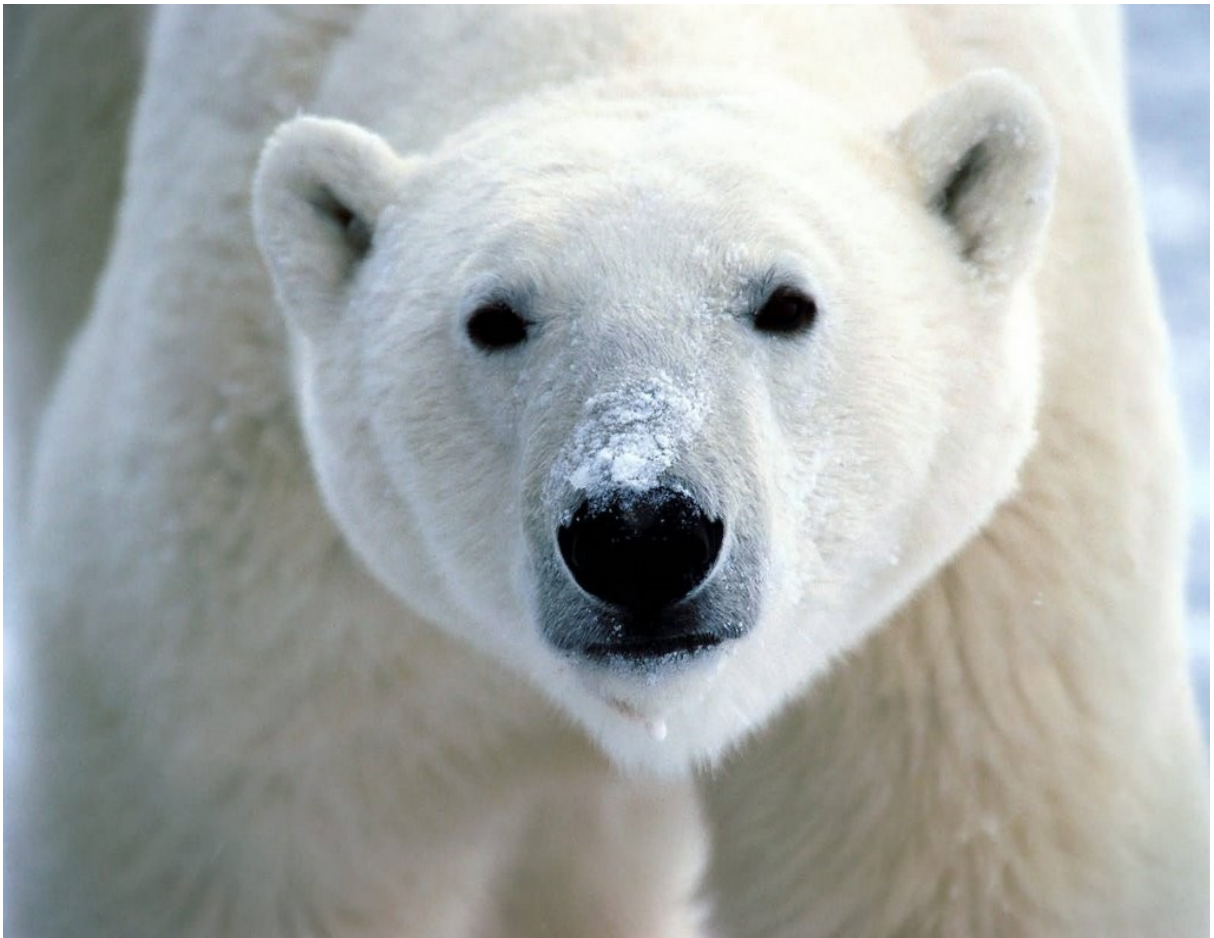


The Polar Bear Telescope

A Variable Star and Light Pollution Monitor For the Armagh Observatory



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Abstract

This project was to involve the continuation of an experiment to build a light-pollution and variable star monitor for Armagh observatory. This was a joint project between myself and another Nuffield student, Stephen Maxwell. Each of us were to concentrate on a significant aspect from the frames received, one would concentrate on the astrometry and the other on the photometry.

The telescopes were already set up on the roof of the observatory and each telescope was focused on a specific area of the sky, which includes the North Celestial Pole (NCP). As the earth rotates this region rotates around the NCP and into the field of view of each camera in turn.

We were given a clear list of goals at the start of the project, these included:

- to obtain a time series of images of the night sky over hours and nights,
- to process these images so that they can be used for scientific measurement,
- to develop an algorithm for identifying the stars visible on each image,
- to develop an algorithm for measuring the light from each star in each image,
- to make a catalog of stars visible, with their magnitudes,
- to obtain light curves for a significant number of these stars,
- to pay due regard to the measurement errors at each stage of the project.

Introduction

The purpose of the Polar Bear Telescope is to investigate light pollution over the City of Armagh and monitor variable stars around the North Pole over a long period of time.

Most stars are thought to be constant in their light output over many hundreds of thousands of years. A few however show large variations in brightness over times between a few minutes and a few years. these variations are important as they allow us to measure properties such as radius and distance directly.

The camera detects the brightness of the night sky and the stars using a CCD (Charge couple device) A CCD is a light sensitive integrated circuit that stores and displays the data for an image in such a way that each pixel in the image is converted to an electric charge. A CCD's charge is created when photons strike the semi conducting material and dislodge electrons, as more photons fall on the device more electrons are liberated, thus creating a charge which is proportional to the lights intensity.

To be able to monitor certain stars we were going to have to be able to identify the same star in each frame we got from the cameras. This would be made more difficult by the fact the stars would b rotating about the north celestial pole. We will therefore have to have some way of identifying where everything is located in the night sky. We do this by using the equatorial co-ordinate system. It is similar to the co-ordinate system on place on the earth, using longitude and latitude, only instead of longitude and latitude it uses right ascension and declination.

We were going to have to take into consideration some of the problems we may run into with regards to the images. One problem we were sure to encounter was vignetting. This means there is a reduction of the images brightness at the periphery,

compared to the center.

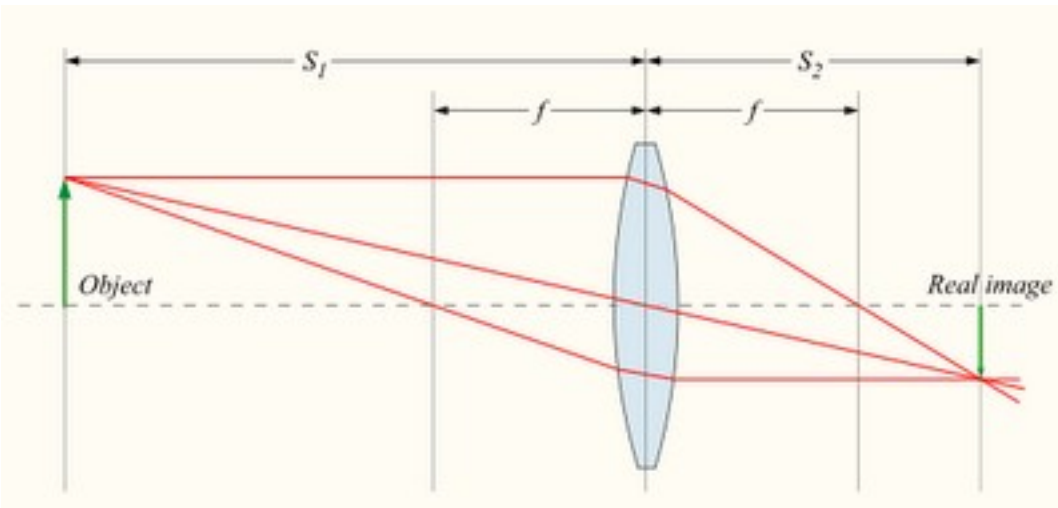
The camera's resolution would help dictate the quality of images that we would get. The greater the resolution, the more likely the camera was to separate, for example, two binary stars into their individual images.

Atmospheric effects will affect the quality of the frames we receive from the cameras. The two main types of atmospheric effects that will affect our images are seeing and extinction. Astronomical seeing refers to the blurring and twinkling of astronomical objects caused by turbulence in the Earth's atmosphere. Extinction is the absorption and scattering of electromagnetic radiation emitted by astronomical objects by matter between the emitting object and the observer.

Method

I began by doing research on the information that you see above, i had to work out what may affect our images in a detrimental way. I then did some calculations to give myself a better idea of the units of measurement i would be using. I was given the task of calculating how many pixels in our CCD were used per arc second in the sky.

I did this by first of all doing research into our camera and finding the size of 1 pixel in our CCD. This worked out to be 7.4 mirometers.



I knew that the diameter of the lens $D = \frac{\text{Focal length}}{\text{F -Ratio}} = \frac{85\text{mm}}{1.8} = \frac{f}{1.8}$

Angular resolution (diffraction limit) $R = \frac{1.22}{D} \lambda = \frac{1.22}{D} 500 \times 10^{-9}\text{m}$

Image size $d = R \cdot f = \frac{1.22}{D} \lambda f = \frac{1.22}{D} 1.8 f \lambda = 10^{-6}\text{m} = 1\mu\text{m}$ (diffraction limit)

I used an image viewing package, "Gaia" to look at the images. Among other things this showed the light count received fro each pixel. One of the first things i noticed

was that the light curve for many of the brighter stars maxed out at a count of 65,535. This puzzled me but further research told me that this was because it was a 16 bit camera, and therefore only had 65,535 grey levels. This apparently may not be as big a problem as it seems though as stellar images are actually spread over 16 pixels or more.

The problem with the "Gaia" program was that it only plotted the stars in a x/y axis. It did not convert the co-ordinates into right ascension and declination, which we would need to be able compare the stars from frame to frame. We needed to convert the x/y co-ordinates to right ascensions and declinations and we needed some sort of system that could do it automatically, as there will be quite a lot of images coming in at once whenever there is a clear night and the cameras become fully functioning. To do this we used software called "astrometry". This program involved inputting the FIT files we got from the cameras, the package would then look for patterns of stars it recognized in the image and would from there identify what area of sky it was looking at and plot the co-ordinates.

"Source Extractor" was able to analyse the output from astrometry and then give the results in a table format. It gave many different analysis' the ones we would be making use of would be the light counts and the co-ordinates, for now anyway.

To see how accurate the "astrometry" program was I then input the co-ordinates of the stars it detected and input them into a website "SIMBAD Astronomical Database" This contains a list of all found stars and other celestial objects. I input the co-ordinates the "Source Extractor" program gave me and found the closest matches "Astrometry" had. I then input both these sets of co-ordinates into a spreadsheet program. I was planning on taking the two sets of co-ordinates and working out the difference between the observed co-ordinates of stars and those given by "Astrometry". I quickly ran into bother as Source extractor gave me co-ordinates in decimal degrees, whereas SIMBAD gave me co-ordinates in hours minutes and seconds. I therefore had to enter formulas into my spreadsheet to convert from decimal degrees to hours minutes and seconds and vice versa. I then

compared the differences between the two in decimal degrees, as i figured this made more sense as the subtraction was alot easier for the computer to do.

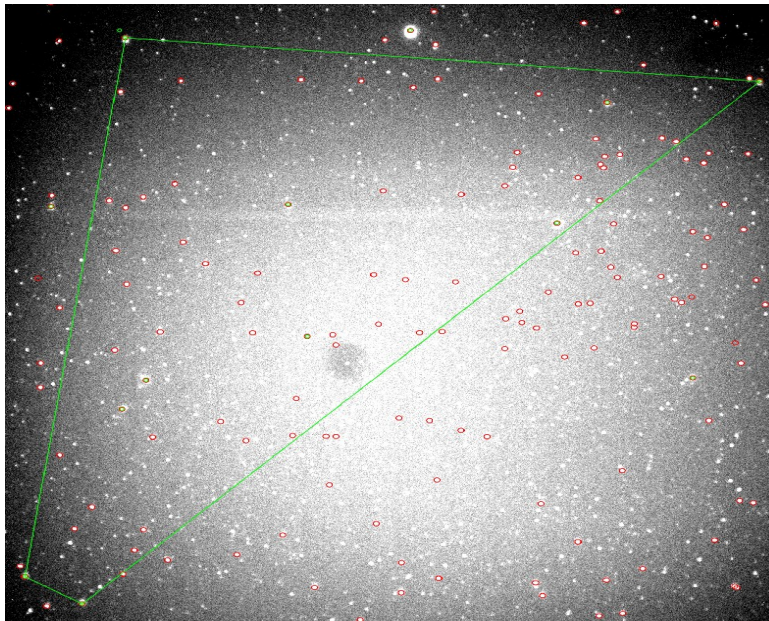
The amount of error for this method was far to big, so to try and remedy this we used a cut out section from each of the images, as in the middle square. This nearly eliminated the effect of vignetting and we hoped it would reduce the error between the "astrometry" co-ordinates and the SIMBAD ones. This did go to to plan. As you will see in my results. The margin of error was greatly reduced when using a smaller section of the image. The final results will use flat fielding to reduce the margin of error even more.

After I established how to reduce the margin of error, I then began to build up a catalog of stars. This would have to include stars that were likely to be in all our frames which we could check our frames against. I did this by getting all the stars above a declination of 80 and over magnitude of 12 in SIMBAD. This give us a base of nearly 7000 stars. I then used commands on the computer to organize them in order of their respective magnitudes.

This catalog was then used to create a light curve for one of the stars over one night's frames.

Results:

Below is an example of how the astrometry program identified what part of the sky it was viewing in an image. As you can see it picked point sources and tried to discern a pattern within them to decide what area of sky it was focused upon.



Below is an example of the output we could get from just one of the stars, I have just included 6 lines of results for example purposes.

1 Camera

2 Year

3 Month

4 Day

5 Hour

6 Minute

7 Image Object

8 Image RA (degrees)

9 Image Dec (degrees)

10 Image Magnitude

11 Image Magnitude error (formal)

12 Image Magnitude error (formal + systematic)

13 Catalogue Object ID

14 Catalogue RA (degrees)

15 Catalogue Dec (degrees)

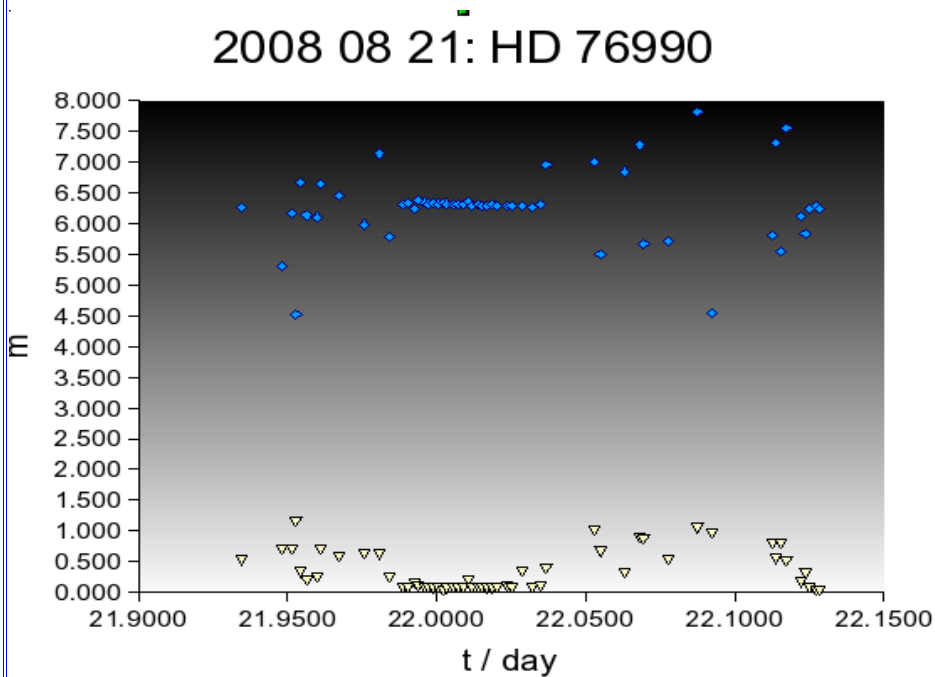
16 Catalogue Magnitude

17 Positional Error (arc minutes)

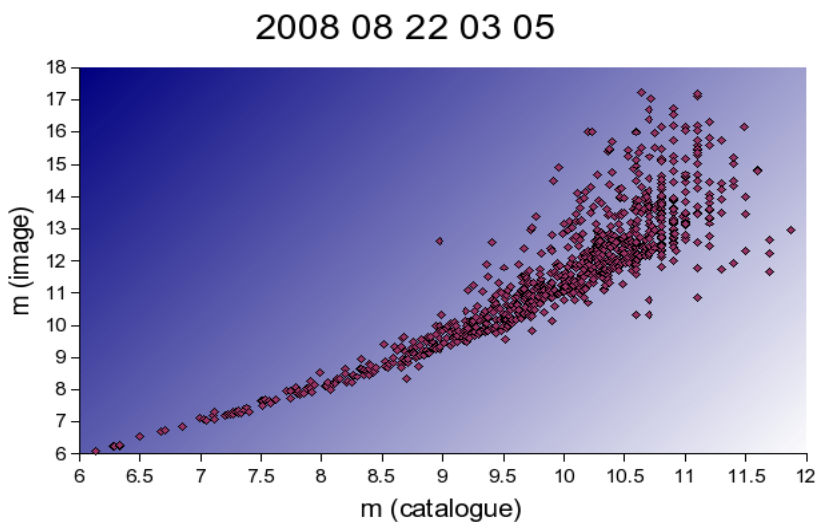
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126 2008 08 21 22 26 24 184.207 86.4347 6.26916 0.034 0.519073 54 184.214 86.4358 6.33 0.0733267
126 2008 08 21 22 45 18 184.209 86.437 5.30455 0.0249 0.699443 54 184.214 86.4358 6.33 0.0727078
126 2008 08 21 22 50 57 184.18 86.4362 6.17838 0.0426 0.692013 54 184.214 86.4358 6.33 0.129901
126 2008 08 21 22 52 55 184.19 86.4357 4.51961 0.013 1.14715 54 184.214 86.4358 6.33 0.0910825
126 2008 08 21 22 54 139 184.123 86.4354 6.67551 0.0078 0.329115 54 184.214 86.4358 6.33 0.340267
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126 2008 08 21 22 57 105 184.174 86.4358 6.13602 0.0038 0.195383 54 184.214 86.4358 6.33 0.148225

Results like these then allowed me to plot graphs. I could then use graphs to see if there was correlation between, for example to check the image magnitude matched the catalog magnitude. Below are some of the graphs I produced and what they mean:

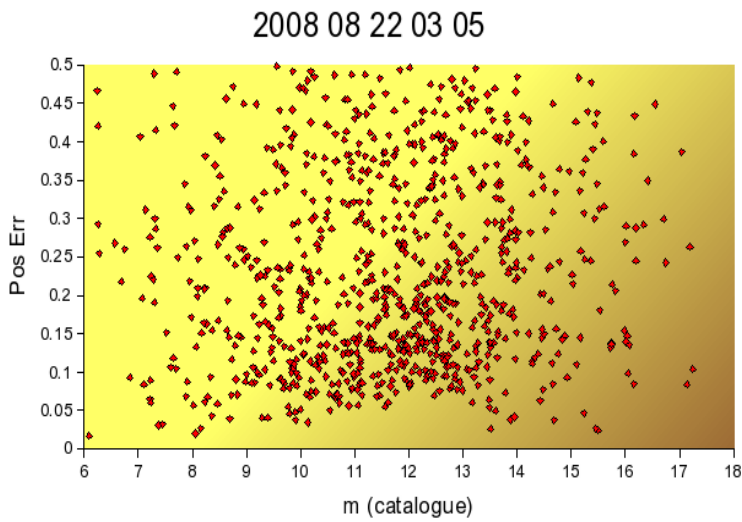


This is the time series for one star over one nights frames. This is the time-series photometry for that particular star.



This is a graph of the image magnitude against catalog magnitude, ideally this would

be a straight line gradient. however this is not the case as you can notice, when the magnitudes decrease the error gets much greater.



This is a graph of position error against magnitude. As you can see there is clearly no correlation here.

Conclusions and Evaluation:

To decide how well i completed my project , i will have to compare to the goals i was set at the beginning of the project.

To obtain a time series of images of the night sky over hours and nights

Achieved/ongoing

We did get results a few nights, however for the project to be completed correctly images will have to be taken over a long period of time. This way there are bound to be nights where there is minimum amounts of atmospheric effects, so with enough results the average should successfully reflect the object.

To process these images so that they can be used for scientific measurement

Achieved/ongoing

We found and used various tools that allowed us to get the necessary values and measurements we needed from our images. However flat fielding will have to be used in the future so as to get most accurate results with the astrometry.

To develop an algorithm for identifying the stars visible on each image

Achieved

We used the computer program "astrometry" to identify stars in each image, then built up a catalog so that we can do it for a large amount of images quickly.

To develop an algorithm for measuring the light from each star in each image

Achieved

This involved converting the light counts the CCD took in and converting these into star magnitudes.

To make a catalog of stars visible, with their magnitudes

Achieved

I made this catalog using the website Simbad and then taking the results into a text editor so they could be used along with a program to help identify stars in our images.

To obtain light curves for a significant number of these stars

Not achieved

We did get a few light curves as i have shown above, however we do not have enough results to get many light curves yet and also the software will need more work so as to improve its accuracy, and to try and eliminate any anomalies.

To pay due regard to the measurement errors at each stage of the project

Achieved

At every stage through the process we tried to take into account any errors. This involved comparing the astrometry from the program to the plotted co ordinates of stars, along with comparing the measured brightness from our camera to the official magnitude of brightness from that star. By doing all this we were able to get an average error and a standard deviation. The smaller we could get these to errors the better.

Acknowledgments:

I would like to thank all those that provided support and help as i progressed through my project at Armagh Observatory; Dr. Simon Jeffery, my project mentor and also everyone else in the observatory who were helpful and were always on hand to provide advice.