Characterizing Chromatic Effects in Small Star Trackers

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1. Overview

1.1. Motivation and Objectives

- Star trackers are sensitive to color of incident light. Two primary effects:
  - Dim stars harder to see due to a color dependent change in the size of the star image, and
  - Attitude determination affected by color dependent change in the position of the star

- Paper presents strategies to characterize, validate, and optimize the performance of satellite instruments.

1.2. Lens Characteristics

- Chromatic aberration has two primary effects:
  - Image-level: change in star size and shape
  - Calibration-level: change in star position

- Knowing the magnitude of these effects is useful in many stages of star tracker design.

2. Stellar Spectra and Classification

- Stellar spectra are classified by:
  - Type (O,B,A,F,G,K,M)/subtype (1-10), which denote the temperature of the star, and
  - Luminosity (I-VI), a measure of the star's intrinsic brightness.

3. Star Catalogs

- Star catalogs are populated to ensure sufficient star detections in every scene.

4. Lens Characterization

- Chromatic aberration effects:
  - Image-level: change in star size and shape
  - Calibration-level: change in star position

- Knowing the magnitude of these effects is useful in many stages of star tracker design.

- Lab-based characterization compares response using a motorized gimbals, a broadband star source, and a set of 5 color filters (see Table 1).

5. Lens Characterization (cont.)

- Calibration of the lens (ACA, Focus)

- Some measure of star brightness (e.g. Vmag)

- Orbital data can be used to refine predictions.

6. Star Vector Error

- Using the computed change of the lens' focal length, \( \delta f_L \), from Table 1, we can predict a net change in the focal length of the lens for any given star with a known stellar spectral type.

- Convert the spectrum's energy flux to photon flux, \( P(\lambda) \).

- Calculate the normalized photoelectric response, \( R(\lambda) \), by conolving \( P(\lambda) \) with the detector's QE and normalizing.

- Calculate the spectral focal length shift, \( \delta f_L \), by convolving measured focal length shift of the lens, \( \delta f_L \), with \( R(\lambda) \).

- Integrate \( R(\lambda) \) to yield the net change in apparent focal length, \( \delta f_T \) for this spectrum.

- Yields a per-spectral correction to the change in focal length due to chromatic aberration.

- Broadband spectra not available for most stars, but color indices are.

- Use reference spectra to map predicted focal shifts to V-I color indices (Figure 6).

- Fitting this trend enables lookup of focal shift with V-I color index.

- Yields per-star correction to change in focal length.

7. Results from On-Orbit Sensors

- Changes are simple: after matching, recalibrate star vectors using star-specific focal lengths.

- Recalibration optimizes \( f_0 \) to minimize RMS errors in angles between stars.

- 12 datasets collected from 6 sensors (1 cal, 1 val, per unit).

- Error ratios between corrected and uncorrected residuals show significant effectiveness.

- Most sensors see improvements of 3-5% RMS.

- Results strongly dependent on stars within the dataset.

- Secondary metric looks at the effect of correction on the magnitude of the arc-length error (last column of Table 2).

8. Conclusions

- Star spectra combine with lens characteristics to alter the brightness, placement and appearance of imaged stars.

- We have presented models that allow designers to:
  - Predict instrument response to particular stars
  - Correct for the most significant chromatic effect.

- Depending on the set of stars in any particular batch of obs., corrections can yield RMS reductions of up to 15%.

- Approach easily adaptable to different sensor designs.