*RevMexAA (Serie de Conferencias)*, **48**, 99–102 (2016)

IV Workshop on Robotic Autonomous Observatories (Torremolinos, Málaga, Spain, September 28- October 2, 2015)
Editors: M. D. Caballero-García, S. B. Pandey, D. Hiriart & A. J. Castro-Tirado

# THE METEOR AND FIREBALL NETWORK OF THE SOCIEDAD MALAGUEÑA DE ASTRONOMíA

J.C. Aznar[1], A. Castellón[1,2], F. Gálvez[1,3], E. Martínez[1], B. Troughton[1], J. M. Núñez[1], and A. Villalba[1]

RESUMEN

Uno de los campos con más actividad a los que se ha dedicado la Sociedad Malagueña de Astronomía (SMA) es el de los meteoros y lluvias de estrellas. Desde el 2006 la SMA remite partes de observaciones visuales así como detecciones fotográficas desde su estación de El Pinillo (Torremolinos, España). En el 2013 se decidió dar un impulso adicional para conseguir una red de estaciones que permitiera el cálculo de la trayectoria atmosférica de un meteoroide y, cuando sea posible, la obtención de los elementos orbitales

ABSTRACT

One of the most active fields in which has been dedicated the Málaga Astronomical Society (SMA) is the meteors and meteor showers. Since 2006 the SMA refers parts of visual observations and photographic detections from El Pinillo station (Torremolinos, Spain). In 2013 it was decided to give an extra boost to get a camera network that allowed the calculation of the atmospheric trajectory of a meteoroid and, where possible, obtaining the orbital elements.

*Key Words:* astrometry — instrumentation: miscellaneous — meteorites, meteors, meteoroids — methods: data analysis


Fig. 1. Location of the stations in the south of Spain

## 1. THE STATIONS

El Pinillo station (Torremolinos, Spain) is operating since 2006 and consists of a CCD SBIG ST-402 adapted by the manufacturer as allsky camera. The adaptation consisted on the substitution of its case for a waterproof metallic box prepared to resist the external conditions, which was provided of superior window covered with filter RG -630. The edges of the opening are heated by a resistance to avoid the dew condensation. A Fujinon 2.6mm F1/6 lens picked up a field of $120^{O} \times 80^{O}$. Unfortunately, in the adaptation process the Peltier cooler and the mechanical shutter were eliminated, which disabled it for the taking of dark frames.

This camera has been modified increasing the upper opening, covered now by a neutral sheet of methacrylate, and designing a new sealing system controlled by Arduino card. The shutter is a two-blade wheel moved by stepper motor. Through two LEDs and a photoresistor the software determines when the shutter is open and when it is closed. Thanks to these additions, now dark frames can be taken. The Arduino card is also responsible for turning on/off the camera. Along with this it has also been installed a Sky Quality Metter that monitors all night background brightness of the sky.

We wrote a complete control software for the camera in C ++ and Perl that runs under Linux operating system. To control the SQM, the PySQM program is used (Nievas Rosillo and Zamorano Calvo 2014).

The second station became operational in April 2014 and was installed at the Torcal Astronomical Observatory (OAT) (Antequera, Spain) through a collaboration agreement with the OAT. It consists of a CCD SBIG AllSky-camera camera and a video camera ZWO ASI-CAM 120MM. The CCD camera

[1]Sociedad Malagueña de Astronomía, C/ República Argentina 9, 29016 Málaga, Spain (info@astromalaga.es)

[2]Departamento de Álgebra, Gemetría y Topología, Facultad de Ciencias, Universidad de Málaga, Campus de Teatinos S/N, 29071 Málaga (Spain), (apncs@uma.es)

[3]Observatorio Astronómico del Torcal, Carretera MA-9016, Km 3.5, Antequera (Spain), (secretaria@astrotorcal.es)

IV Workshop on Robotic Autonomous Observatories (Torremolinos, Málaga, Spain, September 28- October 2, 2015)
Editors: M. D. Caballero-García, S. B. Pandey, D. Hiriart & A. J. Castro-Tirado

is an adaptation from manufactured ST-4 model, located inside a waterproof metallic case with a dome of methacrylate atop, a dew-heater tape, and a fish-eye Fujinon 1.4mm at f1/4 lens, which provides a field of $180^{\rm O} \times 108^{\rm O}$, and mechanical shutter. A USB relay was adapted, that allows to turn on/off the camera remotely. We had to rewrite the whole control software because the provided by the manufacturer did not adjust to the persued goals. The programs are written in Python, C++ and Perl and run on a Windows 7 based computer.

The ZWO video camera has been equipped with a Fujinon fish-eye 1.4mm at f1/4 lens (field of $185^{\rm O} \times 185^{\rm O}$) and is located in a waterproof metallic case, also covered by a dome of methacrylate, as a result of a self-developed prototype (Torcal 1.1). This camera is controlled by a Raspberry Pi, with a control software written in C ++, and also manages the turning on/off via a relay which cuts power through the USB bus.

The third station became operational in August 2015 under a cooperation agreement between the SMA, the Ministry of Environment and Planning of Andalucía, Monte Mediterráneo Foundation. It is located in San Francisco Dehesa (Santa Olalla del Cala, Spain). It consists of a camera SBIG ST-8XME 4mm provided with a Nikkon lens (field of $180^{\rm O} \times 98^{\rm O}$) and dew-heater tape. The enclosure has a dome, a temperature/humidity sensor and an Arduino card that calculates the dew point. The heating tape is turned on by Arduino when the temperature is less than 1C of dew point. It also handles the turning on/off of the CCD. This station is completed with another similar SQM such as the one at El Pinillo.

Apart from these three stations, the SMA has access to AllSky cameras CASSANDRA-1 and CASSANDRA-2 from BOOTES (Castro-Tirado et al. 2008), located in El Arenosillo (Huelva, Spain) and La Mayora (Algarrobo, Spain). Both consist of Apogee $4096 \times 4096$ cameras with regulated temperature and equipped with Nikon lens 16mm providing a field of $180^{\rm O} \times 146^{\rm O}$. They are controlled by the RTS-2 (Kubanek 2010) control operating system under Linux.

Both cameras at El Pinillo and El Torcal stations take rolling exposures (30s integration time each). The one at the San Francisco station takes captures of 45s whereas the ones at El Arenosillo and La Mayora use 36s for each exposure. In the first three stations dark frames are taken every 60 shots, while the other two are taken at the beginning and end of the night.

## 2. THE CONTROL SOFTWARE

To goal is to achieve devoted stations which will operate completely autonomously and not dependent on human supervision, independently of their on/off status and solve any problem which may happen during their operation. This has influeced the writing of the software and all the equipment. Not only automatization has been achieved, but a robotization by reacting to different circumstances. Python, C++ and Perl languages have been used. The capture software performs the following actions on a daily basis:

- It starts by checking whether the camera is accessible, by turning it on, establishing communication and turning it off.
- It creates a directory for the night and opens an incidents file.
- Periodically the Sun's position is calculated. When placed $10^{\rm O}$ below the horizon, the camera is turned on, a temperature of $-10^{\rm O}$C is set, and it takes the initial dark frame.
- While the sun remains below the horizon at $-10^{\rm O}$, successive captures are made and files are stored in the directory of the night.
- Every 60 shots a dark frame is taken.
- If at some point communication with the camera is lost, the universal computing solution is used: turn it off, wait five seconds, turn it on again. In a high percentage of cases this solution works. The incidence is recorded in the incidents file.
- Gif animations are generated at dawn by means of 60 by 60 captures with the FITS files subtracted from dark frames and the mask which cuts horizon accidents. The incidents file where the significant events have been annotated during the night, closes, and starts the detection software which will be described below.
- The generated files (animations and detections) are uploaded to our own cloud server to be later examined.

The software is also capable of handling accidental power outages, re-starting the whole process when power returns. The same applies to possible communication interruptions via USB or RS232.

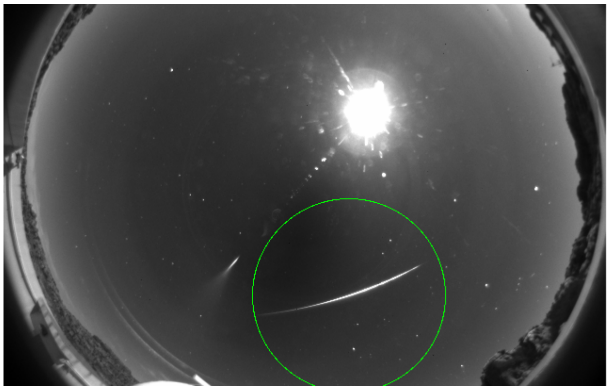

Fig. 2. Fireball captured by El Torcal station on March 31, 2015

## 3. THE DETECTION SOFTWARE

The detection and trajectory and orbital elements calculation process, needs to solve the astrometry of the AllSky images taken by the stations. For this purpose, it has been developed a method that is a variation of the introduced in Borovicka (1995). The changes we have implemented have two goals: firstly, to facilitate the choice of good initial values for the convergence process required in the calculation of the constants of the plate, and on the other hand, increasing computing performance when the time comes to massively act on the image pixels. The detailed description of these procedures is beyond the purpose of this article.

The method has been successfully implemented in all stations, despite harbouring CCD/lens systems of very different types, with chips whose sizes range from $640 \times 640$ to $4098 \times 4098$ pixels, and fisheye lenses from 16mm to 1.4 mm focal length. In all cases subpixel resolution was obtained.

The detection software performs the following actions:

- With the immediately preceding image to the one which will be examined, an artificial diurnal motion is made, namely the position at which each chip pixel will go after the sky has moved during the interval $\Delta(t)$ that is the mean between captures is calculated. A mathematical process distributed proportionally the calculations of that pixel and composes a new FITS file reflecting the sky state at time $t$, but displaced in the celestial sphere until time $t + \Delta(t)$.
- The previous image with the corresponding diurnal motion added, is substracted form the capture to be examined. Almost all stars are eliminated in this subtraction, except the brightest and the planets that have been able to produce different PSF due to atmospheric fluctuations and optical aberrations.
- The position is calculated in the chip of those stars and bright planets to dismiss them from the detections.
- SExtractor is run, in order to detect the centroids of the detected objects and not eliminated by image subtraction.
- Regarding the list of candidates, bright objects previously calculated are eliminated.
- On moonlit nights, the dome itself and the optics, generate image reflections (ghosts) to be discarded. To this end, we have written routines that calculate the positions in the chip of these reflections, depending on the moon position and its apparent brightness.
- If a detection has been achieved at the end of this process, its coordinates, date and time are recorded in a file, and an animation gif with the image detection is generated, the previous and subsequent ones.
- Detections images are packaged, compressed and uploaded to the cloud for examination.

A group of SMA volunteers take shifts examining animations and detections that are uploaded daily to the cloud. This is required because false detections can still show up: traces left by airplanes and satellites, sporadic reflections, cosmic rays, small clouds... (an algorithm detects clouds of medium and large size to discard them as detections).

## 4. CALCULATION OF THE TRAJERCTORY AND ORBITAL ELEMENTS

Once a trace left by a meteor is recongnized, we need to asses its location on the sky by considering two points. Commercial software is commonly used in astronomy and is designed to calculate centroids with roughly circular PSF. Hence we have made specific scripts to accurately determine the positions on the chip of the line ends, which, united with the astrometry resolution of each image, gives the horizontal coordinates for each station that registered the event.

The OAT video camera is programmed to record a sequence of 4s at 10 frames per second each time it detects movement. This allows to determine the angular velocity of the meteor and its atmospheric speed.

IV Workshop on Robotic Autonomous Observatories (Torremolinos, Málaga, Spain, September 28- October 2, 2015)
Editors: M. D. Caballero-García, S. B. Pandey, D. Hiriart & A. J. Castro-Tirado

IV Workshop on Robotic Autonomous Observatories (Torremolinos, Málaga, Spain, September 28- October 2, 2015)
Editors: M. D. Caballero-García, S. B. Pandey, D. Hiriart & A. J. Castro-Tirado


Fig. 3. KML file generated by the software with both ends of the trajectory and the probable impact point

To calculate the atmospheric trajectory and orbital elements (when possible) we have written programs, which implemented methods that are slight variations of those described in Dubyago (1961) and Ceplecha (1987). In the output file corresponding to the atmospheric trajectory, the following information is included:

- Equatorial coordinates of the radiant (J2000)
- Geographical coordinates of both ends of the trajectory, distance from the stations and altitude above Earth's surface in km
- Geographical coordinates of the potential impact location
- Parametric equation of the trajectory in geocentric coordinates
- Trajectory tabulation based on the mileage travelled, expressing geographical coordinates of nadir, celestial coordinates and the station geographical coordinates.
- Angular distances from the calculated radiant to the radiants of the active showers at the current date.

In addition, a KML file is generated to display the path in Google Earth. If the meteor speed can be determined, an additional file is generated, in which the values of the orbital elements, either elliptic, parabolic or hyperbolic orbit are included.

In case the meteoroid has been detected only for one station, a program calculates the maximum circumference of the celestial sphere containing the trace projection and angular distances to the active radiants at the current date. Thus, in many cases, although it has not been possible direct calculation of atmospheric trajectory, we could determine the radiant source. Using the information on the azimuth and zenith distance of the line points, we managed to estimate an approximate trajectory.

## 5. CONCLUSIONS AND PLANS FOR THE FUTURE

Málaga Astronomical Society has set up a monitoring network of fireballs and meteors that has already begun to produce outstanding scientific results. Since in April 2014, we had installed a second station, have been calculated atmospheric trajectory and orbital elements of hundreds of meteoroids. However, there are still pending tasks for the extension and improvement of the network:

- Debug and simplify detection software
- Expand the network with new stations
- Incorporate a diffraction grating to obtain the spectrum of bright fireballs.

**Acknowledgments.** We thank Alberto Castro-Tirado and IAA for providing us access to All-Sky cameras CASSANDRA-1 and CASSANDRA-2 from BOOTES. We thank Torcal Astronomical Observatory (OAT), Consejería de Medio Ambiente y Ordenación del Territorio, and Fundación Monte Mediterráneo for the establishment and maintenance of the stations.

## REFERENCES

Borovicka, j., Spurný, P., and Keclíková, J, 1995, A&AS, 112, pp.173-178

Ceplecha, Z., 1987, Bull. Astron. Inst. Czech., 38, pp.222-234

Dubyago, A.D., 1961, The determination of orbits, The MacMillan Company, New York.

Castro-Tirado, A. J. et al. 2008, Proc. SPIE, 7019, article id. 70191V

Kubánek, P., 2010, AdAst, 2010, id.902484

Nievas Rosillo, M., Zamorano Calvo, J., 2014, "PySQM the UCM open source software to read, plot and store data from SQM photometers", EPrints-UCM, http://eprints.ucm.es/25900/