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RADIANTS OF THE LEONIDS 1999 AND 2001 OBTAINED BY LLTV SYSTEMS USING AUTOMATIC SOFTWARE TOOLS

DETLEF KOSCHNY, JORGE DIAZ DEL RIO, RODRIGUE PIBERNE, MAREK SZUMLAS, JOE ZENDER
Research and Scientific Support Department (RSSD), ESA/ESTEC, Keplerlaan 1, NL-2201 AZ Noordwijk ZH, The Netherlands, (E-mail: Detlef.koschny@esa.int)
ANDRÉ KNÖFEL
International Meteor Organisation, The Netherlands

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Abstract. Both amateur and professional meteor groups are more frequently using Low-Light level TV (LLTV) systems to record meteors. Double-station observations can yield orbit data. However, data analysis normally is still done by hand and thus time consuming. This paper addresses the question of whether available automated tools can be used to determine reasonably accurate orbits with minimum human intervention. The European Space Agency performed several observing campaigns to observe the Leonid meteor stream. In November 1999, the ESA meteor group was stationed at two locations in Southern Spain, in November 2001 at two stations close to Broome in North-Western Australia. Double-station observations with LLTV systems were conducted. The data was recorded on S-VHS video tapes. The tapes were processed using automatic detection software from which meteor heights, velocities and radiants were computed. This paper shows the results for the two maximum nights. The radiants determined in 1999 show a very large scatter due to unfortunate observing geometry and inaccurate position determination since one of the cameras was moving because of the wind. The 2001 data is excellent and the radiant was determined to be at RA $= 153.96° \pm 0.3°$ and Dec $= 21.09° \pm 0.2°$. The error bars for individual meteor radiants are about 0.2° to 0.4°. This demonstrates that is indeed possible to determine good radiant positions using totally automated tools. Orbits, on the other hand, are not well defined due to the fact that the velocity of individual meteors shows large errors. Reasons for this are described.

Keywords: Meteoroids 2004, meteors, Leonids, radiants, LLTV systems, video observations, predictions, automated video systems

1. Introduction

Traditionally, meteor orbits were determined from photographic observations, both using all-sky cameras or batteries of 35 mm film cameras. In recent years, image-intensified video cameras (Low-Light level TV, LLTV) and automatic detection and analysis software has become available in the professional and amateur community. While a video system lacks the resolution of photographic film, the smaller field of views of the cameras combined with much better sensitivity (visual magnitudes of typically 6–8 mag can be recorded) make video systems attractive for orbit determination.

This paper presents results from double-station video camera setups operated during the 1999 and 2001 Leonid meteor campaigns of the Research and Scientific Support Department (RSSD) of the European Space Agency (ESA). In particular, we were interested in finding out whether a fully automated double-station setup would be feasible. It will be shown that this would indeed be possible.

2. The ESA/RSSD Meteor Cameras

The ESA/RSSD meteor group operates two types of meteor cameras. The "Intensified CCD Camera (ICC)" uses a second generation intensifier type DEP XX1700 with a fiber-coupled CCD detector. The CCD is read out by a commercial Sony XC-77DE video camera which can deliver 12 bits of dynamic range. A second camera type, called Low-Cost Camera (LCC), uses second-generation DEP XC1771 intensifiers. Their output was recorded with single-board video cameras (Conrad) with a relay lens. This camera can be read out with 8 bit dynamical range.

Different lenses can be used on the cameras. They are typically operated with Rayxxar lenses (50 mm f/0.75, 80 mm f/1.0), Fujinon (25 mm f/0.85 C-mount) or Zenith (16 mm f/2.8 M42). The configuration used here is given in Table I.

The camera signal was recorded via S-VHS recorders on video tape, limiting the resulting dynamical range to about 7 bit for both camera systems. Time inserters (Dr. Cuno, Nuremberg) were used to insert the time into the video image. In 1999, the inserters were started at 19h00m00s UT on 17 Nov. In 2001, these time inserters were synchronised with GPS receivers and show the time in UTC (Figure 1).

TABLE I

Observing locations of the ESA/RSSD meteor group for the Leonids 1999 and 2001 and the camera configuration used for this study

	Name	Latitude	Longitude	Altitude	Camera	FoV
1999	Observatory Sierra Nevada (OSN)	03°23′05″ W	37°03′51″ N	2896 m	ICC3 80 mm f/1.0	5.6°×7.5°
	Calar Alto Observatory (CAHA)	02°32′47″ W	37°13′25″ N	2168 m	ICC2 50 mm f/0.75	12°×15°
2001	Lake Eda	17°53′20″ S	122°38′52″ E	130 m	LCC3 28 mm f/2.8	22°
	Dampier Downs	18°22′40″ S	123°07′46″ E	130 m	ICC2 50 mm f/0.75	12°×15°

N is the number of meteors recorded in the night of the maximum, *M* the number for which good double-station radiant calculations were obtained.

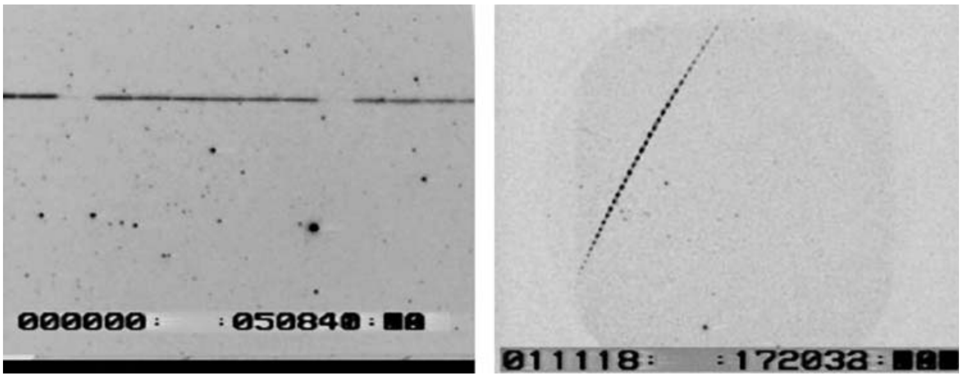

Figure 1. Sample meteor images (negative) obtained with the ESA/RSSD meteor cameras. Left: ICC3, 18 Nov 1999, 00h08m40s UT. The breaks in the meteors path are a result of dropped frames. Right: LCC2, 18 Nov 2001, 17h20m32s UT. Every second frame was recorded.

3. Observing Setup 1999 and 2001

The observing sites for the Leonid campaigns were selected according to visibility constraints and weather predictions. In 1999, the equipment needed support from the local infrastructure, in particular 220 V AC current, whereas in 2001 all equipment was fully portable and could be operated from car batteries. Thus, in 1999 we selected two observatory sites in Southern Spain, namely the Observatory Sierra Nevada (OSN) south of Granada, and the Calar Alto Observatory (CAHA), about 60 km east of OSN. In 2001, we used four-wheel drive cars to reach two sites in the outback around Broome in North-Western Australia, close to Lake Eda and Dampier Downs. Table I gives a summary of the observing locations (from Koschny et al., 2002).

4. Analysis Method

All video data was recorded on (S-)VHS video tape. The video tapes were searched for meteor events using the software MetRec (Molau, 1999). Before the start of the search, one frame is grabbed and read into RefStars (Molau, 1999) for finding out the pointing direction of the camera. This allows MetRec, together with the time of the detected event, to compute the Right Ascension and Declination of the meteor.

MetRec generates a log file listing all meteors and a summary plus one file for each meteor with the position of the event in each video frame the meteor was detected. These files are used by a tool called Meteor Trajectory and Orbit Software (MOTS; Koschny and Diaz del Rio, 2002) to compute each meteor's radiant and, eventually, its orbit. In the paper presented here, we used MOTS to generate radiants only.

MOTS uses the following algorithm. The Right Ascension (R.A.) and Declination (Dec.) for the meteor in each frame as seen from camera 1 are interpreted as vectors, to which a plane is fitted. This plane encompasses the meteor path and the location of camera 1. Each R.A. and Dec. value as seen from camera 2 is again interpreted as a vector. The intersection of this vector with the plane gives a point in x/y/z coordinates in an Earth-centred coordinate system. Doing this for all video frames from camera 2 yields positions of the meteor in space. A straight line fit to these positions gives the path of the meteor. The calculation can be repeated with camera 2 as a starting point. Converting the backward prolongation of the path to R.A. and Dec. gives the coordinates of the meteor's radiant.

Each individual step of the computation is based on all points on the trajectory. E.g. for the radiant, the backward prolongation for each trajectory point pair can be computed. A weighted average is used for the final result, and the error is estimated from the data to allow some quality control station. A detailed description can be found in Koschny and Diaz del Rio (2002).

5. Results

5.1. The data from 1999

While the Right Ascension of the radiant positions was within the expected range around 154°, the Declination was varying between 15° and 50°. Clearly, this variation is not real. Careful analysis showed the following:

The observing geometry was very unfavourable. The two observing stations were in east–west orientation, whereas the observing direction was towards the North (directly to the pole star from OSN). For most of the observing time the meteor radiant was low in the eastern sky and the meteors can be envisaged as describing approximately horizontal lines north of the two stations. Now consider the description of the algorithm as given in the previous section. The plane formed by station 1 and the meteor and any viewing direction from station 2 to the meteor fall almost together. Small errors in angle thus convert into large shifts in position in space, resulting in a large error of the radiant.

5.2. The data from 2001

In 2001 the observing geometry was chosen to be more favourable. The intersection angle between the two stations and the meteors was approximately 90° and good results were obtained.

Figure 2 shows the obtained geocentric radiants, corrected for zenithal attraction and diurnal aberration. MOTS estimates errors in Right Ascension

(R.A.) and Declination (δ) from its computations, these are shown for each individual radiant and are typically ±0.3° for R.A. and 0.1° for δ. The average value is 153.96° ± 0.3° and $\delta = 21.09° \pm 0.2°$, shown as a thick cross in the Figure. Note that all radiants were corrected for radiant drift by shifting them to a radiant time of 20h00m UTC on 18 Nov 2001.

The Figure also shows the predicted value by McNaught and Asher (2001). All values are summarised in Table II.

6. Discussion

6.1. Software performance

To assess the performance of MOTS, the data from 2001 is followed through the processing in more detail in this section. MetRec detected a total of 110 meteors and 145 meteors in the data obtained with ICC2 and LCC3, respectively. MOTS searched for meteors appearing within a maximum of 4 s time difference and marked 64 meteors as potential parallel observations.

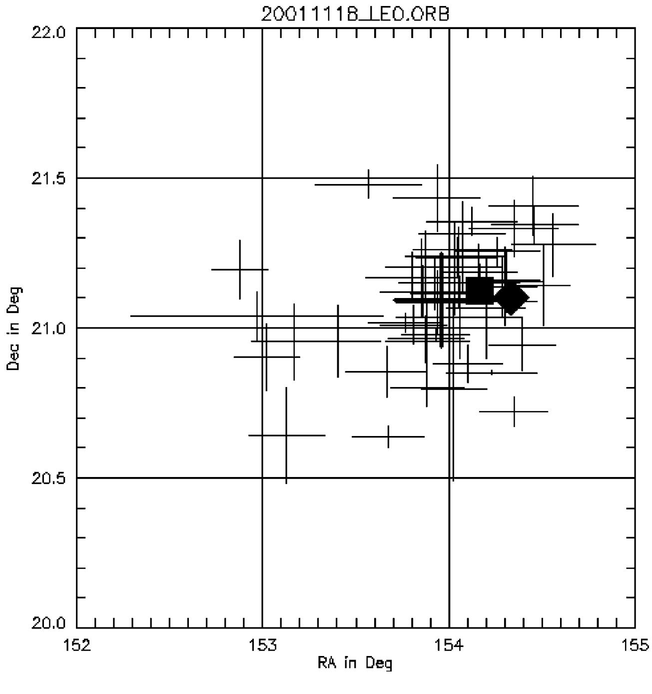

Figure 2. Geocentric radiant positions determined from 48 video meteor pairs. The calculated radiants were corrected for radiant drift to a time of 20h00m on 18 Nov 2001. The thick cross is the mean value. The black diamond and the square denote the predicted radiant for the 4 revolutions trail and 9 revolutions trail, respectively.

TABLE II
Leonid 2001 radiants as determined in this work and predicted values by McNaught and Asher (2001)

	R.A. in deg	Declination in deg
2001 campaign (Australia)	153.96 ± 0.3	21.09 ± 0.2
Prediction:		
9-rev trail (Siding Spring)	154.17	+21.12
4-rev trail (Siding Spring)	154.34	+21.10

This means that only about 50% of the events occurred in the common field of view, all other meteors were either too far or too close in one cameras field of view. Another possibility is that in one of the cameras the meteor was too faint to be recorded.

Using the 64 potential meteor pairs, MOTS computed altitudes. The acceptable height range was set to 40–180 km. Three pairs did not fall into this range and were rejected. 61 pairs yielded good solutions.

In a few occasions, one meteor from one camera would pair with two meteors seen by the other camera appearing within the accepted time window of 4 s. Obviously only one of the pairs can be the correct one. Here, some manual work was required to analyse the errors and select the proper pair. Note that the chances for this to occur under non-storm circumstances are minimal, as normally meteors don't appear within seconds.

After minimal manual intervention, 57 meteors with good radiants were left. 48 of these were Leonids and their computed radiants are shown in Figure 2.

6.2. Radiant determination

Figure 2 shows that the radiants predicted by McNaught and Asher (2001) are well within the observed radiants, i.e. the prediction fits well. There is a scatter around the predicted radiants which is similar to the orbit cross-section plots given by McNaught and Asher. The scatter in the individual radiants is much larger than the difference between the 4 revolution trail and the 9 revolution trail, so the trails cannot be distinguished via the radiants. As the error bars from the processing are only a little smaller than the scatter of individual radiants, it cannot be ruled out that processing errors smear out the individual trail directions.

Torii et al. (2003), Shigeno et al. (2003), and Ueda et al. (2004), find slightly different radiants. However, comparing their data with predictions by McNaught and Asher it can be seen that the difference is the different location of these teams. The authors were located in Japan, where the geocentric radiant also was predicted slightly higher than in Australia, see Table III.

Torii et al. (2003) give error bars of about 0.15°, comparable to those obtained by our cameras. Ueda et al. (2004) give error bars which are almost one order of magnitude larger. Thus our setup is clearly comparable to the CCD/telephoto camera system analysed manually.

Spurny et al. (2001) give error bars for radiant determinations of fireballs by the Czech photographic fireball network. They are in the order of ± 0.02° or better, thus they are again one order of magnitude better than video observations and would – had they the light sensitivity as video systems – allow to separate radiants of different revolutions.

7. Lessons Learnt and Possible Improvements of the Accuracy

In a previous section we already addressed the issue of observing geometry. When setting up double-station systems during the observing campaign of a shower, one should invest some thought into the proper observing geometry. Obviously, for a permanent setup this would play a smaller role as no preferred meteoroid flight direction will be there.

Some of our 1999 data was hard to analyse as we moved the camera's field of view during the night. This should be avoided, as it requires a re-registration of the stars with RefStars.

The main issue with the data from 1999 was that the cameras were not mounted stable enough to withstand the wind (with gusts up to 70 km/h). If observing in strong winds, stable mounting has to be ensured.

One disadvantage of MetRec is that it currently only supports half of the video resolution. It only analyses and stores 384 × 288 pixels in PAL mode and only even fields, i.e. only 25 fields per second. The full PAL resolution would yield two fields of 388 × 576 pixels every 1/25 s, alternating between odd and even lines. This means that effectively only 1/4 of the possible res-

TABLE III
Radiant positions of the 2001 Leonids as observed from Japan

	R.A. in deg	Dec in deg	Remarks
Torii et al. (2003)	154.35 ± 0.15	21.55 ± 0.15	CCD with telephoto
Ueda et al. (2004)	154.2 ± 1.01	21.5 ± 0.65	Watec CCD, 56°×43° field of view
	154.4 ± 1.15	21.4 ± 0.42	LLTV system, 17° field of view
Prediction:			
McNaught / Asher	154.18	21.65	9-rev trail (Tokyo)
	154.33	21.60	4-rev trail (Tokyo)

olution is used. Assuming that the errors scale linearily with resolution, error bars as small as ± 0.05° should be achievable with video systems with the field of views as used here. We have developed a software tool that reads the log file from MetRec and allows to play the video again, then stores full-resolution images. These however currently need to be analyzed manually.

A main problem with the resulting data is that the meteor velocities determined using video data have very large errors. One of the reasons for this seems to be the problem of determining the centroid of an elongated object, as the meteor appears stretched in the possible presence of a wake. This will result in along-path errors in the position of the meteor.

8. Conclusion

We showed that with an observational setup carefully planned, meteor radiants can be obtained with good accuracy using an automated system requiring minimum human interaction. With updates to existing software tools it should be possible to get accuracies which are not more than a factor four worse than photographic radiants, with the advantage of the high light sensitivity of video cameras.

An open issue is the large velocity errors found in video meteor determinations, which will introduce errors in some of the orbital elements.

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