HHEBBES! All sky camera system: status update

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A status update is given of the HHEBBES! All sky camera system. HHEBBES!, an automatic camera for capturing bright meteor trails, is based on a DSLR camera and a Liquid Crystal chopper for measuring the angular velocity. Purpose of the system is to a) recover meteorites; b) identify origin/parental bodies. In 2015, two new cameras were rolled out: BINGO! –alike HHEBBES! also in The Netherlands-, and POgLED, in Serbia. BINGO! is a first camera equipped with a longer focal length fisheye lens, to further increase the accuracy. Several minor improvements have been done and the data reduction pipeline was used for processing two prominent Dutch fireballs.

1 Introduction

HHEBBES! is an automatic all-sky camera concept for capturing bright meteor trails. It is based on a DSLR camera and combined with a chopping Liquid Crystal shutter for the determination of the angular velocity, instead of a conventional rotating shutter. HHEBBES! makes still images, with currently 8 – 21MP resolution.

The development and realization has been described in a series of articles (Bettonvil, 2013). The high spatial resolution and accurate chopping enable accurate trajectory and orbit determination, leading to small D-criteria (Galligan, 2001).

As for all All-sky meteor camera systems, purpose is to a) recover meteorites; and b) indentify the origin/parental body of the meteor. At the beginning of the project, requirements were set to realize an affordable design, ensuring that they can be used widespread inside a large network, incorporate automatic operation, avoiding daily operation tasks, and be robust, minimizing maintenance and periods of malfunction.

HHEBBES! was put into operation in spring 2012 in Utrecht, The Netherlands, and is included in a larger network of DSLR operated All-sky cameras, operated by Dutch amateurs. HHEBBES! is part of the Dutch ASSN network that also includes All-sky video cameras for gathering data on the time of appearance of fireballs.

2 Increase number of cameras

After 3.5 years of successful operation of HEBBES!, in 2015 successively two more cameras were built: BINGO! (*Figure 1*), located at ASTRON/Dwingeloo, 120km North-East of HHEBBES!, and POgLED (*Figure 2*), located at the Petnica Science Center in Serbia. Planned is a fourth camera: RAAK! at Sterrewacht Leiden, University Leiden.

3 Improvements

HHEBBES!, POgLED and BINGO! are not exact clones of each other, but all have small differences and improvements. *Table 1* gives an overview. The main difference is related to the exposure controller:

- HHEBBES! (Bettonvil, 2013) uses a standard Canon TC80N3 exposure controller with in series a DCF clock that twice per night makes a precise 1-minute reference exposure (the TC80N3 is on long term not sufficiently accurate). A twilight sensor, also connected serially, connects and disconnects the exposure controller signal to the camera.
- POgLED does not use a TC80N3 anymore, but instead a Theben 642 DCF Top2 RC astronomical switch[1], which both does the exposure controlling, as well as calculating the sunset and – rise times. There is no twilight switch anymore. *Figure 4* shows POgLED's control cabinet.
- BINGO! does use the (inaccurate) TC80N3 controller with twilight switch (*Figure 3*). The Canon 6D camera used in BINGO! incorporates GPS support, such that the start of each exposure is accurately time stamped in the EXIF header file. It does not require accurate exposure controlling anymore and eases the data reduction process.

BINGO! is also the first camera that uses a Peli® case as housing (*Figure 1*). This type of case is extremely sturdy, weather resistant as well as easy to open for maintenance. The plan is to make all future cameras this way.

[1] Theben (2015) http://www.theben.de/en/Products/Time-and-light-control/Digital-time-switches/DIN-rail/Yearly-program/TR-642-top2-RC

Table 1 – Overview of the different HHEBBES! class all sky cameras. The first three have been rolled out at the time of writing, number 4 planned for the end of 2015.

	HHEBBES!	BINGO!
Camera	Canon EOS 350D 6 MP APC	Canon EOS 6D 20 MP FF
Lens	Full frame Sigma 4.5 mm / F2.8 fisheye	Zeiss Distagon 16 mm / F2.8
Exposure control	Canon TC80N3 Timer controller, DCF clock ref exposures, twilight switch	Canon TC80N3 Timer controller, twilight switch, GPS exp time stamps (6D)
Chopper	LC-TEC optical shutter (10-100 Hz) between lens and camera	LC-TEC optical shutter (10-1000 Hz) internal inside lens
Storage	8 GB CF card	32 GB SDHC card, WiFi
	POgLED	**RAAK!**
Camera	Canon EOS 1100D 12 MP APC	Canon EOS 5D 12 MP FF
Lens	Full frame Sigma 4.5 mm / F2.8 fisheye	Nikkor 16 mm / F2.8
Exposure control	Theben 642RC astronomical timer	Theben 642RC astronomical timer
Chopper	LC-TEC optical shutter (10-1000 Hz) between lens and camera	LC-TEC optical shutter (10-1000 Hz) between lens and camera
Storage	32 GB SDHC card	16 GB CF card

Figure 1 – BINGO! installed on the roof of the ASTRON institute in Dwingeloo. In the background the 25-m Dwingeloo radiotelescope.

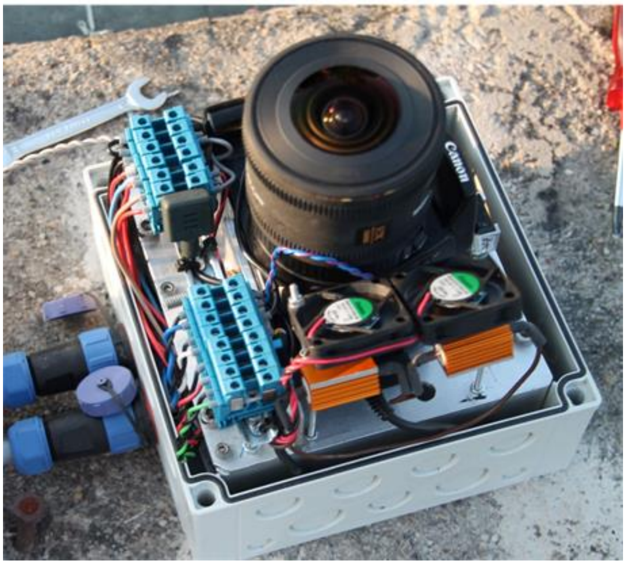

Figure 2 – Look into the interior of the POgLED camera housing.

Figure 3 – Control cabinet of BINGO! with power supplies (black box, bottom), exposure controller (black unit door), DCF clock (grey box middle row left), chopper wavegenerator (blue box), GSM I/O module (grey box door).

Figure 4 – Control cabinet POgLED. Power supply (black box, bottom), exposure controller (grey box, door, lower row, center), chopper controller (blue box, door), GSM I/O module (door, bottom, right).

4 New type fisheye lens

In order to improve the accuracy, it has been proposed (Bettonvil, 2014) to change from APC to full frame sensors (improved detector performance, lower noise) and to increase the focal length (generating a *full frame* instead of *circular* fisheye image, measuring only 180˚ over the diagonal of the sensor). This choice leads to a smaller collecting area, giving up hemisphere at large zenith angles, but at the gain of improved astrometry, as well as allowing higher chopper frequencies, leading to more and more accurate data points. In such a case, the area of The Netherlands can still be fully covered, but requires at least 8 cameras to ensure at least a double station coverage (*Figure 5* & Bettonvil, 2014).

BINGO! is the first station being equipped with a 16 mm lens. The lens chosen for BINGO! (Zeiss Distagon 16 mm F2.8) has an internal filter wheel, which is of no use for our purpose. The location of the filter wheel, being close to the pupil plane, forms however the ideal location for the electronic shutter (*Figure 10*), as at this location the component will not add optical aberrations, which in theory should be even valid in the case the chopper is thicker with respect to the original filters (thickness 1.7 mm instead of 1 mm). A check was performed with the optical ray trace program ZEMAX on a similar fisheye lens (*Figure 6*), which showed that the performance will not decrease and even is marginally better.

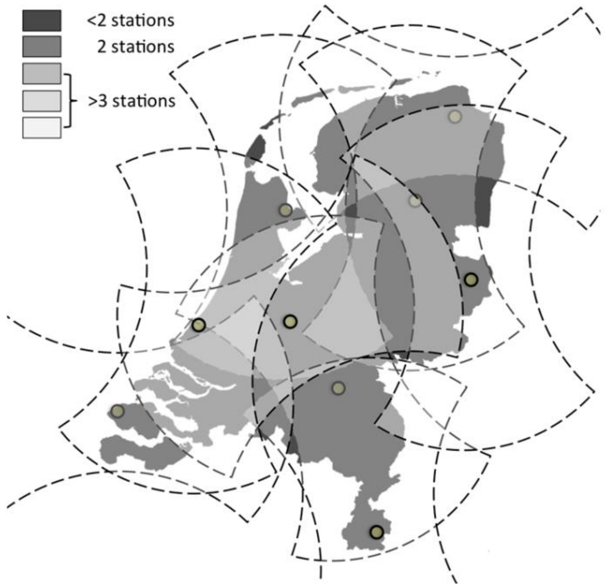

Figure 5 – Map of The Netherlands and coverage in case of eight 16mm fisheye lens cameras, their effective area given for zenith angles >75˚ @30km altitude. From (Bettonvil, 2014).

With help of instructions on internet on the disassembly of similar Zeiss lenses, combined with careful investigation of the lens, the tedious process was started of dismantling the lens in order to reach the filter wheel (*Figure 7, 8, 9*). Due to the purely mechanical nature of the lens (no electronics inside), the entire process turned out to be do-able, although I would recommend it only for experienced ‘instrumentalists’.

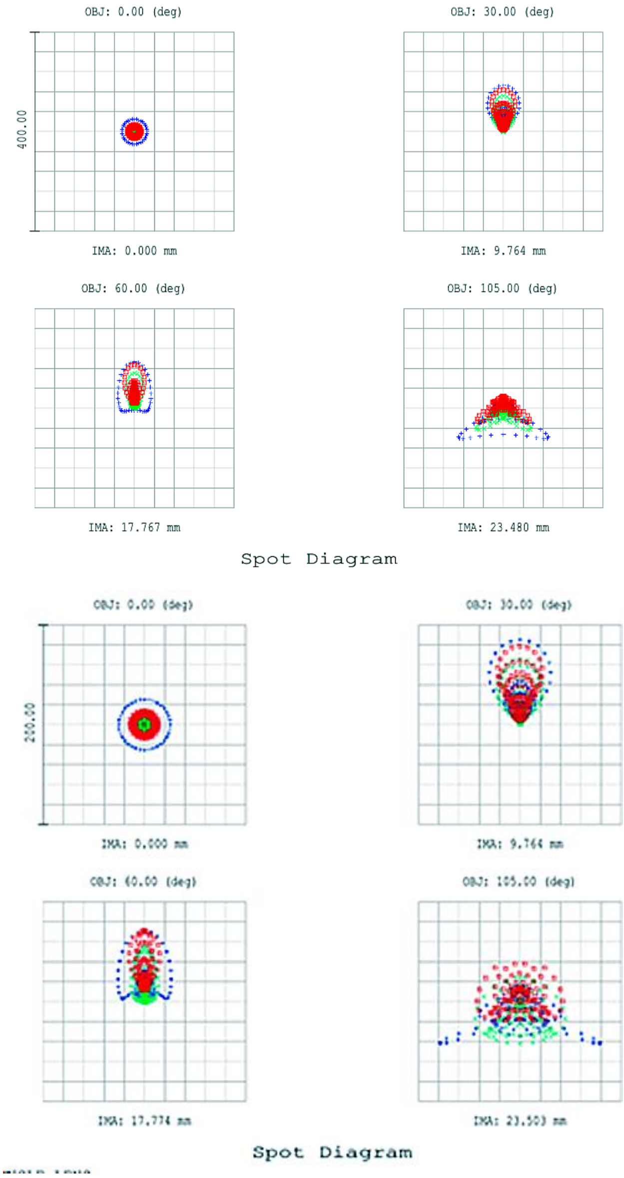

Figure 6 – Spot diagrams of the ray tracing calculation of the fisheye lens without (upper four images) and with optical shutter (lower four images). Each set of 4 images shows the spot diagram on-axis (upper left), at 30˚, 60˚ and 105˚ zenith angle (lower right). The inserted chopper does not degrade the image quality. Note the different scales of the two sets (size grid 400μm vs 200μm).

Figure 7 – Start of the dissassembly of the Zeiss Distagon 16mm F2.8 fisheye lens.

The filter wheel was removed, leaving an empty slit in which the LC-Tec X-FOS(G2) 1x1" model fitted perfectly (*Figure 9*)[2]. The two wires could be directed to the outside through an empty slot of the locking pin handle, which was removed before. The lens was thereafter assembled again, and turned out working as expected.

5 Operational manual

For all the cameras, electronic circuit diagrams have been made for maintenance purposes. For the POgLED camera also an instruction was written (including electronic diagram) which is made available on internet[3].

Figure 8 – The 'heart' of the fisheye lens with front and rear lens groups taken away and internal filterwheel now clearly visible, ready for replacement by the electronic chopper.

Figure 9 – Side view with the LC-TEC optical shutter instead of the filterwheel in place now.

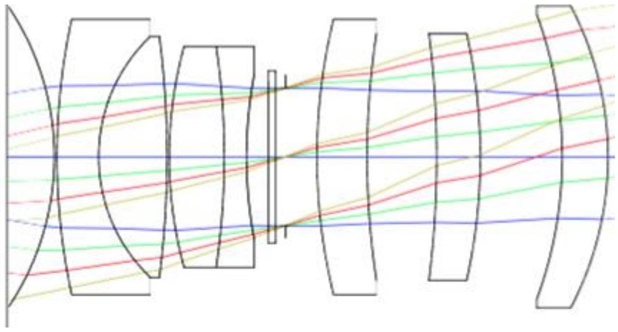

Figure 10 – Part of the optical design of the fisheye lens with in the center the pupil location (diaphragm) and new chopper (visible as plan plate at left side of pupil).

6 Data pipeline

Computation of the atmospheric trajectory and heliocentric orbit is done via the in-house developed software *Meteor35* (in Delphi, running under DOS, see also Bettonvil, 2015). It includes astrometric reduction, atmospheric trajectory and orbital elements calculation.

The astrometric plate reduction is the most time consuming part, as it requires measurement of the image and identification of the set of reference stars. As no automatic package is known to be available for fisheye photos, this part is still done manually:

1. First reference stars are selected and encircled and numbered. The new image is stored.

2. Identification of reference stars is done with Stellarium[4].

3. With SAOImage DS9[5], the position of all reference stars is measured by centroiding (center of star trail) as well as all meteor breaks.

4. All measured positions and reference coordinates (RA, decl) are inserted into a text file, as input for *Meteor35.*

The fourth step currently is a manual process, and it is desired to be automated as this is a time consuming procedure. Automation of the third step is welcome too, but on the other hand, fireballs – due to the irregularity of the fireball trail (overexposure, train) - often require manual processing in some way in order to obtain the most accurate results.

Computation of the dark flight is not possible yet in *Meteor 35*, although on the to-do-list.

7 Results

Each camera records a couple of fireballs each month. Two events were analyzed, i.e. the bright fireball of October 19, 2014 (Miskotte, 2014), which appeared at prime time and was observed by hundreds of witnesses, and the fireball of March 11, 2015 (Langbroek, 2015), which was not seen visually but is candidate for a

[2] http://www.lc-tec.com/optical-shutter
[3] http://werkgroepmeteoren.nl/ wp-content/uploads/POgLED-manual.pdf

[4] http://www.stellarium.org
[5] http://ds9.si.edu/site/Home.html

meteorite dropping. This fireball was captured by 7 Dutch All-sky systems, some of them operated with rotating shutters and also with HHEBBES!, which was used as reference for the velocity estimation. The meteorite, despite a number of meteor hunts in the area, is not recovered yet.

8 Summary and conclusions

- Two new stations have been built based on the HHEBBES! technology. A fourth station is planned.
- The time synchronization was further improved, and is now perfect, thanks to GPS supported DSLRs.
- All new stations are equipped with longer focal length fisheye lenses, improving further the astrometric accuracy and velocity estimation.
- The pipeline is functional, but requires substantial manual work. Further automation is needed and underway.

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The author and 2016 IMC organizer, *Felix Bettonvil*, (left) having a chat with *Paul Roggemans* (right) (Photo by *Christoph Niederhametner*).