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Detecting low signal-to-noise meteor images in the astronomical camera video stream

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Abstract. The analysis of space mission data, such as Long Duration Exposure Facility (LDEF), reveals that the majority of meteor particles fall within the microgram to milligram range. This range corresponds to meteor absolute magnitudes from 5–6 mag to 10–11 mag. Global Meteor Network (GMN) and Mini-MegaTORTORA (MMT) database analysis shows a noticeable decrease in the number of detected meteors fainter than threshold "limiting magnitude minus about 2 mag". This implies that there may be a loss of faint meteors at low signal-to-noise ratios. Therefore, it is crucial to improve the methods for detecting faint meteor events. We present a technique focused on real-time data processing. The key components of the pipeline involve rapidly identifying local peaks and then projecting the chosen points from a series of frames onto a reference frame within a sub-series of several images for analysis using the Hough transform. Initial test observations indicate an increasing trend in the number of faint meteor detections.

Keywords: techniques: image processing; meteors; meteoroids

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1 Introduction

Significant improvements in astronomical cameras, image detectors, and modern image analysis techniques cause the intensification of meteor observations worldwide. This provides new quality data for investigations in a wide set of astronomical fields regarding the Solar system structure from cosmogonic aspects to dust particle dynamics. On the practical side, the exponential increase in the number of artificial satellites requires a forecast of the meteoroid flux within the near-Earth space.

Modern meteor observations in the optical bandpass are typically carried out using wide-angle cameras that capture full frames at a rate of 10 frames per second. The data generated by this system is too large to be completely stored, so it is better to analyze the frame stream in real-time mode.

Some existing meteor networks, such as the GMN (Vida et al. 2021) provide broad geographic coverage and effectively detect pairs of baseline meteor images. These networks rely on a large number of amateur-level cameras. Hence, they are focused on identifying relatively bright meteor events. More specialized systems, like MMT (Karpov et al. 2019) or Ground Wide Angle Camera (GWAC, Chen et al. 2023), conduct effective meteor monitoring and provide information about hundreds of thousands of events up to 10th magnitude through their databases.

Our analysis of the meteor databases indicates that the current video stream processing pipelines may not detect low signal-to-noise images associated with faint meteor events. We present our view on the solution of the problem in this paper.

2 Low signal-to-noise meteor image detection pipeline

It is not difficult to plot a histogram of the meteor event detection versus magnitude using, for example, the MMT database. This is presented in Karpov and colleagues' paper (Karpov et al. 2019). The deficit of meteors fainter than 8th magnitude indicates a problem of low-signal-to-noise detections. Source image shape measurements and extraction of elongated images are effective for relatively well-saturated images. The authors of the GWAC system use binarization and median filtration procedures that exclude faint events. Despite this, both systems are powerful facilities for meteor astronomy. They provided great results and data sets. The next-generation survey systems probably will be based on 40-cm to 100-cm lenses and an f-ratio of $f/1.2$. This requires fast image analysis in a real-time mode and detection quality improvement.

The well-known Hough transform-based technique is often found in meteor detection discussions. This is a natural approach to extracting elongated meteor images.

This method is typically used for direct pixel array analysis. This is a computationally intensive method. We attempt to apply the Hough transform to the x, y array that contains pixel coordinates of all possible local maximums in the image. It is natural, that we detect a lot of false sources at the 1-σ level. It is expected that points from a set of source detections caused by meteor events will lie along a straight line (see Fig. 1). This condition is fulfilled both for one frame and for two or more consecutive frames.

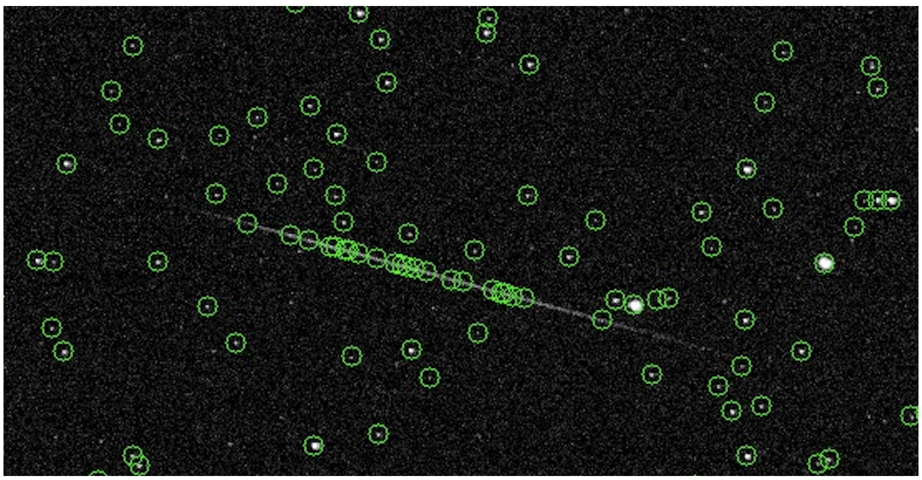

Fig. 1. A faint meteor trail was detected using the described pipeline. This is a 1962×1008 pixels fragment of the image captured using the SSA400 system developed at the Assy-Turgen Observatory (Fesenkov Astrophysical Institute, Almaty, Kazakhstan). The telescope has a D/F ratio of 400/551 mm, a field of view (FOV) of 3.7×2.5 degrees, and an angular scale of 5.6 arcseconds per pixel with 4×4 binning and QHY600 MPCIE camera (Monochrome CMOS camera, pixel size is 3.76 μm $\times$ 3.76 μm, and effective pixel area of 9576×6388).

The fundamental stages of our pipeline are outlined below:

1. Detection of all local maximums in the image.
2. Fitting the signal distributed over pixels in a very close neighborhood to each maximum by second-order surface.
3. In the "parabolic" case, we ensure that the model photocenter is near the local maximum (within 1–2 pixels). Fulfilment of these conditions allows us to interpret the local maximum as a source.
4. We apply the Hough transform to the set of all detected sources within one frame to detect a linear trail that can be a meteor image.
5. We distinguished between meteor and satellite trails by length.

6. We projected all extracted sources onto one plane from a set of consequent frames to detect meteor event images in different frames and measure their parameters.

3 Summary

We provided a brief description of our approach to the detection of faint meteor events with wide-field astronomical cameras. The described technique excludes computationally intensive calculations. Hence, this can be used for analysis of frame stream in a real-time mode.

Application of our code to data generated by the SSA400 telescope of the Assy-Turgen Observatory (Fesenkov Astrophysical Institute, Almaty, Kazakhstan) allows us to detect meteor events up to 13th magnitude during the γ Draconids radiant survey. The data flow was about 0.5 TB per hour.

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