NFC – Narrow Field Camera

Jakub Koukal[1,2], Jiří Srba[1,2] and Sylvie Gorková[1,2]

[1] **Valašské Meziříčí Observatory, Vsetínská 78, 75701 Valašské Meziříčí, Czech Republic**
j.koukal@post.cz, sgorkova@astrovm.cz, jsrba@astrovm.cz

[2] **SMPH, Society for Interplanetary Matter, Kraví hora 522/2, 61600 Brno, Czech Republic**

We have been introducing a low-cost CCTV video system for faint meteor monitoring and here we describe the first results from 5 months of two-station operations. Our system called NFC (Narrow Field Camera) with a meteor limiting magnitude around +6.5mag allows research on trajectories of less massive meteoroids within individual parent meteor showers and the sporadic background. At present 4 stations (2 pairs with coordinated fields of view) of NFC system are operated in the frame of CEMeNt (Central European Meteor Network). The heart of each NFC station is a sensitive CCTV camera Watec 902 H2 and a fast cinematographic lens Meopta Meostigmat 1/50 – 52.5 mm (50 mm focal length and fixed aperture f/1.0). In this paper we present the first results based on 1595 individual meteors, 368 of which were recorded from two stations simultaneously. This data set allows the first empirical verification of theoretical assumptions for NFC system capabilities (stellar and meteor magnitude limit, meteor apparent brightness distribution and accuracy of single station measurements) and the first low mass meteoroid trajectory calculations. Our experimental data clearly showed the capabilities of the proposed system for low mass meteor registration and for calculations based on NFC data to lead to a significant refinement in the orbital elements for low mass meteoroids.

1 Introduction

Conventional CCTV systems operated in European viDeo MeteOr Network (EDMONd) and BRAzilian MeteOr Network (BRAMON) are mostly based on CCTV cameras equipped with 1/3” or 1/2” chips providing standard PAL/D1 signal output with an image resolution of 720x576 pixels (Kornoš et. al, 2014a, 2014b). Varifocal lenses used in these systems have a field of view (FOV) of about 70° horizontally and 56° vertically. Systems with this configuration are able to record faint meteors down to an apparent brightness threshold between $+1.5^{mag}$ and $+2.0^{mag}$. Rather rarely these are able to record even dimmer meteors. However, the efficiency of the systems for these meteors decreases drastically (for meteors around $+2.5^{mag}$ it is only around 10 %) (*Figure 1*).

Figure 1 – Single station range test of the experimental NFC setup (test field χ and h Persei).

A CCTV system for monitoring faint meteors with a limiting magnitude around $+6.5^{mag}$ allows research on trajectories of less massive meteoroids within individual parent meteor showers or within the sporadic background, and also research into the fragmentation of faint meteors. The absence of trails associated with faint meteors is still an open issue. While standard CCTV cameras record meteoroids with parent body weights in the hundreds of grams, a sensitive NFC system is able to record the input body masses between 10^{-2} to 10^{-4} g (depending on the geocentric velocity of the body).

2 History of more-stations faint meteors observation

Simultaneous observation of faint meteors from more than one station, whether via video or photographic techniques, is currently a relatively neglected sector of meteor astronomy.

The first system for faint meteor research was a pair of Baker Super Schmidt cameras (with three meniscus), which were installed at two stations in the US (Sacramento Peak Mayhill) from 1952 to 1954. It was a photographic system with a field of view of 56° and a limiting magnitude of $+11.0^{mag}$ (stars) and $+4.0^{mag}$ (meteors). The registered trajectory of individual meteors was obscured 60 times per second by a rotating sector operating at 1800 RPM. During the working phase of the program about 4500 meteors were recorded in total, more than 3500 of which were captured from both stations. The results of the work were published in a catalog containing 413 very precise meteoroid orbits (Jacchia and Whipple, 1961).

Another attempt in this research field involved the use of two identical reflector telescopes (System Newton) with a mirror diameter 40 cm and a maximum aperture f/4.5 in combination with a CCD camera and image intensifier (QIEBIR) at Observatory Elginfield (Canada). This system was operated during 6 nights in September 2003 and May 2004. The field of view of each telescope was 0.48° vertically and 0.34° horizontally with a limiting magnitude of $+13.0^{mag}$ (stars) and $+9.0^{mag}$ (meteors). The distance between the telescopes was only 27.5 meters (9/2003) and 105.2 meters (5/2004). In this period 87 faint meteors were recorded in total, 56 of which were registered from both stations.

The latest longtime project (also working at present) is the Canadian system CAMO (The Canadian Automated Meteor Observatory), which has been in operation since 2005. The system consists of two identical stations separated by 50 km. Each station includes a high speed (80 fps/s) CCD camera Imperx LYNX IPX-VGA120-L with image intensifier ITT Nitecam 380i. The field of view of the system is 25°x10°, and its limiting magnitude $+7.0^{mag}$ (stars). This camera is used for real time meteor registration and provides data for the real time adjustment of the two mirrors. The mirrors reflect the light of the meteor onward into a part of the camera set up that has a narrow field of view. This consists of a refractor ZenithStar 80/545 mm (f/6.8) with a high-speed (80 fps/s) CCD camera Imperx LYNX IPX VGA120-L and image intensifier ITT Nitecam 380i. The field of view of this part of the system is 1.5° in diameter and the absolute magnitude of recorded meteors is typically in the range between $+4.1^{mag}$ and -1.7^{mag}. The limiting magnitude of this system is $+6.0^{mag}$ (meteors). In cooperation with this project a further pair of PCO Imaging 1600 cameras, once again with image intensifier ITT Nitecam 380i is operated. This system has a wider field of view of 21° (horizontal) with a limiting magnitude $+10.0^{mag}$ (stars) and $+7.5^{mag}$ (meteors). The system has a relatively high resolution camera (1600x1200 pixels) but, unfortunately, has a low frame rate (20 fps/s).

3 System specifications

At present 4 stations equipped with the NFC system (Narrow Field Camera) are operated in the frame of our network. These 4 stations were implemented under the project RPKS (Development of cross-border co-operative networks), of which 2 are operated in the Czech Republic (Valašské Meziříčí and Kroměříž) and 2 in Slovakia (Zákopčie and Kysucké Nové Mesto) (*Figure 2*). Other stations are in preparation in Slovakia (Banská Bystrica-Vartovka, Žiar nad Hronom) by means of CEMeNt network.

The heart of each station is a sensitive CCTV camera Watec 902 H2 Ultimate (1/2” chip Sony ICX429ALL, sensitivity of 0.0001 lux) with fast lens Meopta Meostigmat 1/50 - 52.5 mm (50 mm focal length and fixed aperture f/1.0). Signal conversion of the analog output from the Watec camera to digital input to the PC is realized via USB A/D converter AverMedia DVD EZMaker or Dazzle DVC 101. Recording and evaluation of individual meteors is maintained by the software UFO Tools (Capture UFO, UFO, UFO Analyzer and Orbit). The system is protected against weathering by a heated case Marathon MH 805/12 with IP-66.

Figure 2 – Station Kroměříž, NFC system in its housing.

The field of view of the NFC system is 6.8° horizontally and 5.4° vertically, which is roughly 100 times smaller than conventional systems working in the BRAMON or the EDMONd networks. The limiting magnitude of NFC system during nights with average conditions is $+9.5^{mag}$ (stars) and $+6.0^{mag}$ (meteors). During nights with excellent conditions it is $+10.4^{mag}$ (stars) and $+7.0^{mag}$ (meteors) (*Figure 1*).

4 Two-station meteor observation with NFC

The first NFC station has been in operation since April 1, 2015 in Kroměříž (CZ). The station has a fixed and so it is not possible to change the alt-azimuthal position of the FOV. The FOV center has azimuth 27.9° and elevation 43.4°.

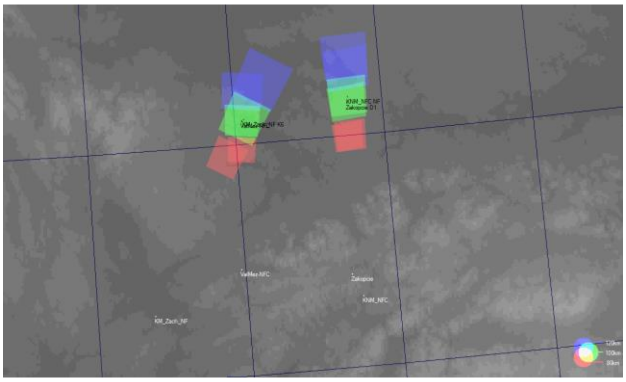

Figure 3 – Fixed stations FOV (Kroměříž, Valašské Meziříčí, Kysucké Nové Mesto, Zákopčie).

The second NFC station was installed at Valašské Meziříčí Observatory (April 15, 2015). This station has the possibility to vary the position of FOV in horizontal and vertical direction and the current position of the FOV center is 4.1° in azimuth and 53.8 ° in elevation. In May 2015 both the Slovak stations at Zakopčie and Kysucké Nové Mesto were installed and are now operational (Kysucké Nové Mesto since May 7, 2015; Zákopčie since May 9, 2015) (*Figure 3*).

Up to August 15, 2015 the four experimental systems had been in operation for 5 months (including tests in 2014), with 1595 single-station meteors recorded in total, 368 of which were registered as two-station meteors (*Figure 4*). Most were sporadic meteors (262 orbits), with others belonging to known showers – PER (22 orbits), ZCS and PCA (6 orbits), SIA and CAP (4 orbits), EUM, AXC and ZCY (3 orbits), AUP, ABA, JEC, PPS, NDA, BCA, SDA, KCG, OCY, BPE and LVI (2 orbits) and other meteor showers (1 orbit) (*Figure 6*).

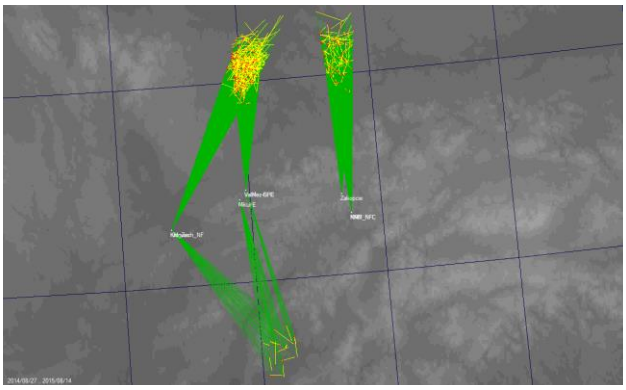

Figure 4 – Projection of two-station atmospheric trails.

Before the test run of NFC in 2014 a theoretical apparent brightness distribution was compiled and the total number of meteors expected to be recorded with NFC was estimated. As a reference data sample, the distribution of apparent meteor brightness from conventional CEMENT network cameras in 2014 (59925 meteors) was used, the limiting magnitude of these systems being considered to be $+5.2^{mag}$. The number of meteors predicted to be recorded by the NFC system was corrected for a small field of view, and also for a higher number of fainter meteors (corresponding to a population index of 2.8). The limiting magnitude of the NFC was considered to be $+9.6^{mag}$, based on the measurements made during the single station tests in 2014.

During the operation of the two NFC stations during the analyzed period the actual magnitude distribution of the meteor brightness was processed and results were compared with the actual number of meteors recorded in the same period by CEMeNt wide field cameras, which have a FOV in the same direction as the tested NFC systems. For the NFC station Kroměříž the Kroměříž ENE wide-field station data and for the station Valašské Meziříčí NFC the Otrokovice N wide-field camera data were used (Valašské Meziříčí Observatory is not equipped with an appropriate FOV direction wide field camera except for spectrographic system, which is not suitable for this purpose).

According to the theoretical model the maximum of NFC registered meteors should be located around the apparent magnitude $+5.0^{mag}$. In the real data sample the maximum was found at $+4.75^{mag}$. In addition the total number of recorded meteors in proportion to the current wide field camera systems was modeled to be around 61%. According to the real data, it is 72 %. The higher number of meteors recorded by the NFC system (compared to the assumption), may be due to a selection effect. April, May and June are characterized by generally low meteoric activity (except for the Lyrids shower) and by a higher frequency of faint meteors. For an accurate comparison of the model and the real numbers of meteors a larger dataset is necessary, ideally a whole year of NFC system operation (*Figure 5*).

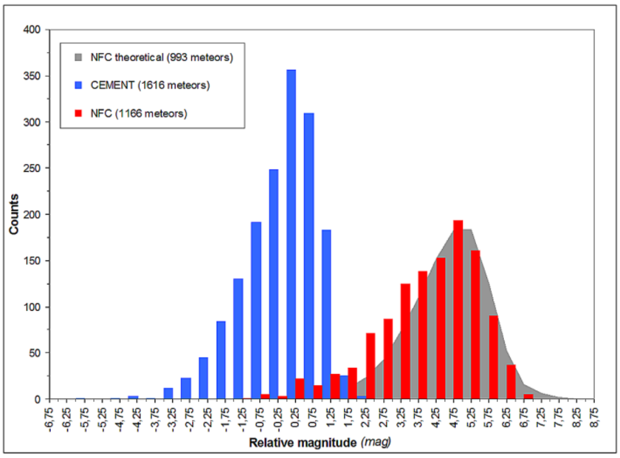

Figure 5 – Comparison of efficiency, histogram of meteors relative magnitudes.

5 Results – two-station meteor orbits

During the operation of the NFC system a total of 368 two-station orbits were derived, the efficiency of single-station meteor pairing was about 46%. The less effective pairing was due to different weather conditions at the stations during two-station operations. The first criterion for data quality monitoring was comparison of the differences in meteor geocentric velocity (v_g) derived from each station. The minimum absolute difference in v_g was found to be 0.008 km/s and the average v_g difference

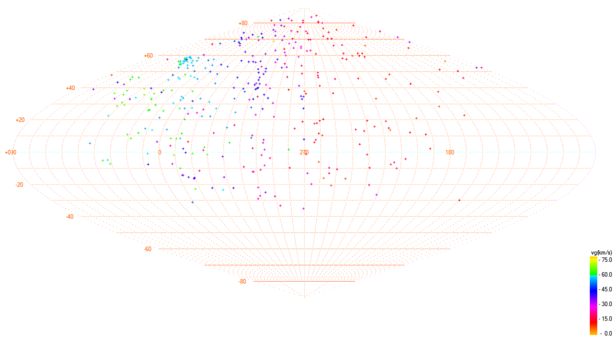

Figure 6 – Radiants of two-station orbits, equatorial coordinate system.

was then 1.006 km/s, the relative difference (with respect to the geocentric velocity corresponding to the calculated two-stations orbit) was at minimum 0.02% and in average 2.87%. The average apparent brightness of meteors recorded by NFC in this period was $+3.01^{mag}$, while the average apparent brightness of meteors recorded on the corresponding wide field CEMENT network cameras (ENE Kroměříž, Zlín N) was -1.25^{mag}.

Another quality criterion for derived meteoroid orbits was an angular deviation of the video registered meteor trail and its linear fit (CDEG parameter) and also the stellar background based astrometry accuracy variations in the frame to frame video points corresponding with meteor trajectory (ddeg). Both of these values are given in degrees. The minimum value of the parameter ddeg for all 1595 single station meteors was 0.00079, maximum 0.00591 and the average 0.00147, while the average value ddeg of all common wide field camera systems in a CEMeNt network in 2015 was 0.01911. The NFC camera system is thus at this point 13 times more accurate than conventional systems. The minimum value of the parameter CDEG for all 1595 single station meteors was 0.00094, maximum 0.00323 and the average 0.00181, while the average value of the CDEG of all common wide field camera systems in a CEMeNt network in 2015 was 0.01842. The NFC camera system is thus at this point more than 10 times more accurate than conventional systems. *Table 1* provides an overview of the CEMeNt and NFC system quality criteria.

6 Summary and conclusions

Results from the five months of NFC system two stations operation clearly show the capabilities of this system in the study of faint meteors – significant refinement of meteoroid orbital elements in the solar system, the possibility of faint meteor trail research and also the possibility of detailed research into fragmentation including for brighter meteors.

Acknowledgment

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Table 1 – Overview of the CEMeNt and NFC system quality criteria.

	CEMENT 2015	NFC	Δ%
Average absolute magnitude (mag)	-1.245	3.014	-
The lowest absolute magnitude (mag)	1.694	6.148	-
Average velocity v_g (km/s)	46.058	35.032	-
Average velocity difference between stations Δv_g (km/s)	5.225	1.006	19.3%
The lowest velocity difference between stations Δv_g (km/s)	0.028	0.008	28.6%
Orbits with Δv_g < 1 km/s (%)	35.1	62.4	-
Orbits with Δv_g < 0.5 km/s (%)	7.5	35.9	-
Average duration of meteors (s)	0.446	0.312	-
Average number of reference stars (-)	54	115	-
Maximum number of reference stars (-)	130	198	-
Average linearity error in analyzing (cdeg)	0.01842 ±0.02821	0.00181 ±0.00197	9.8%
Average positioning error in analyzing (ddeg)	0.01911 ±0.01594	0.00147 ±0.00198	7.7%