DETECTION OF LOW EARTH ORBIT ARTIFICIAL SATELLITES WITH ASTRONOMY CAMERA.

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ABSTRACT

We have built three astronomy cameras dedicated to meteor observation, which also detect artificial satellites on a daily basis. The goal of the present work is to examine the potential of such observations to compute the orbit of artificial satellites. We present the preliminary method and results focused on the detection and accumulation of satellite data. Automated procedures allow us to collect between 10 and 30 images of a single satellite per passage. Future work includes the computation of the trajectory and orbit of artificial satellites.

Keywords: Artificial satellites; Detection and image processing; Optics; Orbit Computation ; Preliminary Orbit Determination .

1. INTRODUCTION

The ”Camera for BEtter Resolution NETwork” (CABERNET) project aims to observe natural meteors with an unprecedented spatio-temporal accuracy. It involves three optical cameras set up in the Pyrenees mountains (Pic-du-Midi observatory, Guzet - France and Montsec - Spain), observing the same portion of the atmosphere on a daily basis since 2011. For triangulation purpose, each camera points to a different part of the sky with a field of view of $40 \times 27°$. The sensor is a full frame 11 Mega pixel LHeritier LH11000 and the camera is equipped with a Canon 50mm f/1.2 lens. One pixel covers $0.01 \times 0.01°$ on the sky. The cameras are embedded in a protection box and controlled via a PC reachable from the distant lab. The details of the setup were fully described in [1]. Images are taken continuously between astronomical twilight and dawn, with a total exposure time of 1 sec and a dead time between two exposures is $1/7$ sec. To increase the time resolution of the fast meteor position measurements, an electronic shutter is coupled to each camera and decreases the effective exposure time to 0.5 sec. A star limiting magnitude of 8 is reached during such an effective exposure time. The meteor detection algorithm is based on difference of images taken by 1 second interval, threshold and grouping techniques. As such, it also creates a detection when a low Earth orbit artificial satellite is in the field of view. Such a detection might prove useful for LEO satellites orbitography, and will be developed in a further step of the project. The orbit determination of meteors is performed using the technique developed by [2].

This paper presents the preliminary results of our study, started in the fall 2018 as a part time student internship, to compute satellites orbits from optical data. Section 2 presents the detection algorithm and section 3 shows how to increase the number of images showing artificial satellites. Section 4 presents the future work.

2. DETECTION OF ARTIFICIAL SATELLITES WITH CABERNET

The meteor detection algorithm is based on image difference between a current image and the one taken one second before. A threshold of 3σ allows us to dismiss the noise. To consider the detection as a valid one, a total of at least 40 changing pixels with a distance between them lower than 40 pixels needs to be detected. Such an algorithm is extremely simple to implement and allows us to efficiently detect the meteors. However, it also allows us to detect artificial satellites, as shown Figure 1. Note that this satellite is uncorrelated with heavens-above to the best of our knowledge[1]. This image result from the subtraction of a current and previous image, i.e. the image taken right before the image of interest (called the current one). It presents dark and light segments, corresponding to the current and previous positions of the satellite, between the current and the previous images. The light part spans 50 pixels long in the original image, representing roughly $0.5°$ During a typical clear night 5 to 20 satellite images are typically collected using this technique.

It is worth mentioning that each detection image is quickly but manually inspected in order to make the difference between a meteor and an artificial satellite. False positive detections caused by the motion of low altitude clouds lighted by the Moon are also removed. To increase the efficiency of this process, we have started to develop

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[1] www.heavens-above.com

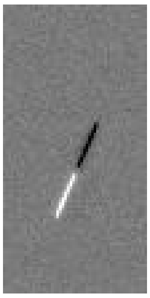

Figure 1. Example of artificial satellite detected with the CABERNET cameras installed at Montsec, Spain. See text for further explanations.

an algorithm based on machine learning and artificial intelligence to automatically sort the images. At the time we write these lines, preliminary results show that the algorithm correctly identifies a meteor or an artificial satellite in 80% cases, which is good but still insufficient for our purpose. In addition, such image recognition technique are widely used today and better results are reasonably reachable.

3. ENHANCING THE NUMBER OF SATELLITE IMAGES

Because the detection is performed on raw images, and because of optical vignetting and the chosen detection threshold, satellites are usually best detected in the central region of the image. In order to better estimate a given satellite orbit, the more the number of images are exploited the better. We therefore searched for a solution to increase the number of images taken for a given satellite.

The first step is to better derive the exact location of the satellite in the image. The current algorithm provides us with the name of the image as well as the coordinates of the detection. The so called ”Negative” image, i.e. taken right before the image of interest is downloaded in order to perform image subtraction and isolate the satellite thanks to its approximate image coordinates. An edge detection followed by a line detection using the well-known Hough transform are performed, after which the location of the satellite is refined. An example of the edge detection is showed in Figure 2. Then the displacement of the satellite during the exposure time is measured, using the level of the pixel at the extremities of the detected line. Finally, the previous and subsequent images are downloaded and analyzed, as long as the satellite is in the field of view, based on the estimated apparent satellite displacement. Such a refinement allows us to increase the number of images for a given satellite from a few to up to 30.

The procedure is repeated for all images where a satellite was manually detected (see section 2). Such a work has started in the fall 2018 and the automated run of the routine has started in early January 2019. The first results show that for a typical night, we collect between 50 and 200 satellite images. The program is written in python and is run automatically on a daily basis.

Figure 2. Example of edge detection performed on a flipped version of the image showed in Figure 1.

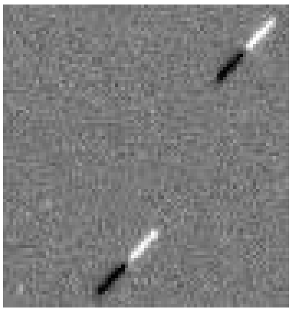

Figure 3. Example of double satellite detection. Note that this satellite is uncorrelated with heavens-above to the best of our knowledge

4. FUTURE WORK

The automatic identification of satellites in the images must be improved to reach at least 98% of success (right now a 80% success is achieved). This will naturally result from the accumulation of manually identified images, which is performed on a daily basis since the fall 2018, used to train the machine learning program. The algorithms are well known and many python libraries are available to perform such a task.

Once the identification works in a satisfactory way, the initial detection criteria might be relaxed, resulting in a higher number of false positives, but also enhancing the number of detected satellites. A clever way to change these parameters will allow us to best tune the whole detection process. In addition, a different image exposure policy might be applied in order to maximize the satellites detection. By removing the electronic shutter mode used for the meteor observations, the effective exposure time and signal to noise ratio of the CABERNET images will be increased by a factor of two.

Once the satellites are identified, the astrometric measurement of the position of each object in the apparent sky will be performed using usual astronomy tools, such as SExtractor and SCAMP [3, 4]. The output will be time series of apparent position of the satellite in the sky, allowing us to derive the trajectory and the orbit of the object. Photometric measurements will also provide us with different characteristics of the target, like the rotation state of the object.

The above described procedures still must be double checked for special cases (e.g. apparently dim satellite, truncated measurements, etc.) and made fully automated, including the identification procedure. Special cases also include double satellite detections, such as presented in Figure 3.

A reverse process is also possible, i.e. to look for an artificial satellite in an image, knowing its Two-Line Elements (TLE). This will interestingly allow us to directly quantify the advantage of optical measurement of LEO compared to radar detection.

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