Data Reduction and Control Software for Meteor Observing Stations Based on CCD Video Systems

J. M. Madiedo • J. M. Trigo-Rodríguez • E. Lyytinen

Abstract The SPanish Meteor Network (SPMN) is performing a continuous monitoring of meteor activity over Spain and neighbouring countries. The huge amount of data obtained by the 25 video observing stations that this network is currently operating made it necessary to develop new software packages to accomplish some tasks, such as data reduction and remote operation of autonomous systems based on high-sensitivity CCD video devices. The main characteristics of this software are described here.

Keywords meteor · meteoroid · fireball · software · meteor showers

1 Introduction

Since 2006 the SPanish Meteor Network (SPMN) has performed continuous monitoring of meteor and fireball activity over Spain and neighbouring countries. For this purpose, we mainly employ all-sky CCD cameras and high-sensitivity CCD video devices to monitor the night sky (Trigo-Rodríguez et al., 2006a, 2007a, 2007b; Madiedo, 2007). In addition, we have employed daytime CCD video cameras since 2007 in order to monitor fireball activity over 24 hours and increase the opportunities for meteorite recovery in Spain. As a result of this effort, a total of 25 observing stations are currently in operation. Several of them have been configured to work in a fully autonomous way. The two main cores of the Network are located in the regions of Catalonia and Andalusia. As these are separated by about 1000 km, there is a higher probability of clear skies and of meteor activity being recorded every night. The establishment of 25 meteor observing stations implies that a large amount of data needs to be reduced. This made it necessary to develop new software tools in order to perform a fast analysis of our data. The main features of these new packages are presented here.

2 Description of the Observing Stations and Procedures

Trigo-Rodríguez et al. (2004) previously reported the first steps in the development of the SPMN that employed low-scan-rate all-sky CCD cameras with +2/+3 meteor limiting magnitude. Since 2006 the

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SPMN started to establish observing stations based on video systems to analyze meteor activity (Madiedo and Trigo-Rodríguez, 2007; Trigo-Rodríguez, 2007a, 2007b). These employ several high-sensitivity Watec CCD video cameras (models 902H and 902H Ultimate from Watec Corporation, Japan) to monitor the night sky. The cameras generate video imagery at 25 fps with a resolution of 720x576 pixels. These cameras are connected to PC computers via a video acquisition card. The computers use the UFOCapture software (Sonotaco, Japan) to automatically detect meteor trails and store the corresponding video sequences on hard disk. The cameras are arranged in such a way that the whole sky is monitored from every station and, so, this maximizes the common atmospheric volume recorded by the different systems. These devices are equipped with a 1/2" Sony interline transfer CCD image sensor with their minimum lux rating ranging from 0.01 to 0.0001 lux at f1.4. Aspherical fast lenses with focal length ranging from 3.8 to 6 mm and focal ratio between 1.2 and 0.8 are used for the imaging objective lens. In this way, different areas of the sky can be covered by every camera and point-like star images are obtained across the entire field of view.

Since 2007 we also started to employ CCD video systems to monitor the sky during the day (Madiedo and Trigo-Rodríguez, 2008). Daytime CCD video cameras work in the same way as nocturnal cameras do, but in this case lower-sensitivity devices are employed in order to avoid image saturation due to sunlight. These are endowed with slower optics (f1.4) and are arranged so that a part of the landscape falls within their field of view. In this way, identifiable structures or buildings appearing in the images can be used for image calibration to obtain the equatorial coordinates of fireballs.

3 Data Reduction Software

For data reduction we have developed a new software called Amalthea. This is a MS-Windows compatible package that has been programmed in C and C++ programming languages. The main characteristics of this software are described below.

3.1 Image and Video Processing

Amalthea was designed to analyze CCD images containing meteor trails and also video files recorded by our high-sensitivity CCD video devices. In many cases these images contain artefacts that may negatively interfere with data analysis. For this purpose, a wide number of image transformation filters have been implemented in the software. These include, for instance, light-pollution removal, brightness and contrast enhancement and video deinterlace filters. Some of these image transformation procedures allow enhancement of the video images before they are used for the astrometric analysis. For instance, our software automatically stacks the frames contained in video files in order to increase the number of stars available for the astrometric analysis described below.

3.2 Astrometry

Meteor and stars positions are obtained from static CCD images or from video sequences recorded by devices that monitor the night sky. The procedure we follow to obtain the equatorial coordinates of the meteor along its path have been described by Trigo-Rodriguez et. al (2007a). In a first stage, reference stars must be specified in order to apply a fitting method that allows conversion between plaque coordinates and equatorial coordinates. Then, by measuring the plaque coordinates of the meteor, these positions are automatically transformed by Amalthea into their corresponding equatorial counterparts.

It must be taken into account that in most cases we employ video devices that provide interlaced video sequences. These sequences must be deinterlaced by our software in order to remove some artefacts that could interfere in the astrometric reduction. Besides, depending on observing conditions in the area where the video stations are located, the number of reference stars in the corresponding video files can be very low, which is not enough to perform a good astrometric analysis. To solve this problem the software follows two different strategies. On one side, it stacks the frames contained in the video files in order to increase the signal to noise ratio of the resulting image. The number of reference stars in the resulting image is significantly higher. On the other side, as the cameras are pointed towards fixed altitude and azimuth coordinates, reference stars obtained at different times can be taken into account for a given measurement.

To perform the astrometric reduction the user manually clicks on the reference stars that must be taken into consideration for the corresponding calculations. Then, the user selects which fitting method must be used to convert from plaque coordinates to equatorial coordinates. Several options are available for this. Then the calculation is performed and the position of the reference stars is back-calculated by Amalthea in order to establish the error (standard deviation) of this calculation. In this way, the user, if necessary, can repeat the calculations by removing those stars which give rise to higher errors or include new ones.

Once we can convert between plaque and equatorial coordinates, plaque coordinates of meteors are specified by the user by clicking on the corresponding positions along the meteor trail. Their equatorial counterparts are then automatically provided by Amalthea. This can be done on static CCD images or on animated video sequences. In the latter case, time information necessary to calculate meteor velocities and decelerations is automatically obtained from the video file. In the former case, time information can be specified by the user if, for instance, a rotary shutter has been used.

3.3 Meteor Atmospheric Trajectory

Amalthea keeps a database with the geographic position of all the observing stations established by the SPMN. For meteors recorded simultaneously from at least two different observing stations the software can calculate its atmospheric trajectory and radiant once the above-described astrometric procedure has been performed. In order to do this the software uses the well-known planes intersection method (Ceplecha, 1987). If time information is available, velocities and decelerations are also calculated along the meteor trail. This allows us also to obtain the pre-atmospheric value of the meteor velocity, V_{inf}.

3.4 Orbital Parameters

The orbital and radiant parameters of the meteor are calculated according to the procedure described by Ceplecha et al. (1987). For this purpose, the values of the pre-atmospheric velocity, V_{inf}, radiant position and meteor apparition time are used, together with the average velocity corresponding to an averaged meteor position (latitude, longitude and altitude) along the meteor trail.

The procedure implemented in the Amalthea software has been tested with the Dutch Meteor Society (DMS) orbit calculation software (Langbroek, 2004) and the MORB software developed by the Ondrejov Observatory (Ceplecha et al., 2000). Although the DMS software does not provide any error parameters, we always found that the results provided by this package and Amalthea are very similar, with differences that are very small and within the error bars provided by Amalthea (Tables 1 and 2). However, significant discrepancies were found for the case of the MORB software. When this situation was analyzed in detail, we found that the origin of these is related to a bug in the calculation of the geocentric radiant in the MORB software.

Table 1. Comparison between orbital parameters calculated by Amalthea and the DMS software for different meteors recorded by the SPMN. Equinox (2000.00).

SPMN Code	Software	*q*(AU)	*a*(AU)	*e*	*i*(°)	*ω* (°)	*Ω* (°)
080806	Amalthea	0.9482±0.0003	9.65±1.5	0.902±0.016	113.58±0.15	149.82±0.32	139.1491±0.00003
	DMS	0.948	9.63	0.902	113.60	149.80	139.15
	MORB	9.558±0.001	21.36±7.76	0.955±0.016	111.79±0.15	152.87±0.35	139.1481±0.0003
210110	Amalthea	0.9543±0.0002	2.85±0.02	0.665±0.003	48.80±0.06	202.46±0.08	301.615±0.00002
	DMS	0.954	2.83	0.663	48.81	202.47	301.612
	MORB	0.9667±0.0006	15.47±5.11	0.937±0.020	44.92±0.28	195.55±0.38	301.6113±0.00003
071106	Amalthea	0.9774±0.0003	17.31±5.6	0.943±0.018	161.35±0.09	167.74±0.22	236.5034±0.00003
	DMS	0.977	16.96	0.942	161.36	167.68	236.505
	MORB	0.9864±0.0017	63.44±88.29	0.984±0.021	156.93±0.80	185.0±2.3	236.50565±0.00007

Table 2. Comparison between geocentric radiant position and pre-atmospheric velocities (geocentric, *Vg* and heliocentric, *Vh*) calculated by Amalthea and the DMS software for different meteors recorded by the SPMN. Equinox (2000.00).

SPMN Code	Software	R.A.(º)	DEC.(º)	*Vg*(km/s)	*Vh*(km/s)
080806	Amalthea	46.85±0.051	57.29±0.05	58.79±0.20	40.73±0.20
	DMS	46.85	57.29	58.79	40.73
	MORB	46.47±0.13	57.070±0.05	58.78±0.20	41.34±0.18
210110	Amalthea	230.03±0.1	66.57±0.03	29.80±0.20	38.61±0.21
	DMS	230.10	66.54	29.79	38.59
	MORB	227.23±0.10	67.41±0.03	29.79±0.05	41.77±0.22
071106	Amalthea	156.51±0.1	21.41±0.05	70.90±0.20	41.76±0.20
	DMS	156.52	21.40	70.80	41.65
	MORB	156.20±0.30	21.53±0.30	70.90±0.20	42.20±0.22

3.5 Meteorite Fall Analysis

Very bright fireballs can be the source of potential meteorite producing events. So, the analysis of these events is fundamental in order to locate, recover and study the corresponding fragments. For this purpose it is necessary to calculate the atmospheric trajectory of the fireball and also to model the so-called dark flight, which is the portion of the trajectory followed once the particle has been decelerated in such a way that no light is emitted. The atmospheric trajectory is determined by following the procedures described above. Then, our Amalthea software solves the aerodynamic equations that describe the dark flight of the meteoroid. To do this, information about the particle and its terminal point must be entered. A standard Runge-Kutta procedure is followed in order to integrate the position of the particle from the terminal height to the ground. Wind data are also taken into account by entering, as a function of height, latitude and longitude, the values of atmospheric pressure, temperature and wind velocity and direction. The resulting meteorite impact position is shown both numerically and drawn on a map.

In order to test the calculation procedure implemented in Amalthea, we have compared the results provided by our software to those provided by the software developed by Z. Ceplecha, P. Spurny and J. Borovicka for the case of the Villalbeto de La Peña meteorite fall (Trigo-Rodríguez et al., 2006b). The fall of this L6 chondrite occurred on January 4, 2004 in north-west Spain (Trigo-Rodríguez et al., 2006b; Llorca et al., 2005). Both software packages provide the same result.

3.6 Meteor Spectra Analysis

Some of the all-sky CCD cameras and high-sensitivity video devices employed by the SPMN are endowed with holographic diffraction gratings (600 to 1200 lines/mm) in order to obtain meteor spectra. Typically we can obtain these spectra for meteors as bright as mag. -4 or lower without using any image intensifier device. These spectra are very useful in obtaining chemical information about meteoroids (Trigo-Rodríguez et al., 2009).

The Amalthea software is able to analyze these spectra when they are recorded on AVI video files or on static all-sky CCD images. These raw spectra must be calibrated in order to take into account the response of the camera to different wavelengths. This information can be taken from the documentation provided by the manufacturer of the camera or can be experimentally obtained by comparing a known spectrum of an astronomical object with the spectrum obtained by the camera for the same source. Once this calibration is performed, the software identifies the main meteor emission lines. Figure 1 shows an example of the emission spectrum of a sporadic fireball recorded by the SPMN from Sevilla on May 27, 2010, at 3h19m40.1 ± 1s UTC. The two most prominent lines correspond to Na_I -1 (589.5 nm) and Ca_I-1 (422.7 nm).

4 Description of the SPMN Video Station Control Software

The number of SPMN video meteor stations has increased from 2 in 2006 to 25 in 2010. This has resulted in the necessity to address two main issues that have arisen from this situation: the establishment of a system to check the large volume of data provided by these observing stations in order to identify multiple-station events and potential meteorite dropping events, and the necessity to locate several autonomous meteor observing stations in remote locations or in places where no direct human intervention is always possible. Thus, during 2009 new software packages have been developed in order to achieve a fully robotic operation of several video meteor observing stations. These new packages also allow the systems to be remotely controlled though an Internet connection. A prototype robotic video station was setup by the University of Huelva in the environment of the Doñana Natural Park (south-west of Spain) in April 2009 (Madiedo et al, 2010). This station was fully operative till the robotic system was completely developed in August 2009. Nowadays, three robotic video meteor stations are operative in the south of Spain. Two of them are located in the western area of Andalusia, in the provinces of Huelva and Sevilla. The latest one has been setup in Sierra Nevada (Granada), in the eastern part of this region.

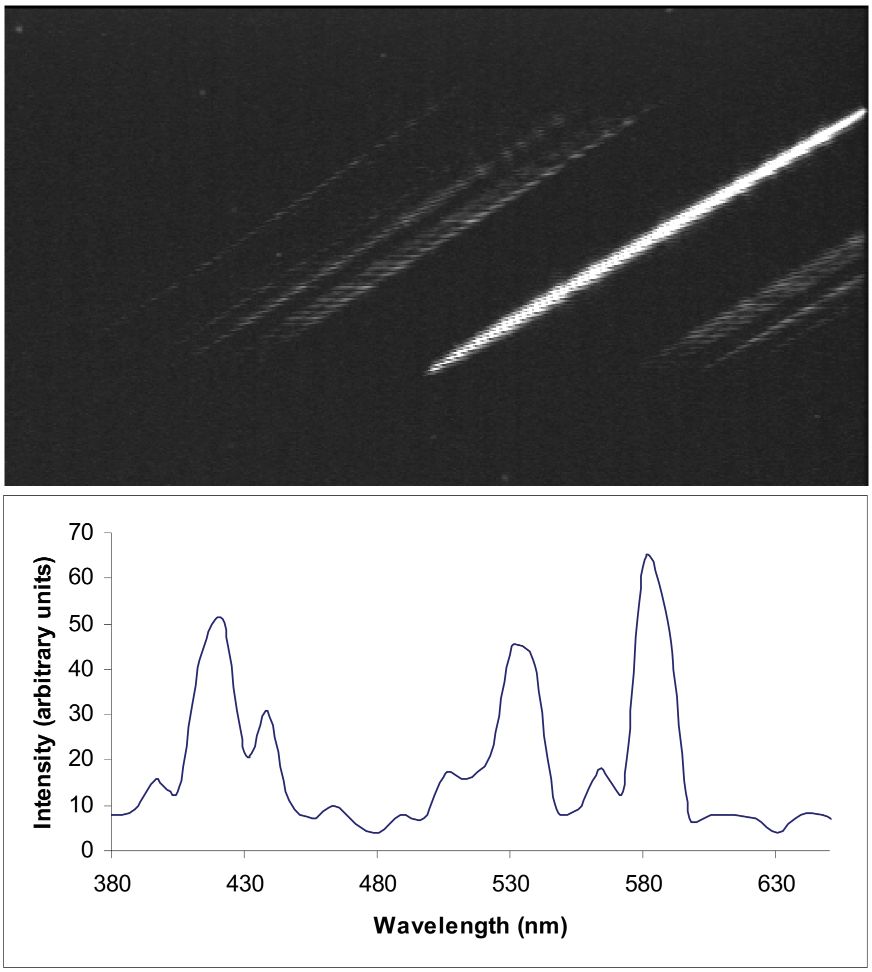

Figure 1. Sporadic fireball recorded from Sevilla on May 27, 2010, at 3h19m40.1 ± 1s UTC with a high-sensitivity CCD video camera endowed with a diffraction grating and its emission spectrum analyzed by the software Amalthea.

The PC computers that control the new robotic stations have been configured so that they are automatically switched on and off when data acquisition must start and finish, respectively. When the PCs are started, one of our recently developed software packages starts the data acquisition software (UFOCapture) and monitors that this application is properly working during the whole observing session. We have also developed another software package that automatically checks the meteor trails recorded by the system. Then, if a very bright fireball is detected (typically mag. -12 or brighter) which could give rise to a potential meteorite fall, an email is automatically sent to the operator together with the corresponding images.

These robotic stations provide a huge volume of data, as they are currently an average of over 1000 meteors per month. In order to handle this information, we have also developed a software package that is automatically started when the observing session is over. Then, this application checks every meteor trail recorded on hard disk. These data are compressed and sent to a FTP server for further processing. The application also checks other data stored by this FTP server, as data from different robotic stations are also placed there, and identifies which meteor trails have been simultaneously recorded from at least two different locations. The operator receives an automatic email with these data, which can be reduced to obtain the atmospheric trajectory of the corresponding meteoroid and also radiant and orbital information.

5 Conclusions

A continuous effort is being made by the Spanish Meteor Network in order to improve and expand our meteor observing stations based on high-sensitivity CCD video devices. Software engineering has been one of our priorities in the latest years and, as a result, a new software package for data reduction has been developed and successfully tested with other existing applications. However, significant discrepancies have been detected with the results provided by Ondrejov's orbits calculation software (MORB). This is due to the fact that MORB software does not calculate as a result of an incorrect calculation of the geocentric radiant. Besides, the possibility of installing high-sensitivity video systems in remote locations made necessary the development of robotic systems that are able to operate in a fully autonomous way and also to automatically notify the occurrence of remarkable events. Several software packages have been also developed in order to accomplish these tasks.

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