tjorven@arcsecspace.com

laila@arcsecspace.com

Abstract

Star trackers are the most accurate attitude estimation sensor. With current advancements in small satellite technologies, the pointing accuracy requirements are increasing for both commercial and scientific missions. CubeSpec is an in-orbit demonstration CubeSat mission to unravel the interior of massive stars using asteroseismology by high-cadance monitoring of the variations in spectral line profiles. This paper examines attitude estimation strategies for a multi-star tracker ADCS for CubeSpec mission. The new methodologies are tested with both simulation and hardware-in-the-loop night sky tests. The proposed solution, improves both availably and accuracy of the attitude estimates specially during the daylight section.

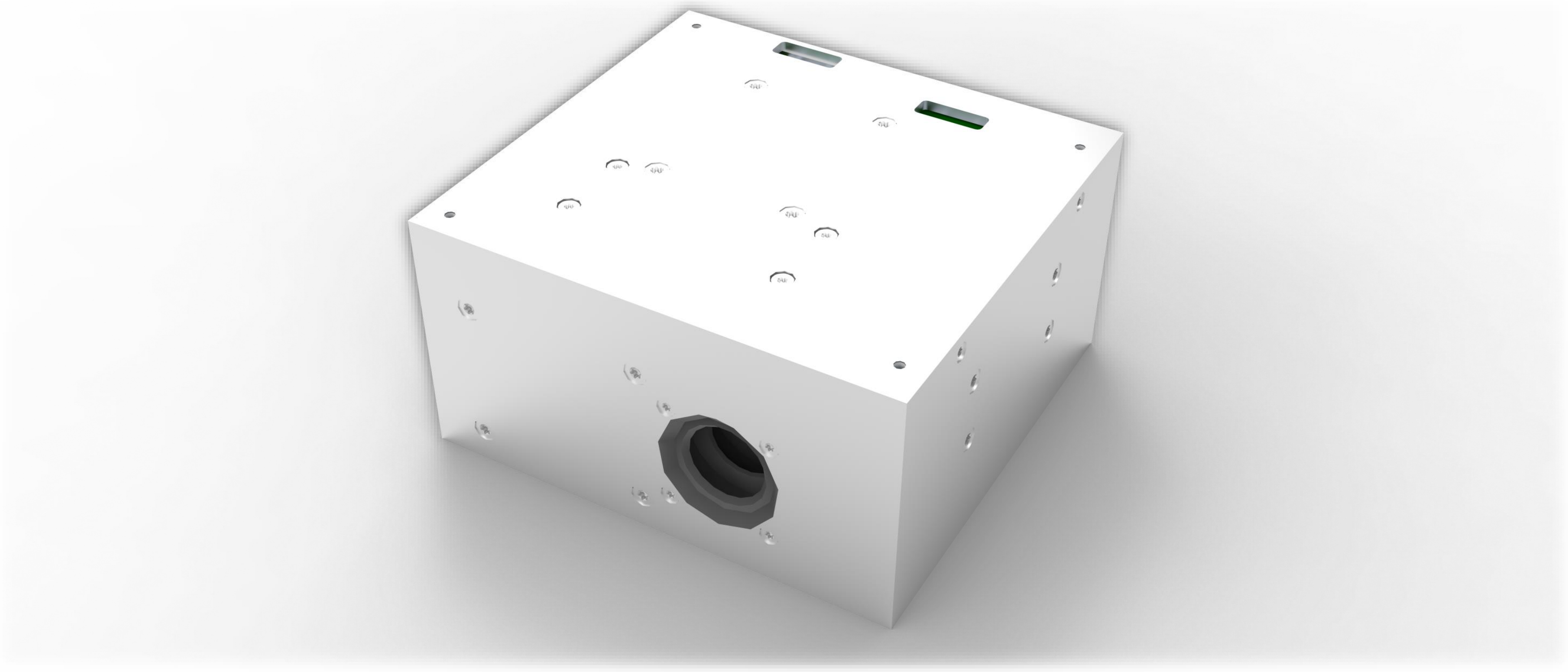

Fig 1: Arcus ADCS

Star Tracker Attitude Estimation

Star tracker provides accurate attitude measurements as a quaternion with two major drawbacks:

1. Availability is restricted when bright celestial objects are within the field of view such as the Sun or Earth
2. Accuracy of the boresight axis is lower than the cross-boresight axes

→ A system of multiple star trackers mounted at different angles remedies both drawbacks.

→ Requires fusing algorithms to obtain optimal overall attitude solution

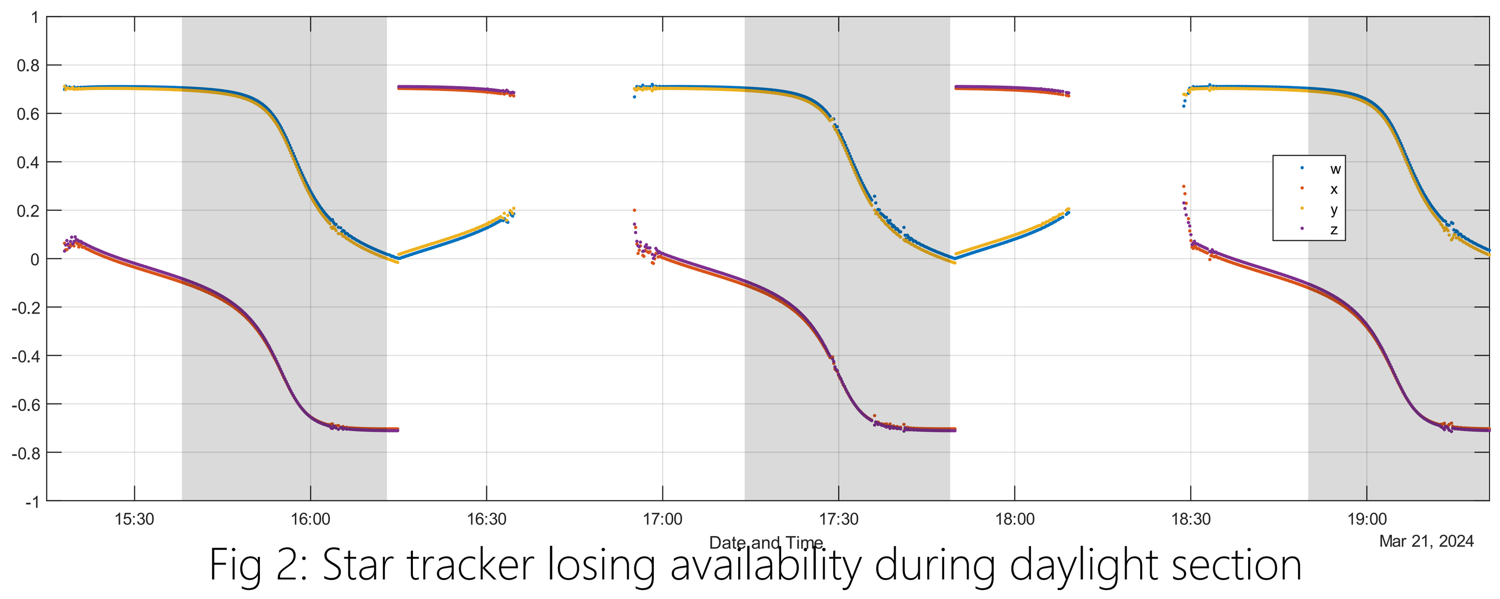

Fig 2: Star tracker losing availability during daylight section

Fusing algorithms – comparison

	QAVG	MEKF	AQEKF	PAD
Name	Quaternion Averaging	Multiplicative Extended Kalman Filter	Attitude Q-method Extended Kalman Filter	Prediction Attitude Determination
Principles	Preserves the normalization of quaternions	Prediction step based on estimated angular rate with kinematic model	Prediction step based on estimated angular rate with kinematic model	Preserves the normalization of quaternions
	Single time step fusing of quaternions	Update step based on small angle deviation with measurements	Update step based on averaging of measurements (similar to QAVG)	Combines prediction and update step by correcting model directly with the measurements in single step
Initialization	No initial condition	Initial estimate required	Initial estimate required	Initial estimate required
Features	Neglects time difference between measurements → Easier, but loss of information	Estimation of non-attitude states (attitude is not a state, but deviation is) → Avoids singularities	Direct estimation of quaternion without linearization in update step	Uses star vectors → ST can also contribute without having an individual attitude solution
Solving method	Maximum likelihood principle	Prediction step and first-order approximation update step with ST measurements	Maximum likelihood solution of both prediction step and update with measurements	Minimal model error propagation with vector measurements

arcsec Star Trackers

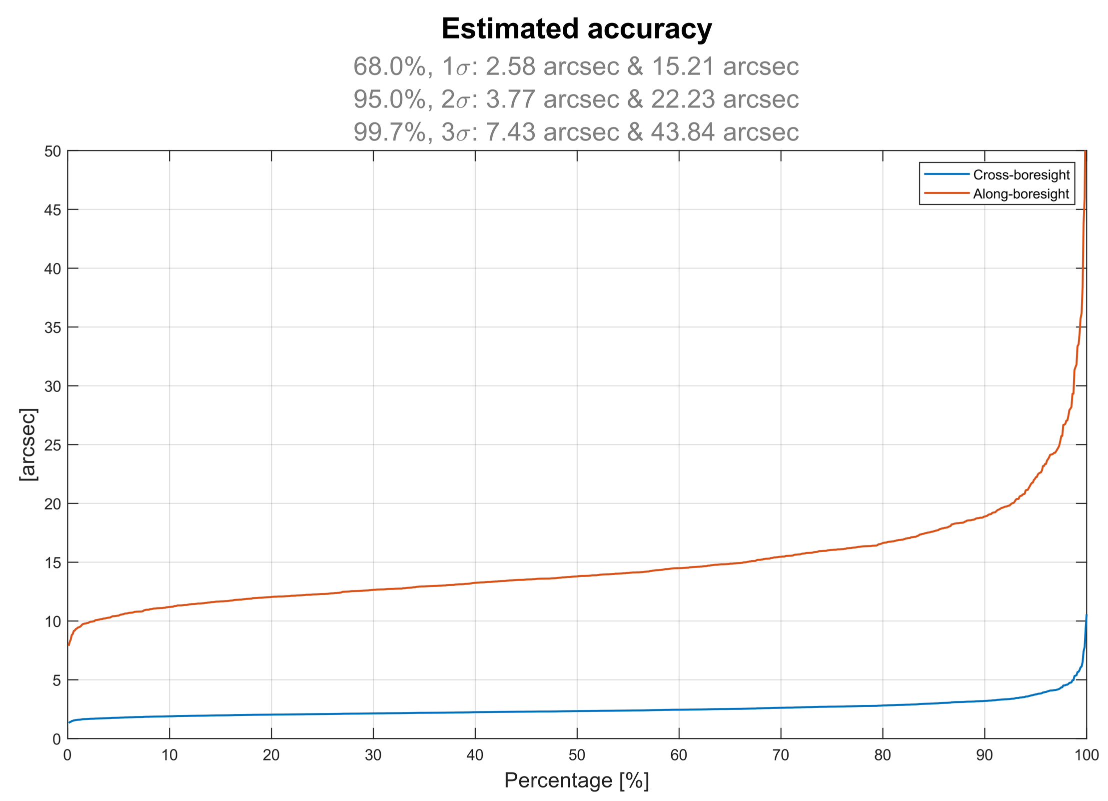

Fig 5: Sagitta star tracker On-orbit performance accuracy

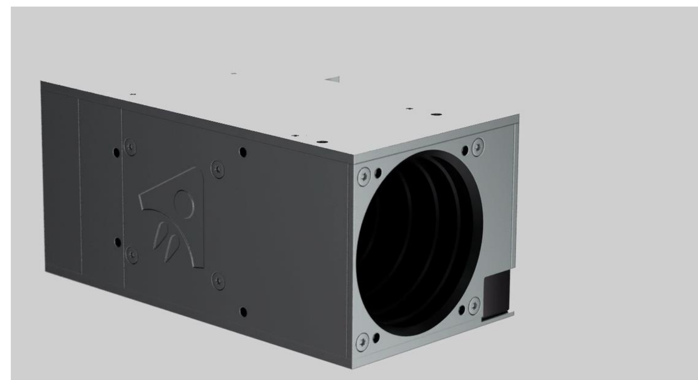

Fig 3: Sagitta star tracker

Fig 4: Twinkle star tracker

Results

All methods reduce the total Euler angle error and benefit from the 90° mounting configuration

Max reduction in Euler angle error by the MEKF and AQEKF (69.1% ↓)

→ Benefit of filtering effect of prediction step which is not present in the QAVG

Error of QAVG is equal to the only available cross-boresight axis

No reduction of noise for *z*-axis by attitude fusing algorithms

→ Overestimation of the Twinkle modelled noise variance around that axis

NEES probability of PAD is lower (less consistent and poorer estimation of the noise variance)

Algorithm	Euler angle error ["]	*x*-error ["]	*y*-error ["]	*z*-error ["]	NEES probability [%]
Sagitta	20.25	19.91	3.40	1.43	61.30
Twinkle	63.35	6.58	63.00	1.28	67.90
QAVG	7.30	6.32	3.40	1.38	74.00
MEKF	6.26	5.35	2.96	1.33	78.00
AQEKF	6.26	5.35	2.96	1.33	78.00
PAD	6.28	6.12	1.04	1.18	61.71

In-orbit demonstration

To demonstrate arcsec's fusing library Cerberus, an in-orbit demonstration mission will be launched in January 2026. The product involves four Twinkle star trackers under different angles (see Fig. 6) and with different external baffles. These baffles are designed to reduce the sun exclusion angle from 80° to between 15° and 35° (respectively for the longest and shortest baffle). The performance of the individual star trackers and the different fusing algorithms will be demonstrated during this mission, including the attitude knowledge accuracy, rate resilience and the in-orbit exclusion angles. The four Twinkles are connected to an interface board which controls the Twinkles and runs the fusing algorithms.

Fig 6: In-orbit demonstration of 4 star trackers

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