that is needed is the length of a baseline and the two angles between the baseline and the direction to the target across the river. However, as it happens, the Hyatt Hotel in Cambridge is almost due North of BU and the footpath on the far side of Storrow Drive runs nearly East-West. It will be possible therefore to simplify things considerably by setting up a right triangle to solve the problem, as shown in the following sketch.



In the diagram, the angle, **A**, is assumed to be 90 degrees. This means that the distance from the baseline to the target across the river (the width of the river) is just :

Width = **baseline** x tangent(**B**).

The length of the baseline and the angles A and B can all be easily measured, and many calculators have a tangent function key to get the tangent of the angle B.

B. Parallax to Barnard's Star – Although we cannot observe a stellar parallax directly, there is at least one star, called Barnard's star, that is close enough to us that the effects of parallax can be easily seen on photographs taken at 6 month intervals. However, in addition to showing parallax effects on images taken 6 months apart, Barnard's star is also moving in the plane of the sky at a rapid angular rate, meaning it is moving through the Milky Way.. This **proper motion** is seen as that motion of the star's position against the fixed background stars which does not return to its original value one year later. Recall that on photographs taken exactly one year apart, stars will show no parallax effects. This means that a series of images, taken over more than a year, can be analyzed to measure the star's parallax, and therefore distance. Also, these same images can be used to measure the star's proper motion and combined with the distance value can be used to determine the speed of the star as it moves across the sky.

Detecting the small parallax of Barnard's star requires a large telescope with either exceptionally good seeing or a location in orbit about the Earth. And, while HST has not studied Barnard's star, we have calculated some simulated images for this star and its neighbors and will use these to deduce the star's distance and speed.

Available Equipment

1. A compass.
2. Meter stick
3. Large protractor
4. String
5. Fake images of Barnard's star

Suggested Experimental Procedure

A. Charles River Experiment - This experiment should be done on the footpath along the South side of the Charles River. There are two possible ways to do this lab. For the first method, the following steps are suggested:

1. Choose a suitable target on the far side of the river.

2. Using a compass, measure the direction along the footpath, relative to North.

3. Calculate the compass direction of a line at an angle of 90 degrees to the footpath direction.

4. Walk along the footpath until your compass points to your target – that is get your target lined up at a 90 degree angle to the footpath. You are now at A in the diagram above.

5. Starting from the position you have just found, lay out a suitable baseline, A to B.

6. Finally, from the other end of the baseline, measure the angle B.

For the second method, either attach a large protractor to your meter stick, or use a meter stick that already has a protractor attached.

1. Choose the target, as before.

2. Now lay a meter stick on the footpath, and sight along it to align the meter stick in the direction of the footpath.

3. Using a string attached to the meter stick, sight along the protractor to identify a landmark on the other side of the river that is at an angle of 90^o to the footpath direction. You are now at position A.

4. Next lay out the baseline, and measure the angle B of your triangle, as shown in Figure 1.

All these measurements can be done several times with the partners switching roles. You should also try several different baselines.

B. Barnard's Star Parallax – Begin by examining the simulated HST images to identify Barnard's star (the one which moves the most).

1. Trace the location of Barnard's star onto a single sheet of paper.

2. Decide on a strategy to separate the star's proper motion from its parallax motion. Using the images, find the value of the star's proper motion, in units of mm (on the images) per year of time.

3. Similarly, determine the value of the star's parallax, in units of mm (on the images).

Analysis and discussion

The analysis for this exercise is exceedingly simple. Either use equation (1) above to solve for the width of the river, or use a ruler and a protractor to draw a scale model of the scene on a piece of paper. Because you have multiple measurements of the width of the river, you can use these to estimate your errors. The goal of the project is the width of the Charles River, but you also need to concentrate on HOW WELL you know your answer. Which factors give the most accurate results? To find the parallax of Barnard's star you will need the focal length of the HST camera (72 meters). This leads to a "plate scale" of .117 arcseconds per mm on your paper. Using this factor, what is the parallax of Barnard's star in arcseconds? Estimate the error of your calculation.

Records and Data

Your data pages for this lab should include a description of your target, the orientation of the footpath, notes about your method for setting up the baseline or baselines, the measurements of the angles A and B and the details of the procedure you actually followed – Don't just repeat the procedure outlined here. You must attach your **origina**l data pages and lab notes to your report. These should include notes on the details of your experimental procedure, all your actual measurements, and any other materials that you generate while you are doing the lab. Your report should be consistent with these data pages.

AS 102 – Lab 4 Preparation
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Name________________________

Answer the questions directly on this page and hand the form in at the beginning of the lab.

1. Which step in your measurement of the width of the Charles River will probably have the largest source of error?

2. How could you measure the height of the Hyatt without crossing the river?

3. What is the difference between parallax and proper motion? (You may need to refer to your text to answer this one.)

4. What are some of the things that you do not understand about this exercise?