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Photoelectric photometry era at the Astronomical Institute of the Slovak Academy of Sciences III.

Fast photometry

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Abstract. We present a continuation of the article series describing the photoelectric photometry era at the Astronomical Institute of the Slovak Academy of Sciences. The paper aims to provide a comprehensive technical description of implementation of the fast photometry at the Stará Lesná Observatory and estimates its photometric precision. Using integration times of 0.1 s and 0.01 s, an estimated photometric precision of the fast photometry is about 0.02 mag and 0.06 mag, respectively. Here, we also show the observation principles of the fast photometry and its use in positive observation of stellar occultation lasting 18.44 s by the asteroid (85) Io.

Key words: photoelectric photometry – asteroids – occultations

1. Introduction

The main properties and features (instrumentation, color system, extinction, software and reduction techniques) of the photoelectric photometry used in the past at the Skalnaté Pleso Observatory and Stará Lesná (SL) Observatory were already described in the articles of Vaňko *et al.* (2014a,b). The present paper concludes this series with the focus on fast photometry (hereafter FP).

FP is a field of photoelectric photometry aiming to measure brightness changes with time resolution from several seconds down to a few milliseconds or even better. Its application involves several types of flare objects, cataclysmic variables, polars, symbiotic stars, X-ray and gamma-ray bursters, optical pulsars, white dwarfs, and extragalactic sources displaying rapid flickering (Warner, 1988; Kanbach *et al.*, 2014). FP provides particularly valuable data in stellar occultations by solar system bodies yielding measurements of stellar angular diameters (Sato *et al.*, 1993), detection of stellar multiplicity, and angular separations of otherwise-unresolvable close binaries and multiple systems. On the other hand, occultations yield unique direct measurements of characteristics of occulting bodies, or even detection of their rings and satellites. For example, stellar occultations by asteroids offer an excellent opportunity to obtain direct high-quality information on the position, size, shape, and the existence of satellites of an asteroid (Ďurech *et al.*, 2011). Deriving information on stellar radii from lunar occultations requires a millisec time resolution, while for asteroid diameter determinations, time resolution of about 0.1 s is sufficient.

2. Precision of fast photometry

One of the most important assumptions for obtaining usable data is a telescope with the sufficient size of an aperture determining the number of photons and errors caused by scintillation. A signal-to-noise ratio for such short exposures is defined mainly by the Poisson noise. The number of detected photons also depends on other factors, *e.g.*, using a filter, quantum efficiency of a photomultiplier at a given wavelength, additional optical elements of a telescope (Kanbach *et al.*, 2014). Moreover, FP is critically dependent on the statistics available from often faint sources embedded in the background brightness of the night sky.

In so far that the scintillation is of paramount importance for quality and precision of FP given as the root mean square (rms) of scintillation-induced intensity fluctuations $I_{\rm rms}$ to the mean intensity I by the formula (Young, 1967; Warner, 1988)

$$\frac{I_{\rm rms}}{I} = S_0 D^{-2/3} X^{3/2} {\rm e}^{-h/{\rm H}_0} \Delta\nu^{1/2}\,, \qquad (1)$$

where S_0 is a measure of the intensity of the scintillation, which is 0.09 in good seeing (Warner, 1988), D is the telescope aperture in centimeters, $X \approx \sec z$ is the airmass at the zenith angle z, h is the telescope altitude above sea level, $\rm H_0 \approx 8\,km$ is the density scale height, $\Delta\nu$ is the width of a low-frequency band related to the integration time t in seconds as $\Delta\nu = k/t$, and the parameter k is 0.5 (Warner, 1988) or 0.25 (Young, 1967).

Evaluating Eq.(1) for a 60-cm telescope at SL at an altitude of $h = 810\,\rm m$ taking $t = 0.1\,\rm s$ for a typical $X = 1.3$ and $k = 0.5$ gives the photometric precision of $\Delta m = -2.5\log(1 + I_{\rm rms}/I) \approx 1.086 I_{\rm rms}/I \approx 0.02\,\rm mag$. In the case of FP with $t = 0.01\,\rm s$, the photometric precision is $\Delta m \approx 0.06\,\rm mag$, which can be considered as a typical error of FP attainable at SL. While for bright targets the photometry precision is limited by scintillation, for faint sources it is the Poisson (shot) noise.

3. Fast photometry at the Stará Lesná Observatory

Instrumentally, FP at SL is realized by Mayer's photometer (Fig. 4 in Vaňko *et al.*, 2014a) switched to the FP regime with optimized time resolution to assure accuracy of timing. The FP realization involves the following components:

- **Interface** provides a synchronization impulse for communication between the computer and the photometer (SYNC). Time accuracy and time reso-

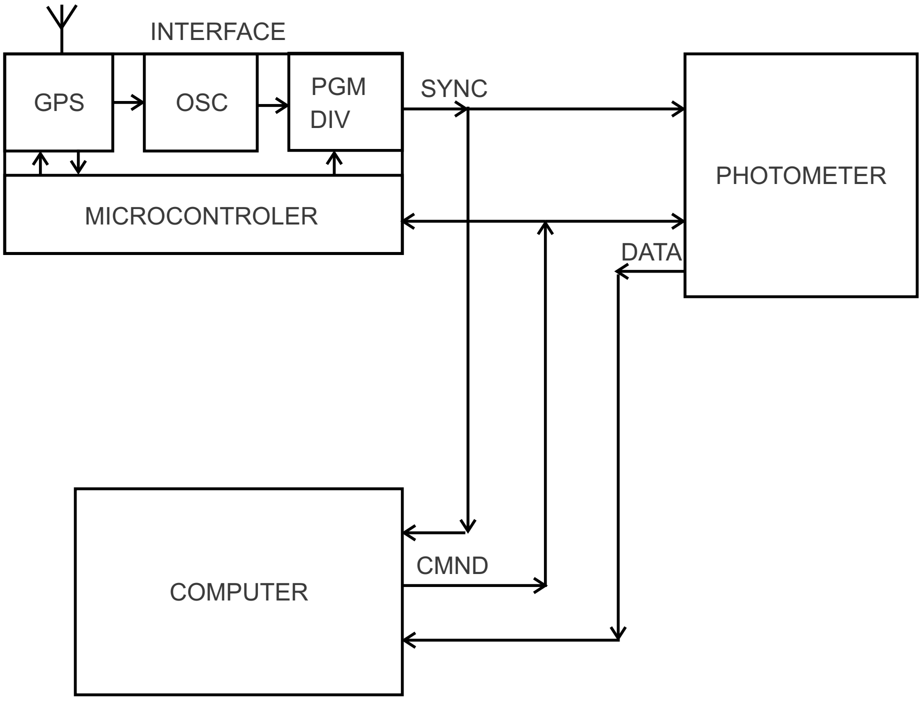

Figure 1. The block scheme of installation.

lution is determined by a GPS module Motorola Oncore GT12T[1]. At the beginning of every UT second, the interface sends a short signal (electric impulse) lasting 10 μs, with the default frequency of 1 Hz. The microcontroller, the oscillator (OSC), and the programmable divider (PGM DIV) allow to change the output frequency to 10 Hz or 100 Hz. The block scheme of the installation is shown in Fig. 1.

- **Computer** transmits the command byte (CMND) controlling the photometer filter settings and sets the normal or fast mode of photometry.

- **Photometer** provides the data bytes (DATA). The first data byte contains information about an actual filter. Next three bytes are the result of partitional timing integration.

- **USART** All blocks contain the USART (Universal Synchronous/Asynchronous Receiver/Transmitter) set in the asynchronous regime. It means that a

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[1] http://www.cnssys.com/files/M12+UsersGuide.pdf

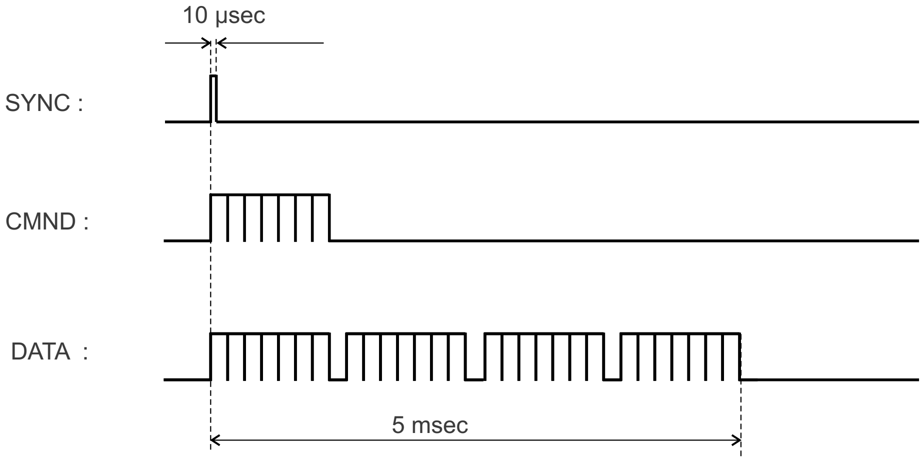

Figure 2. A timing diagram of communication.

serial port can transmit and receive information simultaneously. Every block has input with an interrupt request.

- **PC activity** The SYNC impulse in PC activates a resident program. At first, the resident sends a command byte and waits for four data bytes from the photometer. After decoding the obtained information it displays it at a defined place of the screen communication box.

- **Photometer activity** The rising edge of the same SYNC impulse (the constant dead time lasting 10 μs) in the photometer reads the content of the pulse counter from the photomultiplier and the falling edge clears the counter. Then the photometer sends the data byte with information on the filter setting, mirror turning position (switching light between the eyepiece and the photometer), etc. Later on, after completing the previous process, the photometer transmits three bytes containing actual information from the counter, *i.e.*, the actual intensity of photomultiplier illumination.

- **Communication duration** The duration of a complete communication, with the speed of 9600 Bd, is $\approx$ 5 ms when the maximum speed of the photometer is limited to 100 Hz. In other words, such communication repeats every 10 ms, *i.e.*, it counts hundred measurements per second (Fig. 2).

- **An accuracy** of timing inferred from FP is given by the accuracy of GPS, which is 20 ns. This should be regarded as the theoretical limit.

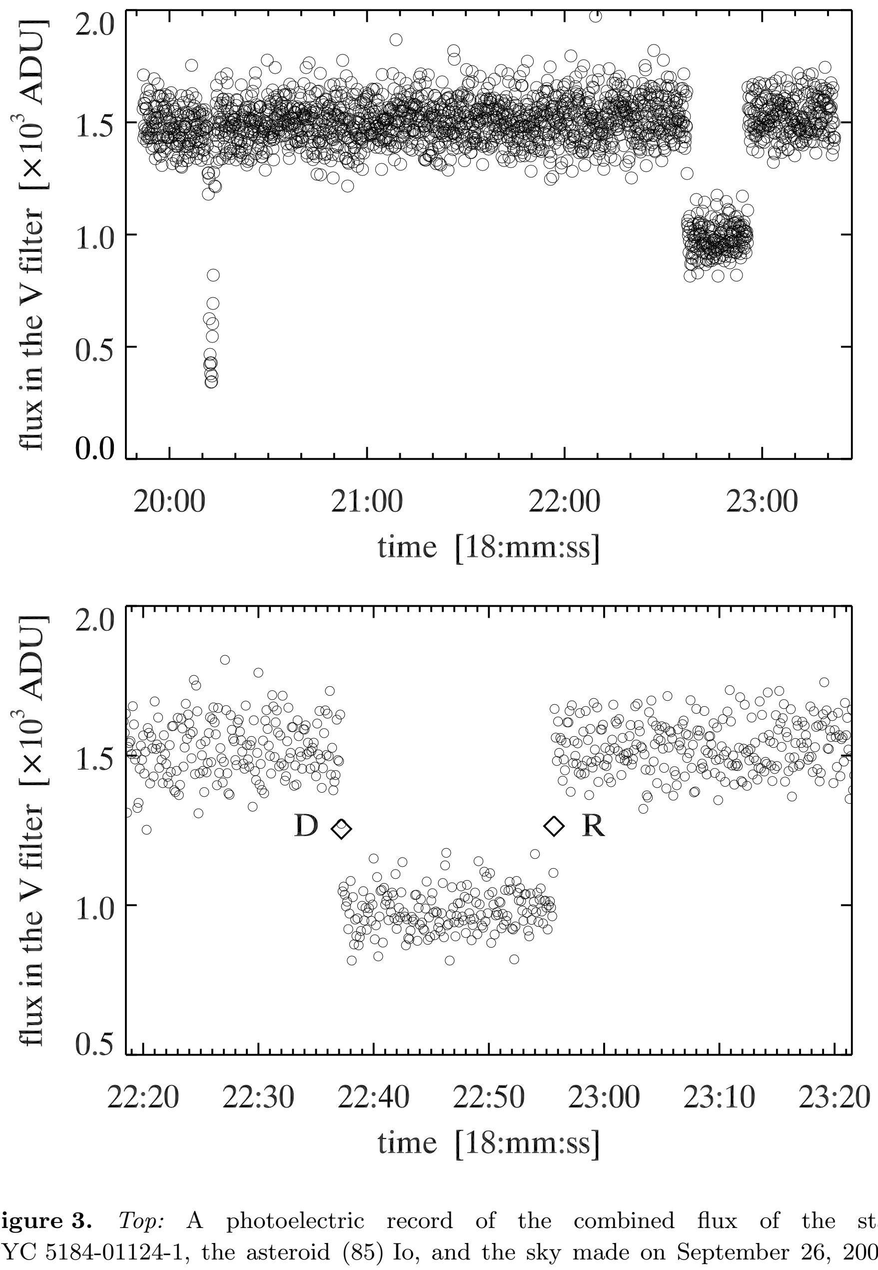

Figure 3. *Top:* A photoelectric record of the combined flux of the star TYC 5184-01124-1, the asteroid (85) Io, and the sky made on September 26, 2003. The system timebase is offset about 30 s with respect to UTC. *Bottom:* An enlarged part of the photoelectric record showing the primary minimum due to occultation of the target star by (85) Io. Diamonds define a time interval of the occultation of the star and fluxes used for timing of disappearance (D) and reappearance (R).

4. Application and summary

The paper provides a comprehensive technical description of the implementation of the fast photometry at the Stará Lesná Observatory. Using integration times of 0.1 s and 0.01 s, its estimated photometric precision is about 0.02 mag and 0.06 mag, respectively.

We show in Fig. 3 an example of the fast photometry application resulting in positive observation of occultation of the star TYC 5184-01124-1 by the asteroid (85) Io on September 26, 2003. The lightcurve was obtained with the integration time of 0.1 s and it shows the combined flux of the star and the asteroid. The primary and a secondary minimum at about 18:22:45 and 18:20:13, respectively, correspond to the occultation and to a brief drop out of the target star from the photometer diaphragm. The target star disappeared at 18:22:37.20 and reappeared at 18:22:55.64 after an occultation lasting 18.44 s. Since the system timebase was not synchronized with UTC prior to the observation, the event timings are offset about 30 s with respect to UTC. The predicted and observed magnitude drop of the target star were 0.7 mag and 0.5 mag, respectively. However, in the latter case the sky brightness was not subtracted. The detailed analysis of this occultation, together with others, will be published elsewhere. We emphasize that a key person standing behind this success was Jan Mánek who computed and updated Edwin Goffin's nominal occultation prediction and alerted us timely prior to the event. The update was computed by the last-minute asteroid astrometry obtained at the US Naval Observatory in Flagstaff and at the Table Mountain Observatory in California.

This paper concludes the papers by Vaňko *et al.* (2014a,b) about the photoelectric photometry era at the Astronomical Institute of the Slovak Academy of Sciences. We hope that the whole series will be used as a good, short handbook for observers still using photoelectric photometry.

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