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Automated Detection and Analysis of Meteor Events
Using Nightly Calibrations of Observed Stars

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College of St. Benedict/St. John's University

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of the Requirements for Distinction

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by

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Abstract:

Every night we experience the celestial phenomenon of meteors falling to Earth. Meteors are chunks of space debris composed of mostly rock or metal, which light up the night sky and are more popularly known as “shooting stars”. I used an all-sky camera to observe these meteors. The all-sky camera is a low light sensitive camera with a fish-eye lens so it can observe the whole night sky. If a meteor occurs, the ASGARD motion detection program saves a video of the event along with the summary of each frame of the event. I calibrated the images to get a better estimate of the magnitude of the meteor. Each image is calibrated by using the known stars in the camera’s field of view. The calibration of an image is the difference between the magnitude of the image and the magnitude of known stars that are in the image. Differences in observation environment, such as cloud cover or a bright moon result in different images and each image needs its own calibration. Since each image gets its own calibration there is a distribution of calibration values for all the events. Comparing my new programs to the old method of one calibration for all events it was determined that the per event calibration has on average a +1.5 magnitude shift in the peak magnitude of the event.

Introduction:

The aim of the project was to determine the magnitude of meteor events visible at CSB/SJU. Magnitude is a standard measure of brightness of an object. On the magnitude scale an increase in magnitude of 1 is a decrease in brightness by a factor of 2.51 (Goldsmith). The higher the magnitude, the dimmer the object. I have created programs to make these calculations of each meteor event more accurate. My programs include a way to identify stars and non-stars for calibration. When the program finds the stars, it can calibrate each image
based on the observable stars’ magnitudes. By knowing the non-stars, the program removes them from being used for calibration.

**Meteor Theory:**

There are chunks of matter in space called meteoroids, ranging in size from less than a millimeter to tens of meters across. Once they hit Earth’s atmosphere they heat up and begin to vaporize; these are called meteors more popularly known as shooting stars. If a fragment of the meteor survives to reach the surface of Earth it is called a meteorite (Paschoff, 275). When meteors enter the atmosphere they burn up, but not from friction. Ram pressure, produces a pocket of highly compressed hot air in front of the meteor. The transfer of heat from air to meteor results in the meteor burning (Britt). Meteors often occur in a shower, which is caused by the Earth passing through the path of a comet and moving through the debris (Paschoff, 279).

Although meteors occur at all times they are more frequent during the later hours of the night. This is because of the Earth’s orbital motion around the Sun. The hours between 3 am to 6 am have the most meteor events because these locations occur in the leading edge of Earth. Earth moves through them while meteors at other times must catch up to Earth (Figure 1) (Whipple, 249).
Figure 1: Earth's revolution around the Sun causes more meteor events near dawn (Terhaar).

Meteors can be classified into two main categories based on their composition. The majority of meteors are in the stony meteor class composed of rock and minerals. Only six percent of meteors fall into the classification of metal meteors composed of mostly nickel and iron (Goldsmith, 391).

The magnitude of a meteor can tell you the size and composition of the meteor. A stony meteor will break up more quickly while a metal meteor will stay more intact and has a higher chance of becoming a meteorite. Magnitude distributions are important to meteor research, because they can be used to find properties of a shower. The data obtained from meteor magnitude distribution may be used in studying hourly rate profiles.

One of the properties found in a shower is the population index. The population index of a shower is the ratio of meteor magnitudes for each class. It is a value that indicates how many times meteor magnitude m+1 occurs compared to magnitude m. The population index can tell us how many meteors will be missed under poor viewing conditions. A high number under poor conditions means that a lot of meteors are missed. If we have a small index number it means
that it is an older meteor stream. Most of the small meteoroids that cause a large index are gone, thus on average the observed meteors will be brighter (NAMN).

Since meteor showers are primarily caused by comet debris, the information on meteors will tell us information about the parent comets that they were left from. If the meteor is from a non-shower, the information can tell us about near Earth space debris.

**CSB/SJU All-Sky Camera:**

The all-sky camera is designed for the continuous observation of the sky. It is a low light sensitive camera with an attached fish-eye lens, which allows for a full view of the night sky. Since the camera is extremely sensitive to light it can easily detect meteors as they occur and the brighter stars in the sky.

The all-sky camera is a Supercircuits PC164CEX CCD camera enclosed in an acrylic dome and mounted to the side of the SJU observatory. The all-sky camera was designed by Josh Novacheck in the summer of 2009. The main enclosure is a four inch diameter PVC pipe strapped to a wooden bracket made of 2x6’s. At the top of the four inch PVC pipe there is a smaller removable assembly that holds the camera. Above that there is a piece of plywood with black sheet metal attached to it; both pieces have a large circular hole for the camera. The acrylic dome is attached to the sheet metal along with two small heaters. The heaters are to make sure that condensation does not form on the inside of the dome as well to melt any snow that may be on the dome (Novacheck). In July of 2010, Ross Terhaar added to small fans to the enclosure because the camera was heating up past the manufactures maximum operating temperatures (Terhaar).
ASGARD:

ASGARD is the motion detection program that was used to detect meteor events. ASGARD compares neighboring pixels from frame to frame and looks for groups of pixels that have increased in intensity. If there was an increase it is flagged as an event and a summary of the event is created, which includes a data file, video of the event, a frame right before the event begins, and an image of the stacked frames of the event. The stacked frames are all of the frames from the video stacked on top of each other to see the direction of the meteor. (Figure 2) (Weryk). The event summary is what is used to determine if it was a meteor event of a false positive. The stacked frames and the video were used to manually check to see if it was a meteor event, and the image before the event is used for the calibrations. ASGARD has a mask so it will not look for meteors in the tree line as well it not save events that it believes are not meteors. Events that are not saved include events that are less than four frames or last longer than 15 seconds.

Figure 2: Stacked frames of a meteor event taken on 08/09/2011. The stacked frames are all of the frames from the video stacked on top of each other to see the direction of the meteor. This is one of the items that ASGARD saves to when it detects a meteor.
Programming:

I created multiple programs to determine the calibration of an event. My programs were created in the IDL programming language, I used three programs **FIND, APER, and dbfind** from the NASA IDL library within the programs that I have created.

The first thing I had to do was remove the non-stars from the image. The detection program ASGARD saves an image every half hour throughout the day. Using these images the programs can find all of the hot pixels that are in all of the frames. A hot pixel happens when there is an increase in charge for the individual pixel without an increase in light. The charge causes the pixel to read as high value and it becomes brighter. It is brighter than the neighboring pixels in all the images. I want the hot pixels removed from my images because they appear as stars and they will make magnitude calibration of the image incorrect. By taking all of the images from sunset to sunrise over a few months I found the median of every pixel in the frame. This creates a nearly constant grey background with the hot pixels in white (Figure 3). I used the **FIND** program on the median image to look for objects that **FIND** determined were stars. These were not stars but instead hot spots. The coordinates of hot spots were saved, so they could be removed from the meteor event calibrations. I used a small window of ±2 pixel from the hot spot to be removed from the event.
Figure 3: The median of each pixel over 3 months of images used to find hot spots. It has a nearly constant grey background with hot spots that look like stars.

To get a calibration as close to the event as possible the frame right before the event starts is what is used (Figure 4a). **FIND** goes over the entire image and looks for groups of neighboring pixels that have a higher intensity compared to the surrounding background. This finds many objects many of which are not stars (Figure 4b), so a mask is applied to remove anything that **FIND** found in the tree line (Figure 4c). After the mask is applied the hot spots are removed (Figure 4d). I am left with an image that has possible stars on it (Figure 4e).

With each event I am using the visible stars to calibrate the image. The possible stars’ pixel coordinates must be converted into a form that will identify what star it is. I run a program that takes the (x,y) pixel coordinates and converts them to polar coordinates (theta, phi) and then into (altitude, azimuth) coordinates. With these new coordinates and the known date and time of the event, I can get the right ascension and declination (RA,Dec) of the stars. RA,Dec is
the sky’s coordinate system, RA is like longitude projected onto the sky measured from 0 to 24
hours. Dec is like latitude projected onto the sky, the equator at 0°, North Pole at +90°, and
South Pole at -90°. After finding the stars’ coordinates, I compare it to a star catalog and take
the closest known bright star compared to the event star. To find the stars the program uses
dbfind, which allows the program to set parameters to find the known stars. Each search
window was set to a ±15° right ascension and ±15° declination to allow for uncertainty in the
direction the camera was pointing. The parameters also allow it to look for bright stars that are
magnitude 2.5 or less. The magnitude parameter was chosen because I knew the camera could
see magnitude 2 stars and was unable to see magnitude 3, so the middle of 2.5 was chosen as
not to exclude the stars slightly above 2 that the camera may be able to see.

When the stars on my image have been matched to known stars, the magnitudes of the
known stars are used to calibrate the event. If more than one known star is found near the
image star the closest known star to the image star was used. After I know that stars have a
match I run APER on the images stars to get the image magnitude. By subtracting the
magnitude of the known star found by dbfind, from the magnitude of the event star
determined by APER, I have the magnitude calibration for each star. The average calibration of
each star in the event is used to find the calibration of the event. The error in the calibrations
was found by taking the standard deviation of the mean. A file is saved with information on the
known star and image star (Figure 5). With the calibrated images I then run a meteor
photometry program that finds the light curve of the meteor event (Figure 6).
a) The frame before the event is called in for the programs to run.

b) **FIND** looks for all spots on the image that it believes are stars.

c) The mask is applied to remove all spots in the tree line.

d) The hot spots are removed from the image.
e) **dbfind** looks for star and the remaining points are known stars.

Figure 4: A visual understanding of how the programs identify stars.

<table>
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<tr>
<th>RA</th>
<th>Dec</th>
<th>Known Magnitude</th>
<th>X</th>
<th>Y</th>
<th>Magnitude</th>
<th>δ Magnitude</th>
<th>Julian Date</th>
<th>Catalog Number</th>
</tr>
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<td>44.947498</td>
<td>1.90</td>
<td>250</td>
<td>19</td>
<td>19.89</td>
<td>0.21</td>
<td>2455417.9</td>
<td>2088</td>
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<tr>
<td>11.062139</td>
<td>61.750832</td>
<td>1.79</td>
<td>427</td>
<td>44</td>
<td>18.49</td>
<td>0.07</td>
<td>2455417.9</td>
<td>4301</td>
</tr>
</tbody>
</table>

Figure 5: Table showing an example of the data saved for each calibration star.
Figure 6: Light curve for meteor event taken on 08/09/2010 at 8:33. The event has a calibration of 17 that was on the higher end for calibrations but it had a peak magnitude around +.5, that is within the typical values seen.
Results:

Figure 7: Distribution of calibration for events. Events were taken from 08/01/2010 to 10/31/2010. A total of 550 events were taken over a three month window.

Seen in Figure 7 there are 550 events taken over three months, and the majority of the calibrations are in the 15.5 to 17 range, with a median calibration of 16.2. Last year Ross Terhaar used one calibration of 17.7 for all his events, the documentation did not include a reason or explanation for choosing the event that he used for his single calibration. I think that my calibrations are more accurate because I am looking at all viewing conditions and many events. Some of the values were far from the main distribution because of poor viewing conditions, but a meteor event was still detected. These cases were typically cloudy nights that
obscured many stars so my programs were not able to accurately find known stars. For those few events the calibration was set to the median value of 16.2 and the error was removed to show that it was an event that had to be set. Only 12 of the 550 events had to be set to a standard value.

For a comparison of events using my programs to the old calibration, I ran the 550 events and graphed the peak magnitude per event. I have included 3 figures to show the comparisons. My programs were only able to create light curves for 399 of the 550 events. This is because occasionally ASGARD will skip a frame in the video. The meteor photometry program that was created in a previous stage of the project does not handle skipped frames well and drops the event with skipped frames. Figure 8 is peak meteor magnitudes using the old calibration of 17.7. In Figure 9 I compared it to the peak meteor magnitudes obtained using a calibration of 16.2, to see if the shape was similar. The shape is similar however not exactly the same because of rounding and the bin size. The difference is a magnitude shift by +1.5 from the old standard to the median. Figure 10 shows the per event calibration and is very different from the old calibrations with the peak around magnitude -0.5, I believe this is an accurate because most meteors that were observed are not much brighter than the brightest stars in the sky.
Figure 8: Peak meteor magnitude of 399 out of 550 meteor events using the old calibration of 17.7 found by one night calibration.

Figure 9: Peak meteor magnitude of 399 out of 550 meteor events using median of event calibrations 16.2 found by taking the median of all event calibrations. This has a magnitude shift of +1.5 from the old calibration.
Figure 10: Peak meteor magnitude of 399 out of 550 meteor events using per event calibration.

It is much different than the previous two graphs with the peak of the graph near magnitude -0.5.

**Discussion:**

The programming works well and it is more accurate than the old method of one calibration for all events. I know that it works because I took multiple different events and found a calibration by hand. I would look at the image and find stars then compare them to stars found in XEphem, a night sky program. The calibrations found by hand were the same as the ones my program found. These results are more accurate because each individual event gets a calibration. The old method of one calibration was higher than the majority of all events calibrated.

However, this method will not work for anything past April of 2011, not because the programs do not work, but because the camera is no longer pointing the way it should be. The
camera and the program is set up to be 35 off from north, now the camera is 60 degrees off from north. The camera has been rotated as well the center is no longer pointing in the same spot. If the camera is off the programs do not work, because they use what is called a plate file. The plate file has all of the information of where geographically the camera is and where in the sky it is pointing. This information needed to identify stars, because if we do not know where the camera is pointing then we get incorrect (RA,Dec) values. I ran the program over three months 08/2010 to 10/2010 because the last plate that we have was created on 09/2010. Since that was the last plate, I knew near that date the camera would still be in the same position. Currently, we are unable to obtain an updated plate.

In conclusion, I was able to create programs that could distinguish stars from non-stars to determine a calibration for every meteor event. The median of the per event calibrations was determined to be 1.5 magnitude more than the previous calibration. The per event calibration ranged range from 14 to 18 magnitude.

**Future Work:**

There are still many more things can be done with the all-sky camera, such as fixing the camera so that our programs know where it is pointing. The best option would be to make another plate file, however since we do not know how to make one we would have to reverse engineer our current file and then create a new one based on our new information. This would be favorable because then we can make a plate whenever we want to such as every six months, or after the camera is cleaned. Alternatively, we could create a program to convert (x,y) coordinates directly into (RA,Dec) by following known stars throughout the night.
If we had a higher quality camera we could change our search parameters to include dimmer stars that would allow us to use more stars and get a better calibration. If we could set up multiple cameras we could use them to do triangulation on the meteors. Triangulation would allow us to determine entry point in the sky, angle of entry, and the velocity of the meteor. By using multiple cameras each one may calculate a slightly different calibration. We could use all three of the cameras calibration to more accurately get a correct calibration and determine the error in the calibration.
References


