Maximizing the Performance of Automated Low Cost All-sky Cameras

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Abstract Thanks to the wide spread of digital camera technology in the consumer market, a steady increase in the number of active All-sky camera has be noticed European wide. In this paper I look into the details of such All-sky systems and try to optimize the performance in terms of accuracy of the astrometry, the velocity determination and photometry. Having autonomous operation in mind, suggestions are done for the optimal low cost All-sky camera.

Keywords all-sky · meteor camera · performance

1 Introduction

Since the 1960s and 1970s automated networks of meteor cameras have been in use to collect data on fireballs and recover meteorites. Well known are the Prairie Network (United States), the Meteorite Observation and Recovery Program MORP (Canada) and the European Network (former Eastern Europe), being examples of professional projects from that time. The European Network is still in operation nowadays [Spurný 2010, Flohrer 2006] and also other networks arose both on professional level (e.g. ASGARD in Canada [Brown 2010]; DFN in Australia [Bland 2008]) as well as amateur networks like the Polish Fireball Network [Olech 2006], and many others. Building and operating fireball patrol stations have always been well in reach for amateurs. Nowadays, with digital recording methods being used everywhere, this is true even more. Much digital imaging is done with sensitive (intensified) video cameras; in this paper on the contrary I will look into DSLR cameras with fisheye lens, because of their much higher resolution (10 Mpixel and more, compared to ~600x800 for standard video techniques) and which could be purchased for just under 1000EUR. I aim in this paper at an autonomously working station, which is easy to built and easy in use. Details of the setup are given in Table 1.

With the above as baseline, the goal we try to achieve is: (1) Accurate astrometry (error in semi major axis Δa < 0.01AU) [Vaubaillon 2007], (2) Accurate velocity determination (idem), (3) Proper photometry (for mass estimates and trail density distributions, but no requirement defined).

Table 1. Evaluated hardware setup

Camera	Canon EOS 350D (6 Mpxl)
Lens	Full frame Sigma 4.5mm F/2.8 fisheye
Exposure control	Canon TC80N3 timer controller; twilight switch. No PC
Timing	GPS/DCF clock for time reference marks in star trails
Chopper	LC-TEC optical shutter (modulation freq. 10-100 Hz)

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2 Astrometry

One camera pixel equals on average ~5’ and the plate reduction error of the combination camera-lens turns out to be of the same order [Bettonvil 2006]. When assuming that the error in radiant position caused by astrometry is of the same amount, we can calculate the effect on the orbital elements, which is illustrated in Table 2 for an asteroidal fireball (being an example of the type of fireballs that is of most interest for meteorite recovery). It shows that the error in the semi major axis is just within our goal[2].

Table 2. Effect of errors (respectively in radiant position (error A) and velocity (error B)) on the orbital elements for an ι-Aquarid [Bettonvil 2006].

		Radiant			
Radiant	Observed	Geocentr.	Heliocentric	Error A	Error B
R.A. [°]	342°,959	343°,201		±0,100	-
Decl [°]	-05°,281	-07°,367		±0,100	-
Heliocn. Longitude [°]			288°,647	-	-
Heliocent. Latitude [°]			-0°,179	-	-
Velocity [km/s]	32,292	30,183	34,967	-	±0,096
		Orbital elements			
Longitude of ascending node [°]		(Ω)	322°,528	±0,339	±0,024
Inclination [°]		(i)	0°,322	±0,161	±0.019
Argument of perihelion [°]		(ω)	131°,029	±0,432	±0,057
Semi major axis [AU]		(a)	1,6758	±0,0095	±0,0135
Perihelion distance [AU]		(q)	0,2415	±0,0012	±0,0011
Aphelion distance [AU]		(Q)	3,1102	±0,0178	±0,0282
Eccentricity [AU]		(e)	0,8559	±0.0001	±0,0018

For automated operation a window cover is required however, which either could be a hemispherical acrylic dome or watchmaker’s glass (Figure 1 left). Although the first seems preferred due to the (insensitive) perpendicular penetration of the light beam, performance was measured too be bad due to local irregularities (Figure 1 right). A watchmaker’s glass appears to be fine.

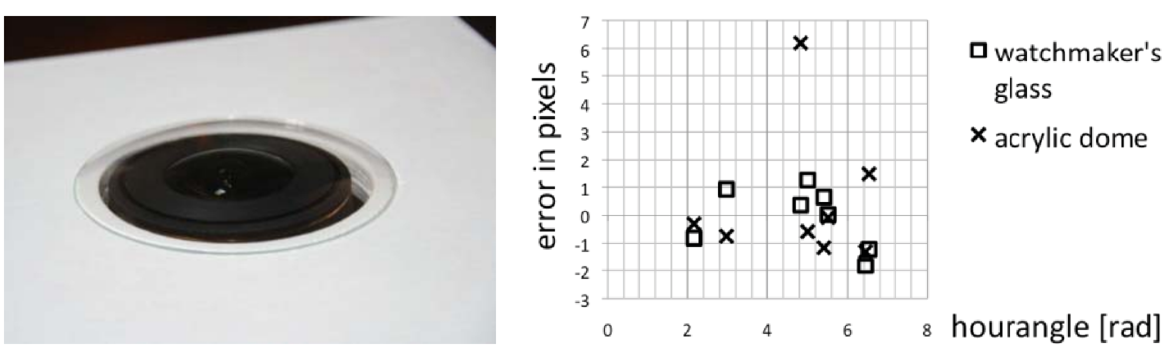

Figure 1. (left) Watchmaker’s glass; (right) measured difference in star position between an acrylic dome and watchmaker’s glass for several stars in azimuthal direction. The measurement resolution was 1 camera pixel. The single high outlier for the acrylic dome is real.

[2]Also the other orbital elements are affected by a change in radiant position, and even Ω, which is due to the ecliptical origin of the investigated meteor.

3 Velocity Determination

For measurement of the velocity, I chose not to use a conventional rotating chopper in front of the lens, but instead a liquid crystal shutter (LC-TEC 2010), mounted between lens and camera [Bettonvil 2007b, 2010]. Advantage is that the chopper frequency can be more accurate (crystal operation, no rotating parts, no wind influence). Optical ray tracing and measurements showed that no significant aberrations occur [Bettonvil 2010].

Instead of direct measurement of the chopper breaks, frequency analysis with FFT is used, which, after doing simulations and tests, gave velocity errors of 0.2-0.5%, 3-5 times better than conventional choppers [Bettonvil 2008]. A 0.3% velocity error (Table 2, error B) is required to stay within our requirements for the error in semi major axis (Δa < 0.01AU).

4 Photometry

DSLR camera's, when read out in RAW mode, allow up to 10-15 bit dynamical range, much more than video camera's (7-8 bit). Nevertheless, because in photography exposures are being integrated over a (much) longer time, the noise and dark level easily go up to unacceptable levels, reducing the effective dynamical range. Dark level and noise is mitigated by: (a) subtraction of 2 successive images; (b) the use of low camera sensitivity (i.e. ISO setting); (c) short exposure times. Sensor cooling with Peltier elements is a very effective method [Bettonvil 2007a], but disregarded here, due to its complexity.

Saturation of fireballs is also to be avoided, which is the second reason for choosing low sensitivity. Figure 2 (left) shows the relation between ISO setting and brightness for fireballs and stars. It confirms that ISO 100 (is lowest value, resulting in noise counts of ~100) is preferred for allocating sufficient dynamical range for bright fireballs ($\sim m_v$ = -12). The sensitivity for stars is of course low then (+2), which affects the number of reference stars for astrometry. It is solved by combining multiple exposures. Figure 2 (right) shows the measured linearity of the camera as derived from stars. It shows non-linearity in the order of 0.1mag.

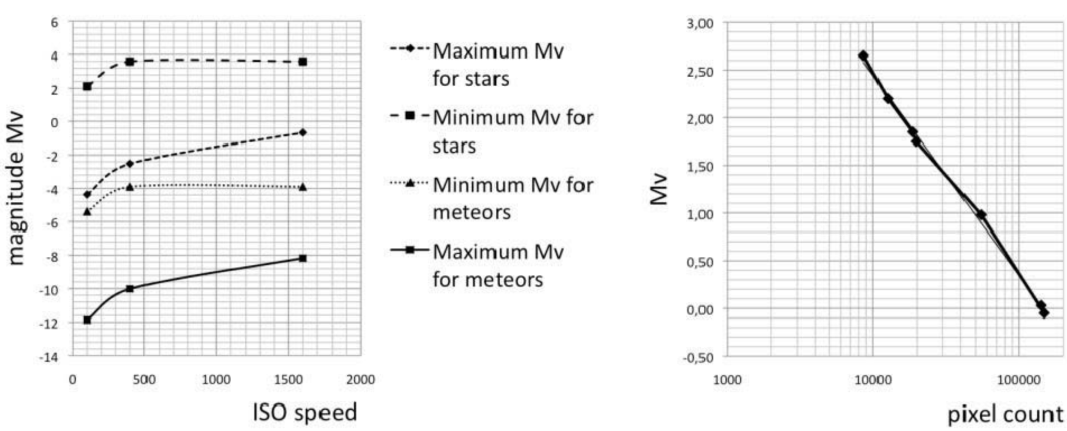

Figure 2. (left) Faintest detectable stars and meteors, as derived from the noise level, and brightest detectable stars and meteors before saturation occurs, as function of ISO speed; (right) linearity of the camera response for stars.

For cometary fireballs [Jenniskens 2006], with v = 25 km/s and at 100 km distance, we can write for the relation between mass M and brightness m_v:

$$\frac{dM}{dm_v^{abs}} = -0.92 \cdot 10^{0.933-0.4\,m_v} \quad (1)$$

A photometry error of 0.1 mag results then in a ~10% error in the estimate of the mass of the meteoroid, which seems acceptable.

5 Conclusions

It seems that useful astrometry, velocity determination and photometry, of bright fireballs can be done with a DSLR camera with full frame fisheye lens. Part of the camera is an optical Liquid Crystal shutter. Operation with very low sensitivity (ISO100) as well as short exposure times is recommended to maximize dynamic range and avoid saturation.

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