Using star data to show all-sky imagers are calibrated consistently

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1 Introduction

The goal of this summer project was to answer the question of whether the all-sky imager devices placed in various sites across Canada are calibrated correctly, using star brightness values, which are expected to be consistent wherever stars are visible. Right now I believe we are a few steps away from answering part of that question, which is whether the different instruments appear to be calibrated to function identically to one another. In this report I intend to list and describe those steps: produce a dependable means of tracking the same star over time, at different sites and on different nights; select candidate stars for tracking; gather as much reliable star data from as many different sites as possible; and determine whether the data collected is consistent when external mechanisms affecting apparent star brightness are accounted for, such as atmospheric extinction.

2 Star tracking

A large portion of the time I've spent so far has been devoted to developing various methods of tracking a star as it travels across the sky over time. This work has led me to conclude that the only truly reliable method of tracking a star is to have a very good idea of where it is going to be at all times, using its position in standard astronomical coordinate systems. Fortunately, a lot of the work involved in turning astronomical coordinates into the position of a star in an image, taken at any given time at any one of the imager sites, existed before I started working on this particular method - the `geo_aim__define` methods allow me to input the star's right ascension and declination, and the time and location at which an image was taken, and receive the star's azimuth and zenith angles, both defined specifically at the site. These angles are easily converted to Cartesian coordinates as required on the image, then an image is produced that defines a region in which the star will most likely be found, which is within a small radius of those coordinates. In this way I am able to produce an image 'mask' that narrows down where to look for the star by setting everywhere it can't be to zero; I can find the star by selecting the maximum among the remaining nonzero pixels, provided that the region is small enough that there are no other stars inside the region.

In fact, at the time of this writing I have a working version of this procedure that is almost complete. Using the procedure I am able to gather star data from a single data set in about twenty seconds, so optimization may be possible but unnecessary for now.

The most important consideration I have come up with to improve this procedure deals with some assumptions that have to be made regarding the equivalency of the azimuth/zenith coordinate system to the coordinate system of the imager data. Ideally, since the images are all 256×256, the full range of $180°$ that one expects to be visible would be equivalent to 256 pixels, giving a precise ratio for easy conversion. While I have found that zenith angle and distance from the zenith is linear, I have not been able to measure what the true ratio is exactly. Another assumption is that the center of the image, between (127, 127) and (128, 128), is the zenith with which the coordinate system is defined. This depends both on whether the coordinates I use for for the site are exact, and whether the instrument is perfectly vertically aligned, neither of which seem like safe assumptions. Finally, it does not appear to be safe to assume that the celestial pole is exactly north of whichever point is found to be the zenith. This would indicate that the imagers are not aligned so that the y-direction points towards geographic north, perhaps because they are instead aligned towards magnetic north. However, as an example, the Gillam, Manitoba site is listed as having a magnetic declination of about half a degree, but my most reliable value for the angle at which the instrument is rotated is about $2°$.

The only means I have currently of correcting these assumptions is to manually align several of the tracking masks I described earlier, one each for six bright stars on each image. I wrote a procedure that redraws the pointing masks on top of an image as the three parameters - the ratio of zenith angle to pixel distance, the location of the zenith on the image and the angle of the celestial pole relative to the zenith - are adjusted using keyboard input. So far I've only needed to perform this correction procedure once for each site I've looked at, indicating that the manual method stays consistent over different days, but it would be helpful to have real, accurate information with which these parameters could be defined.

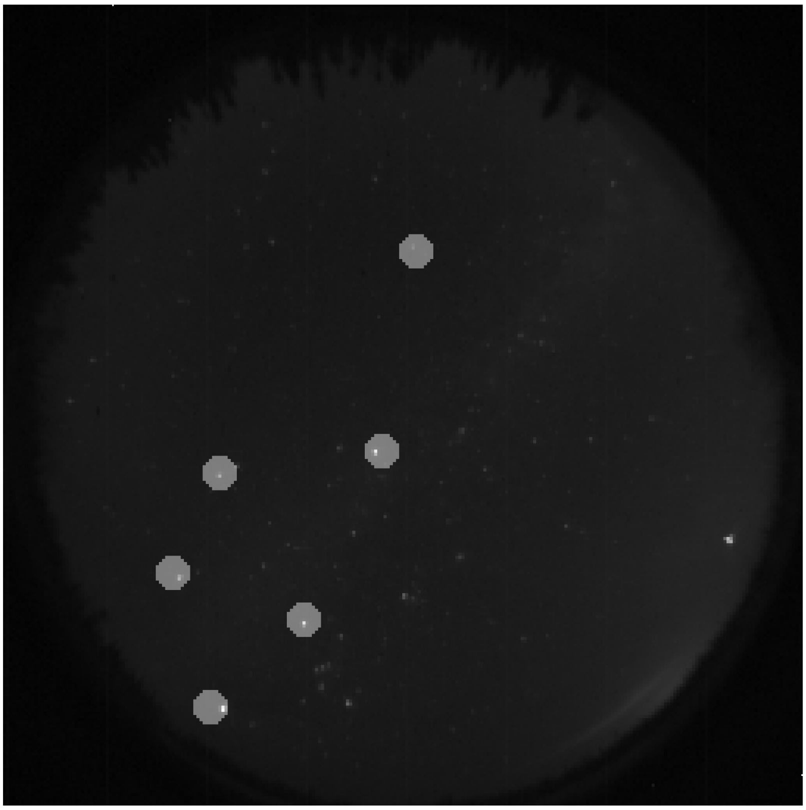

Figure 1: Using several non-overlapping masks for stars to determine alignment parameters. The process of redrawing six different masks at six sets of coordinates for a changing set of parameters is quick enough that the time it takes to update the image is noticeable but seems to take just about as much time as the square root applied to the image to enhance contrast.

3 Which stars do we track?

One star I've found useful to work with, particularly while trying out star tracking methods, was Capella, a bright star with a high declination, meaning it is close enough to the celestial pole that most of the path it takes is within the field of view for the sites examined so far. This means that even after data is rejected due to low visibility, either because of aurora or cloud cover, a reasonable amount of data remains.

Another star I intend to gather data for is Polaris, which is almost on top of the celestial pole, so that it is almost stationary in every data set, and visible whenever the sky is clear, though not as bright as Capella. If brightness is determined exclusively by atmospheric extinction then the brightness of Polaris should be constant at any particular site, and the differences observed between sites should corellate well with the latitude of each site, making it what I believe to be important data.

One last candidate for tracking is Vega, which we know to be very bright, but has a lower declination, so it is visible for significantly less time than Capella or Polaris in any data set. It may be useful to gain some insight on how well the methods outlined work for very limited data sets, which I expect to produce after tracking Vega and throwing a large amount of data out either because of aurora or clouds, or simply because it shouldn not even be in the field of view.

4 Gathering data

The methods I am currently using require me to manually look at a data set and extract regions in which stars are visible for tracking. This can often take a while as I try to avoid throwing too much data out, and leaving too much in wastes tracking time on frames that cannot be used anyway. When this is finished I typically end up with half a dozen days out of a month from which a few hours of useful data can be extracted - clouds, the Moon and aurora all render stars either completely invisible or, in the case of aurora, having unreliable brightness values due to the background.

The issue with aurora is that stars are not blocked out by aurora like clouds do, nor does it flood the field of view like the Moon, two reasons that ostensibly make aurora-filled frames useable. But unlike clear frames it is not possible to obtain consistent star brightness values simply by subtracting the background produced by the aurora from the star, either because an aurora background is non-uniform, or because the interaction between aurora and star brightness is more complex than the aurora simply adding to the star's luminance. A significantly larger amount of data could be gathered if aurora-filled frames could be made to be as reliable as clear frames.

5 Interpreting star data

My first attempts at looking at star brightness over time showed that star brightness would follow a well-defined curve that peaked at the point where the star was closest to the zenith. This leads me to believe that a crucial mechanism that should be considered while looking at star brightness is atmospheric extinction, which accounts for a star's brightness being dependent on its zenith angle. To get to a point where it is possible to predict brightness based on zenith angle, it is necessary to determine how pixel values are related to stellar magnitude, figure out how apparent magnitude is affected by airmass, and find a relation between zenith angle and airmass. It is known that the latter can be approximated using the secant of the zenith angle for zenith angles up to about $60°$, so this should work well for Polaris given that I think most of Canada is upwards of $30°$ latitude north.

Once as many external mechanisms as possible that could possibly affect star brightness are identified and accounted for, any differences between data would have to be attributed to the instruments themselves, and we should be in a position to compare the

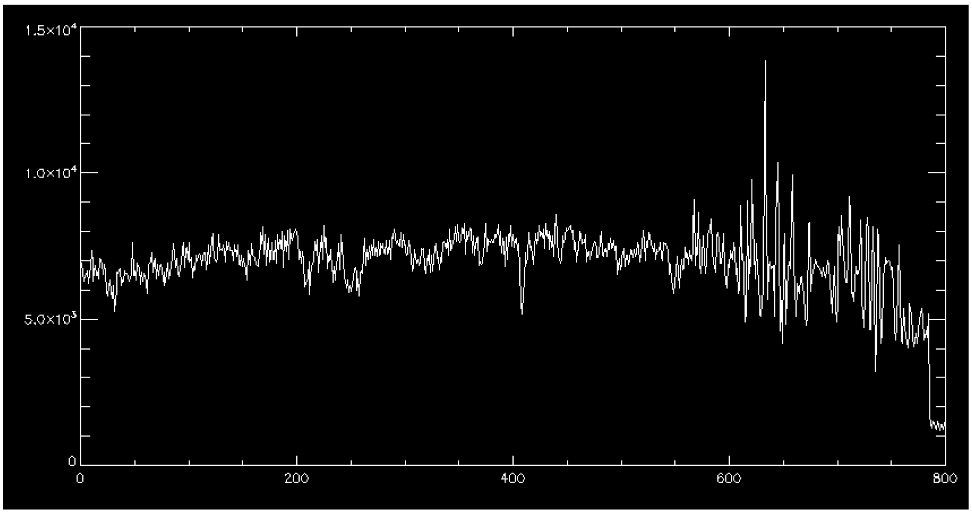

Figure 2: The brightness of Capella over time on the night of 1 January 2011. The night is clear until around frame 550, when aurora starts to become visible.

processed data from different sites and conclude whether the different instruments work identically.