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Calculating stellar magnitude to enhance guide star catalogs

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A method for calculating instrument stellar magnitudes for silicon photosensors assists the development of guide star catalogs for modern star trackers, and estimates the error of that technique.

When compiling guide star catalogs for modern star trackers, the use of instrument stellar magnitudes, rather than standard photometric star catalogs, can help avoid 'blind spots' in the sky, where the instrument's field of view has an insufficient number of stars to enable satellite orientation. The calculation of instrument stellar magnitude is a necessary step in developing guide star catalogs for star trackers that use silicon photosensors, such as star tracker 348K (see Figures 1 and 2). Using standard photometric star catalogs—as used in older trackers—may lead either to the tracking of too many stars that a guide star catalog lacks and that will be regarded by the instrument as pseudo-stars, or to stars emerging in the catalog that will never be tracked by the instrument.

Working out a guide star catalog requires that one transfer stellar magnitudes to the star tracker's passband. This allows optimization of a tracker's characteristics, namely, weight dimension characteristics of the optical system, the amount of memory used by the instrument calculating unit, and the time of calculations required for orientation purposes. Star tracker 348K, developed by JSC NPP Geofizika-Cosmos, is an autonomous multiple-head star tracker with a 19 degree field of view. Each optical head comprises an active pixel sensor (APS)-based camera with a Peltier cooler. Using advanced field and spectral correction and radiation-hard glass, each optical head has three variants of baffles: 40, 30, and 25 degrees. A unique feature of 348K is an internal optical reference mechanism in the optical head. This provides in-orbit self-calibration of bias shift and estimation of object defocus. Using its tracker hardware and software, 348K can reach 11 arcseconds (three sigma) accuracy of attitude determination during its 150,000 hour lifetime.

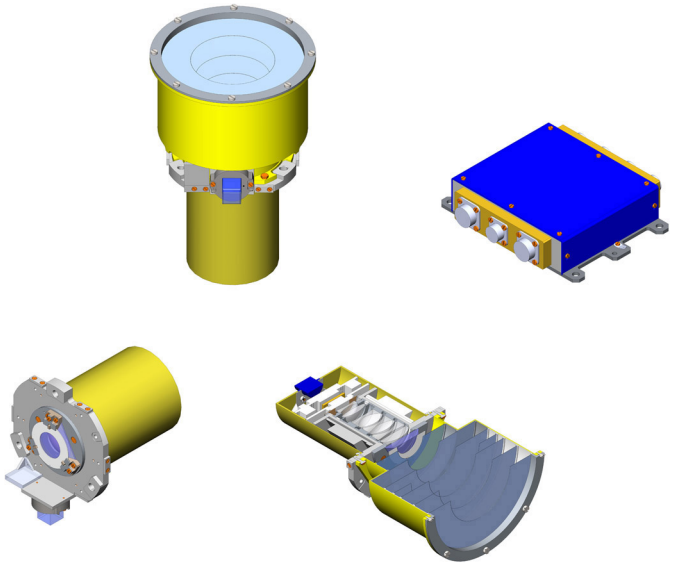

Figure 1. *Star tracker 348K.*

When we tested 348K on the night sky from Earth,[1] data showed that the star tracker identified stars as bright in its instrument stellar magnitude, but weak in the visual passband. The results demonstrate the need for an accurate calculation of instrument stellar magnitude.

Sternberg Astronomical Institute created 348K's guide star catalog using the instrument's field of view and the star tracker's spectral response (see Figures 3 and 4). The process of creating a catalog involves two steps: first, evaluating 348K's instrumental stellar magnitude; and second, forming the star cluster (stars located in such proximity that they are identified by the star tracker as one star) and the catalog's decimation, i.e., the reduced numbers of 'operational' stars visible in the celestial sphere, even when there are a large number of stars in the star tracker's field of view.

To evaluate instrument stellar magnitude,[1] we used the Bt, Vt, and J passband data from the Tycho-2[2] and Two Micron All

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Sky Survey (2MASS)[3] catalogs for star trackers whose maximum spectral response falls within the IR/near-IR spectral region. A stellar instrument magnitude—m(inst)—is evaluated using data from the Tycho-2 and 2MASS catalogs, based on a stellar magnitude in the Vt band and a function of the Bt-Vt and Vt-J color indices: m(inst)-Vt = f(Bt-Vt,Vt-J). The function of two variables f(x,y) is defined as follows:

$$f(x, y) = k_0 * f_0(x, y) + \ldots + k_n * f_n(x, y)$$

where $f_0, \ldots, f_n$ denotes the basis of functions, and $k_0, \ldots, k_n$ interpolation factors, which must be calculated for every value of every specific star tracker response.

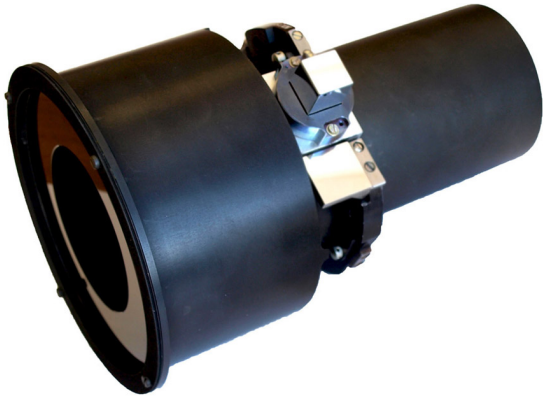

Figure 2. *Optical head of star tracker 348K.*

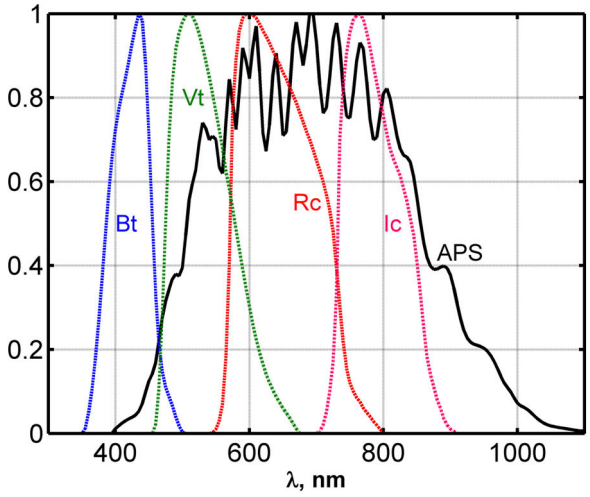

Figure 3. *Spectral bands of standard star photometric catalogs and 348K spectral response. Bt: B passband of the Tycho-2 catalog. Vt: V passband of the Tycho-2 catalog. Rc: R passband of the Cousins catalog. Ic: I passband of the Cousins catalog. APS: Active pixel sensor. λ: Wavelength, nm.*

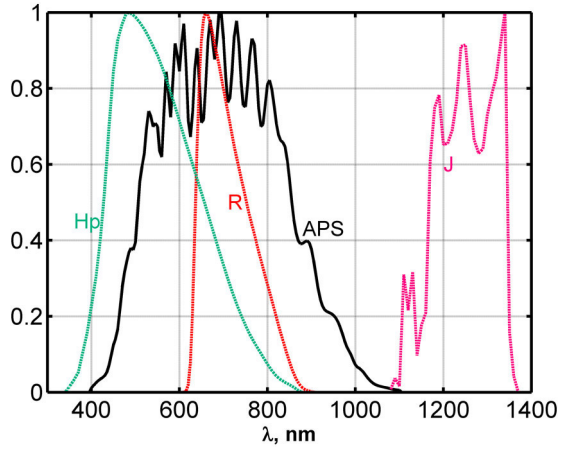

Figure 4. *Spectral bands of standard star photometric catalogs and 348K spectral response. Hp: H passband of the Hipparcos catalog. R: R passband of the Tien Shan (WBVR) catalog. J: J passband of the Two Micron All Sky Survey (2MASS) catalog.*

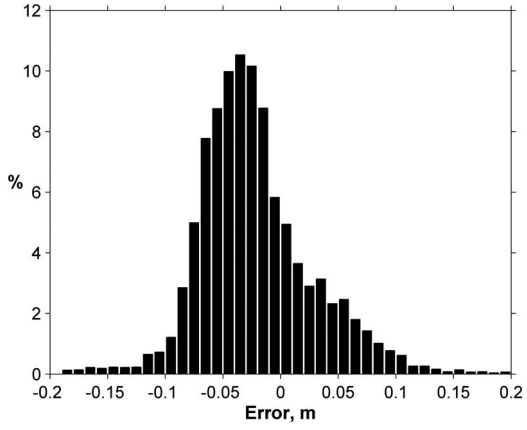

Figure 5. *Error of calculated instrument stellar magnitudes (m), based on data from the 2MASS and Tycho-2 catalogs.*

Evaluation of the coefficient method for $k_0, \ldots, k_n$ for the given photodetector spectral response is central to this technique. We calculated the coefficients of the function using the least squares method for color indices of artificial stars.[1] We created spectra of artificial stars on the basis of reddening of typical subclass spectra without interstellar extinction, with such spectra taken from the Pickles[4] catalog. We selected the thickness of the interstellar medium for reddening based on random law.

The technique described allows us to evaluate instrument stellar magnitudes for silicon photodetectors, as well as the technique's error based on data from the photometric star catalogs

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2MASS and Tycho-2. Using the method of error estimation suggested, we found that the mean square deviation of the error of instrument stellar magnitudes is 0.05–0.07m (see Figure 5). Consequently, we suggest the technique may be used to compile high-precision guide catalogs for star trackers. Using the 2MASS catalog data, the number of stars below 7.0m in the guide catalog of a star tracker grows by 30% as against the use of data from the Tycho-2 catalog only.

Our next step is to test the technique on a tracker with a smaller field of view. Sternberg Astronomical Institute has used our method to create a guide star catalog for a tracker with a two degree field of view that it is developing. The tracker's anticipated accuracy of attitude determination is 0.1 arcseconds, for which the developers required a catalog of 9.0–11.0m stars. Testing of the tracker is ongoing.

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