Transient Detection Using Panoramic All-sky Cameras

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Abstract

A method of using on-going panoramic all-sky monitors for the purpose of bright optical transient detection is described. The detection is performed by comparing all-sky images to canonical images taken at the same sidereal time. The described approach has been implemented and tested using the infrastructure of the *Night Sky Live* network of panoramic all-sky cameras. Preliminary results of detected bright flashes are presented in the paper.

Keywords: image processing – methods: data analysis

1   Introduction

Real-time detection of bright optical transients has an important role in modern astronomy. In order to search for astronomical transients, many robotic telescopes have been built and operated around the globe (Cern et al. 2003; Vestrand et al. 2003; Akerlof et al. 2003; Steele et al. 2004; Lipunov 2004). However, since traditional narrow-angle telescopes cover only a very small portion of the sky at a given time, one can reasonably assume that some bright short-timescale transients may not be recorded by the available narrow-angle sky surveys (Nemiroff 2003).

One approach of searching for bright optical transients is by deploying and operating continuous panoramic all-sky cameras. This policy guarantees that any optical transient appearing on a clear night is recorded, given that the transient is brighter than the limiting magnitude of the all-sky camera.

The ability of all-sky optics to observe faint sources is not comparable to even simple narrow-angle telescopes. However, since brighter optical transients are sometimes considered more interesting to science (Lindley 1987; Menzies et al. 1987), the approach of using fish-eye lenses that can record bright transients by covering almost the entire sky can be weighed against narrow-field robotic telescope that are capable of recording much fainter sources, but cover only a narrow field of view.

In Section 2 we describe the construction of the database of canonical images, in Section 3 the transient detection using all-sky images is described and in Section 4 the implementation and preliminary results are presented.

2 Canonical Image Database

A first step all-sky transient detection is to create a comparison image from which any image can be compared. This image can be composed of images taken at the same sidereal time as the given frame, and will be called the "canonical image". One can think of the "canonical image" as a hypothetical image taken when the sky is completely clear. In reality, the canonical image is better created from several relatively clear images taken at the same sidereal time. To proceed, the system first needs to acquire a sufficient database of relatively clear images.

One approach of obtaining this database is to manually select images taken at clear nights. However, observing images by eye is a time-consuming task, and the required human resources are not always available. Moreover, since thin cirrus clouds are hard to detect, a human observer might consider some images as *clear* while in fact parts of the sky are covered with light clouds.

Another approach, which we have found more appropriate, is to use an algorithm that automatically searches for images taken at clear nights. The algorithm is based on applying a star recognition algorithm that associates the point spread functions in the image with star catalog entries (Shamir & Nemiroff 2005a). After the point spread functions are associated with known stars, the algorithm checks if the stars that are brighter than a pre-set visual magnitude are detected at a pre-set statistical confidence level. If the PSFs of a sufficient percentage of expected stars are found in the image, the image is classified as *clear*, and added to the database.

The percentage of stars visible at a certain frame is dependent not only on the sky clarity, but also on the darkness of the sky. For instance, faint stars near the galactic plane will not be detected as easily as stars far from the Milky Way. Therefore, the pre-set threshold of visual magnitude should be chosen such that stars near the center of the galactic plane brighter than the threshold can be detected. Since this problem becomes more substantial when the moon is up, canonical images are added to the database only when the moon is down.

When an image is added to the database, it is averaged with all other images taken at the same sidereal time that are already present. Averaging the images gives a better signal to noise ratio than using a single exposure. The large pixel size and the absence of moving parts in the all-sky monitoring system simplify the process of image co-adding.

3 Transient Detection Using All-sky Images

The detection of transients in all-sky images requires several logical steps. The first is the building of a canonical image taken from previous images taken at the same sidereal time, as discussed last section. Another step is the rejection of pixels dominated by cosmic-ray generated counts. Rejecting cosmic rays by comparing two images of the same field (Shaw & Horn 1992; Fixsen et al. 2000) cannot be used for this purpose since this method inherently rejects flashes appearing in one image but not appearing in the other. Since the use of this approach is inappropriate for the described system, rejections should make use of the non-point source nature of cosmic ray splashes. We chose to use a fuzzy logic-based algorithm for cosmic ray hit rejection from single images (Shamir

2005a). This algorithm is reasonably accurate and provides low computational complexity allowing it to process images in a relatively short time.

Next, bright planets are also rejected using a star recognition algorithm designed to find astronomical objects in wide angle frames (Shamir & Nemiroff 2005a). In the same fashion, high-amplitude variable stars can also be rejected from the image.

After cosmic ray hits and bright planets are rejected, the system searches for PSFs that are a given σ brighter than the local background. Each PSF is then compared with the canonical frame. If the PSF does not appear in the canonical image, it is assumed to be a transient.

Due to the relatively high density of artificial objects in orbit around the earth, one can expect that most detected flashes would result from the presence of artificial objects (Schaefer et al. 1987a; Varady & Hudec 1992). In fact, some flashes that were suspected to be true astronomical transients (Halliday et al. 1987) appeared later to be nothing but background flashes (Schaefer et al. 1987b). Another source of background flashes is bright meteors and fireballs that may also be recorded by all-sky cameras (Shamir 2005b).

The more interesting flashes may be those that seem to rotate with the sky, which may be an indication of a true astronomical source. One way to find such flashes is by simply observing the list flashes recorded on a specific night. A flash appearing in more than one frame at the same geocentric coordinates can be a good candidate to be regarded as a true astronomical transient.

Some bright flares may be too short to appear in more than one image. One approach to detect transients that appear in just one frame is by comparing images taken by two all-sky cameras located far enough from each other, but record the same area of the sky where the transient was detected. If the flash was detected in two images taken at the same time by two cameras, the flash may be a true astronomical source.

All-sky cameras are usually passive and do not track the sky. Therefore, stars may "trail" in the image, given that the duration of the exposure is long enough to let the star move more than (at least) one pixel on the CCD chip. This seemingly disadvantage can be used here to find flashes that rotate with the sky. If the PSF of the flash seems to trail to the same direction of nearby stars, this may be an indication of a true astronomical transient. Flashes that their PSF does not trail can be either very short flashes or flashes resulting from geosynchronous satellites (Shamir & Nemiroff 2005c).

4   Implementation and Preliminary Results

The described method has been implemented using the infrastructure of the global *Night Sky Live* network (Nemiroff & Rafert 1999). The Night Sky Live network consists of 11 nodes called *CONCAM* located at some of the world's premier observatories. Each node incorporates an SBIG ST-8 or ST-1001E CCD camera, a Nikon FC-E8 or SIGMA F4-EX 8mm fish-eye lens and an industrial PC. Each *CONCAM* takes one 1024×1024 180-second exposure all-sky image every 236 seconds. The FITS files are then transmitted to the main server where they are copied to the public domain and can be accessed at http://nightskylive.net. The Night Sky Live network provides features such as bright star monitoring (Shamir & Nemiroff 2004) and all-sky opacity maps

(Shamir & Nemiroff 2005b). FITS frames are stored in the main server for two months, after which they are archived on DVDs and removed from the server, but are still available upon specific request. The limiting stellar magnitude is dependent on the hardware being used and can get to 6.8 near the image center.

The described system is currently being tested using the CONCAM camera located in Roque de los Muchachos observatory in La Palma. Between June 24th and July 24th 2005, the system recorded an average of ~8 bright optical flashes per night. Most flashes were recorded only in one image. Some flashes appeared in more than one image, but did not rotate with the sky and therefore assumed to be glints of geosynchrnous satellites (Shamir & Nemiroff 2005c).

The limiting stellar magnitude of the CONCAM camera located in La Palma is ~5.9. The limiting magnitude of a flash is dependent on its duration. For instance, if the duration of the flash is 2 seconds, its limiting magnitude would be $5.9 + 2.5 \log \frac{2}{180} \simeq 1.01$. The limiting magnitude as a function of the duration is described in Figure 1.
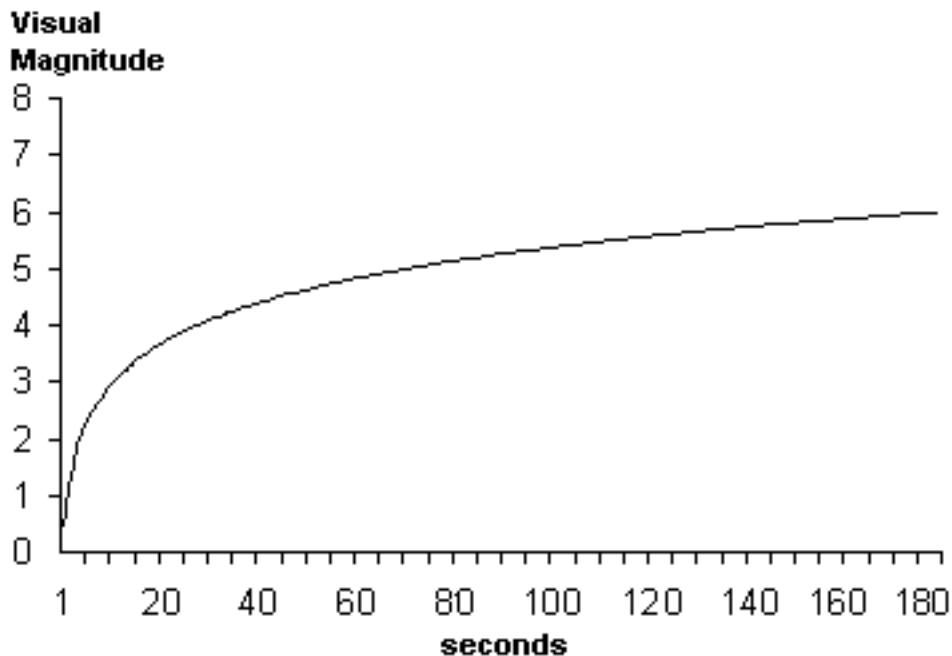

Figure 1: Limiting magnitude as a function of the exposure duration

Figure 2 shows a flash recorded at RA=~18.36h, DEC=19.65^{o} by the CONCAM camera operating in La Palma on the night of July 11th 2005 at 3:25:03 UT. The flash was recorded in just one image. From the non-trailing nature of the point spread function, one can deduce that the flash was either of a very short timescale, or did not rotate with the sky (meaning it was probably a glint from a geosynchronous satellite).

Figures 3 and 4 show a flash that may be rotating with the sky, and therefore may be a true astronomical source. The flash was recorded in two consecutive images taken on the night of July 18th 2005 at 04:32:30 UT and 04:44:06 UT. The flash appeared in the constellation Aries around RA=~2.39h, DEC=~
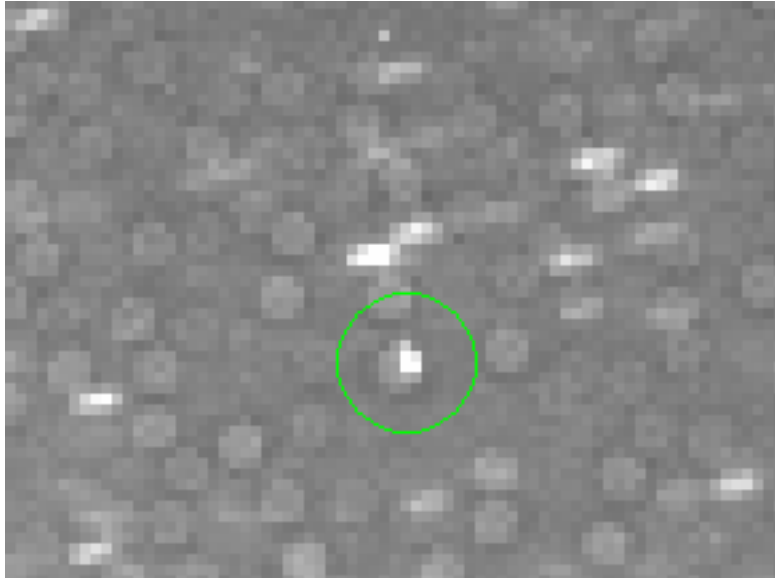
Figure 2: A flash recorded by CONCAM all-sky camera located in La Palma on July 11th 2005 at 3:25:03 UT

25.35^{o}, and the point spread function seems to trail in a fashion similar to the other neighboring stars recorded in the same frame. The bright star at the bottom of Figure 3 is Alpha Arietis and the star at the top left corner is 41 Arietis. The intensity of the flash is comparable to the intensity of Kap Arietis ($\sim$5th magnitude). Unfortunately, other CONCAM cameras covering the same portion of the sky were not active due to technical problems so the flash could not be cross-checked with other cameras covering the same area of the sky.

5   Conclusion

In this paper we showed that all-sky cameras can be used for the purpose of bright optical transient detection. The full coverage of the sky provided by all-sky cameras can be weighed against the low limiting magnitude, and can be effective for the purpose of automatic detection of very bright optical transient. Due to artificial luminous objects in orbit around the earth, short-timescale transient detection requires an array of all-sky cameras sharing the same sky so that possible discoveries can be cross-checked.

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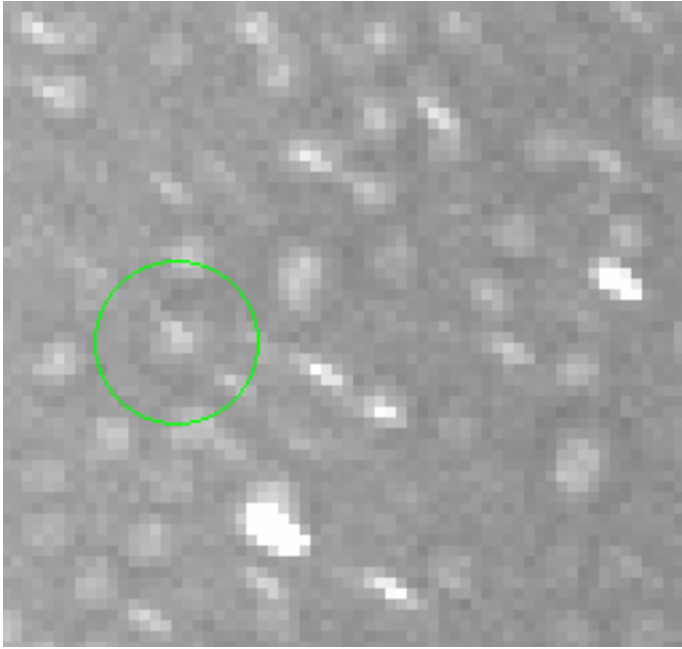C. Cern et.al, 2003, Rev. Mex. Astro. y Astrof., Ser. Conf, 16, 77

Figure 3: A flash recorded by CONCAM all-sky camera located in La Palma on the night of July 18th 2005 at 4:32:30 UT
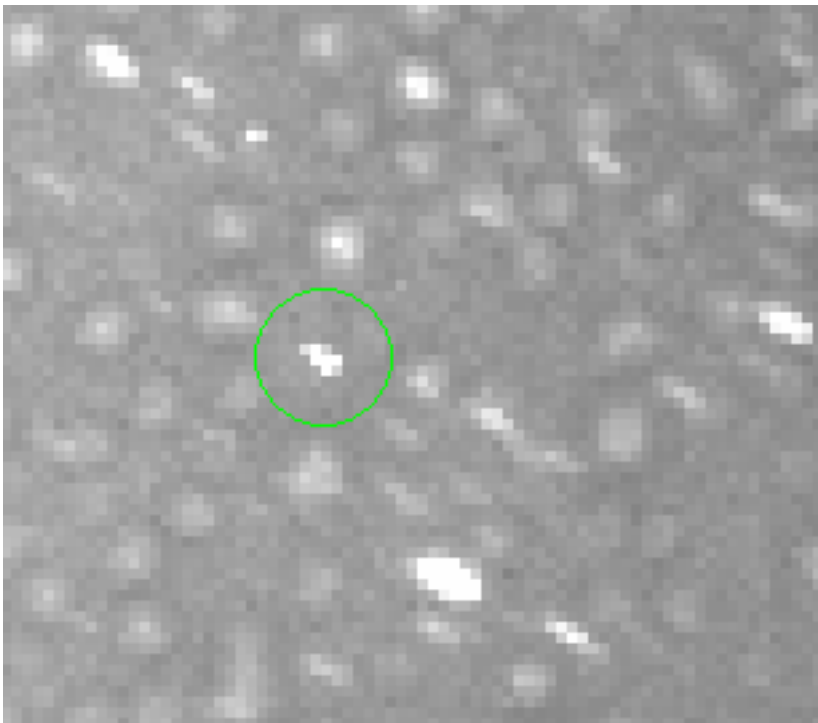

Figure 4: A flash recorded by CONCAM all-sky camera located in La Palma on the night of July 18th 2005 at 4:44:06 UT

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