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The Fly's Eye project

Sidereal tracking on a hexapod mount

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Abstract. The driving objective of the Fly's Eye Project is a high resolution, high coverage time-domain survey in multiple optical passbands: our goal is to cover the entire visible sky above the 30° horizontal altitude with a cadence of $\sim 3\,\mathrm{min}$. Imaging is intended to perform with 19 wide-field cameras mounted on a hexapod platform. The essence of the hexapod allows us to build an instrument that does not require any kind of precise alignment and, in addition, the similar mechanics can be involved independently of the geographical location of the device. Here we summarize our early results with a single camera, focusing on the sidereal tracking as it is performed with the hexapod built by our group.

Key words: Techniques: photometric – Instrumentation: miscellaneous – Telescopes

1. Introduction

In the recent years, many initiatives have been started in order to perform optical astronomical surveys in the time domain. Some of the projects intend to focus on a few specific disciplines, e.g. the *Kepler* mission (on exoplanetary and astroseismology research, see e.g. Borucki et al. 2007) or cover dozens of independent scientific key projects, such as the Pan-STARRS (Kaiser et al. 2002) or the Large Synoptic Survey Telescope (LSST, Ivezić et al. 2008). These surveys attain their success due to the extreme light collecting power or *étendue*, which is the multiple of the net aperture area and the effective field-of-view of the imaging optics (basically a measure of light collecting power). The aforementioned projects perform observations by either covering a smaller celestial area with frequent sampling (such as *Kepler*) or larger areas with sparser sampling (Pan-STARSS or LSST), however, all of them deal with high imaging resolution. The goal of the Fly's Eye Project is to develop, and operate, a high coverage, high cadence, but lower imaging resolution instrumentation with a comparable étendue to the previously mentioned projects. The scientific goals of our project also cover dozens of astrophysical phenomena, as it is described in Pál et al. (2013). Our expectation is to achieve photometric precision at the millimagnitude level for stars with a brightness of Sloan $r = 10^{\mathrm{m}}$, as well as a faint depth of $r \lesssim 15^{\mathrm{m}}$ with S/N of 5 or more for isolated objects.

The high coverage and high cadence is attained by observing the visible sky simultaneously using numerous wide-field cameras (similarly to Deeg et al. 2004 or Pepper et al. 2007). Although the imaging resolution is essentially low ($22''$/px), even high cadence images require precise sidereal tracking during the exposures. In our design, this tracking is achieved by a hexapod mount (also known as the Steward-platform), which has many advantages due to conventional bi-axis mechanisms, including the lack of proper adjustment and the usability of the same instrument independently of the geographical location. In this paper we briefly summarize the key concepts of the hexapod itself as well as the results of our first tests related to the sidereal tracking.

2. The hexapod design

Due to its complexity, hexapods are barely involved as a primary mount in astrophysical applications. Mainly, these are used as a support for secondary mirrors (see e.g. Geijo et al. 2006), and there are direct applications in the field of radio astronomy (Koch et al. 2009) as well as optical spectroscopy (Chini 2000). Since with the exception of the Fly's Eye initiative, there is no direct application for optical imaging, in this section we summarize the key concepts of our hexapod design.

Mechanics. As its name suggests, our hexapod involves six identical linear actuators with two universal joints mounted at both ends. Our choice of electromechanical actuators exploits a jack screw in order to transform rotary motion into linear one. The total stroke of our actuator is limited to 100 mm, while the net length of a single leg in "home position" is approximately 510 mm. The net length is defined as the distance between the two corresponding universal joint center points, while the "home position" is defined at halfway between the fully retracted and full stroke state. Magnetomechanical switches ensure the proper limiting of each actuator, while the position feedback is done by a Hall effect based rotary encoder having a resolution equivalent to $\pm 0.1\,\mu m$ stroke.

Both on the base and the payload platform, the universal joints are mounted to a triangle-shaped structure whose side is approximately 700 mm. Hence, the characteristic instrument size and the actuator travel length (100 mm) give us approximately $\pm 10^{\circ}$ of a rotary domain of the hexapod, that is sufficient for more than an hour of sidereal tracking. The CAD view as well as the complete hexapod (with a camera and optics at the current state) can be seen in Fig. 1.

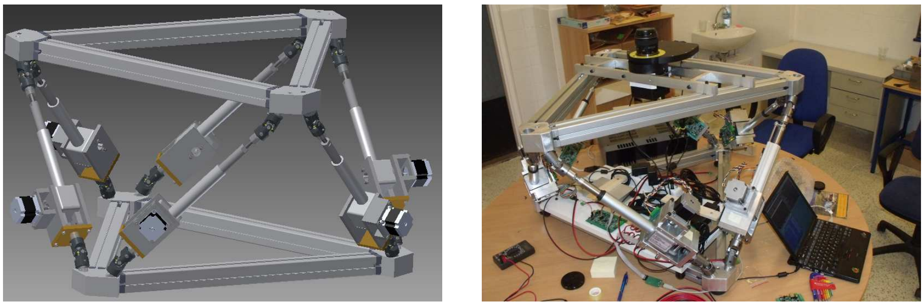

Figure 1. Left panel: a CAD view of the hexapod skeleton, showing the base and payload platforms and the six legs. Right panel: the fully assembled hexapod with a single camera–filter–lens set in the lab, just prior to delivery for first light tests.

Electronics and firmware. The actuators are driven by stepper motors that are controlled by a customized electronics board, one mounted on each leg. Each of the boards is connected to the Hall rotary encoder electronics that, with additional non-volatile ferroelectric RAM based storage, allows a complete stateless operation of the full device. The core of each board is an AVR (Advanced Virtual RISC) architecture microcontroller with identical firmwares. The real-time code multiplexes the communication with the control bus (see below), the motor driver circuit and the position encoder.

Control subsystem and software. The onboard leg electronics are connected with each other by an RS485 bus. This bus system allows a complete synchronized operation: the leg movement parameters (duration, stroke/retract, higher order polynomial coefficients, etc.) are uploaded in a unicast manner to each leg while the "start" command is a broadcast message. During motion, the status of the legs can be polled directly. Although RS485 lets distant parts to be connected, this bus is also driven locally by a single-board computer (SBC) which serializes commands received on TCP/IP to the RS485 bus.

Camera control and data acquisition. During the test runs, we employed a single CCD camera with a KAF-16803 detector and an $f/1.8$, $f = 85\,\mathrm{mm}$ lens, equipped with $50 \times 50\,\mathrm{mm}$ Sloan g', r' and i' filters. The camera has been mounted on the geometric center of the hexapod payload platform (see Fig. 1, right panel) The camera and the filter wheel are controlled via USB, while the USB is hosted on the same SBC that drives the RS485 bus (see above). The electric lens focusing is realized via an SPI (Serial Peripheral Interface) bus, also hosted on a RS485 node, connected to the same bus. Hence, the traffic of the whole device, including the camera, filter, hexapod mount control, as well as other housekeeping sensors (humidity, temperature, etc.) are tunnelled via

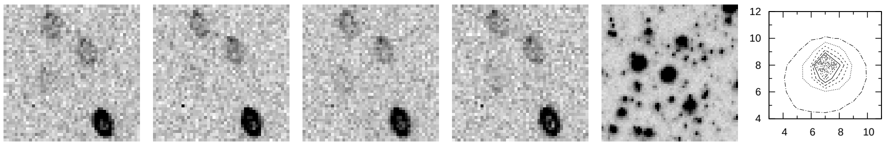

Figure 2. Left four panels: Tracking using an $f = 800$ mm lens during a 3 min interval (note: the stellar profiles are defocused on these $1.8' \times 1.8'$ stamps). Second to the right: Image stamp of 64×64 pixels, taken with an $f = 85$ mm lens, exposure time: 130 seconds. Right panel: PSF of the stellar profile at the center of the previous image.

multiple TCP/IP channels. The data acquisition could therefore be controlled by any machine connected to the Internet. In our tests, while the device was located at Piszkéstető station, in most of the time data acquisition was managed by a computer located at Budapest.

3. Sidereal tracking

During our first test runs, we acquired more than 4,000 individual frames in a filter sequence of g'-r'-i'-r'. For simplicity, the subsequent data acquisition steps (hexapod repositioning between exposures, filter changing, focusing, readout) were not done in parallel, hence the duty cycle is currently somewhat smaller than our final goal (70% instead of 90%+).

3.1. Self-calibration

It is easy to see that 3 linear combinations of the 6 leg strokes yield nearly pure pitch, roll or yaw rotations. By setting properly the actuator stroke speeds using this 3 combinations, one is able to attain proper sidereal tracking with the hexapod. As a self-calibration procedure, we gathered 4 series of subsequent image pairs in order to obtain the numerical derivative of the field centroid coordinates with respect to the pitch, roll and yaw speed offsets. This is done under the assumption that the device is exactly aligned to the compass points and to the horizon. For this analysis, we employed the tasks of the FITSH package (Pál, 2012).

Since the hexapod geometry (determined by the universal joint center positions) is known with a significantly better relative accuracy ($\approx 3 \times 10^{-4}$, assuming an assembly precision of ≈ 0.3mm) than the alignment ($\approx 1 \ldots 5 \times 10^{-2}$), we could set up a set of equations by saying that 1) the rotation speed must be equal to the sidereal and 2+3) the apparent drift of the centroid (in the CCD plane) must be zero. By solving these 3 equations, we could determine the offsets that should be added to the pitch, roll and yaw speeds.

3.2. Precision and repeatability

Our initial results show that despite its simplicity, the above procedure yields indeed proper sidereal tracking on the time scale of a few minutes, even considering that actuator stroke speeds are constant on the timescale of exposures. We performed these tests not only with the $f = 85\,\mathrm{mm}$ lens but also with a catadioptric optics of $f/8$, $f = 800\,\mathrm{mm}$ ($\approx 2.3''$/px, see also Fig. 2). The latter tests yielded a tracking drift of $0.5''\mathrm{min}^{-1}$ (see left four panels of Fig. 2) which is equivalent to a relative error of 6×10^{-4}. This value is well comparable to the *a priori* assumption of the assembly precision.

As it is discussed in Pál et al. (2013), images are acquired by synchronization to Greenwich sidereal time. By comparing field centroid celestial coordinates of corresponding images taken on subsequent nights, we could reliably characterize the repeatability of the instrument since the hexapod performs hundreds of independent movements between two respective frames. We found that this repeatability is at the level of some tenths of pixels using the $f = 85\,\mathrm{mm}$ optics, that is in the range of a few arcseconds.

4. Summary

This paper described the first results of the Fly's Eye project related to the sidereal tracking as it is performed with a hexapod mount. Despite the very simple tracking algorithm and self-calibration procedure, we found that the precision is well beyond within a magnitude than our needs, justifying that the hexapod is an adequate mount for such an optical imaging instrument. The complete analysis of the test runs will be presented in further paper(s).

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