STAR SENSOR SPECIFICATION STANDARD

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Abstract

In recent years there have been rapid developments in star tracker technology, in particular with great increases in the level of sensor autonomy and the associated capabilities. The variety of sensors now available, combined with the complex on-board algorithms, has led in general to disparate and manufacturer-specific sets of performance specifications, making it difficult or impossible to compare sensors. A standard has now been prepared, covering areas such as nomenclature, definitions, performance metrics etc., for the performance specification of Star Sensors. This will allow consistent description of, and direct comparison between, the performance of devices from differing manufacturers. The approach taken in the standard is, as far as possible, consistent with the content of the ESA Pointing Error Handbook [1]. The formal definitions provided are augmented with specific examples of manufacturer's data sheets and user specifications in order to aid application of the standard in the industrial context.

1 Introduction & Background

In recent years there have been rapid developments in star tracker technology, in particular the emergence of autonomous devices with the ability to provide an inertially-referenced attitude quaternion output starting from a 'lost-in-space' condition. The variety of sensors now available, combined with the complexity of on-board algorithms and the use of multi-head devices, has led in general to disparate and manufacturer-specific sets of performance specifications. This has made it difficult or impossible to compare sensors based on manufacturer's data, and has also led to differing approaches by users when developing sensor specifications for particular missions, which will in general dictate unique sets of operating conditions.

The problem can be illustrated by considering, as an example, specifying the accuracy of the output attitude quaternion. The achievable accuracy depends on a large number of conditions, including:

- The number of stars in the field of view, governed by the observed area in the celestial sphere and hence the sensor attitude.
- Angular proximity to the Sun and other solar system bodies.
- Spacecraft body rates in sensor axes.
- Lunar or planetary intrusion into the sensor FOV.
- The precise definition of the statistical metrics used to specify the performance.

This wide range of conditions leads to a variety of accuracy specifications depending on both the sensor type and the conditions which apply to its intended use.

In order to address these issues, the Star Sensor Specification Standard has been produced by Analyticon under contract to ESTEC. The Standard provides a set of standard star sensor terminology, sensor capabilities, standardised outputs, performance specification definitions and performance conditions. This provides a framework for the performance specification of both traditional and autonomous generations of star sensors, allowing performance metrics (such as the accuracy of the output attitude quaternion) to be described in a consistent way with well-understood and well-defined sets of conditions. The standard has been developed in close collaboration with industry, covering both manufacturers and users of star sensors, and is intended to allow consistent classification and performance specification of different sensor types. This, it is hoped, will facilitate comparison of performance between devices from different manufacturers, thus enabling users to make more meaningful comparisons, trade-offs and sensor selections.

2 Development of the Standard

The approach adopted in the development of the Standard, together with an overview of the areas addressed, are summarised in Figure 1. The key areas are described in more detail in the following sections. The production of the Standard began with a review of existing specifications and

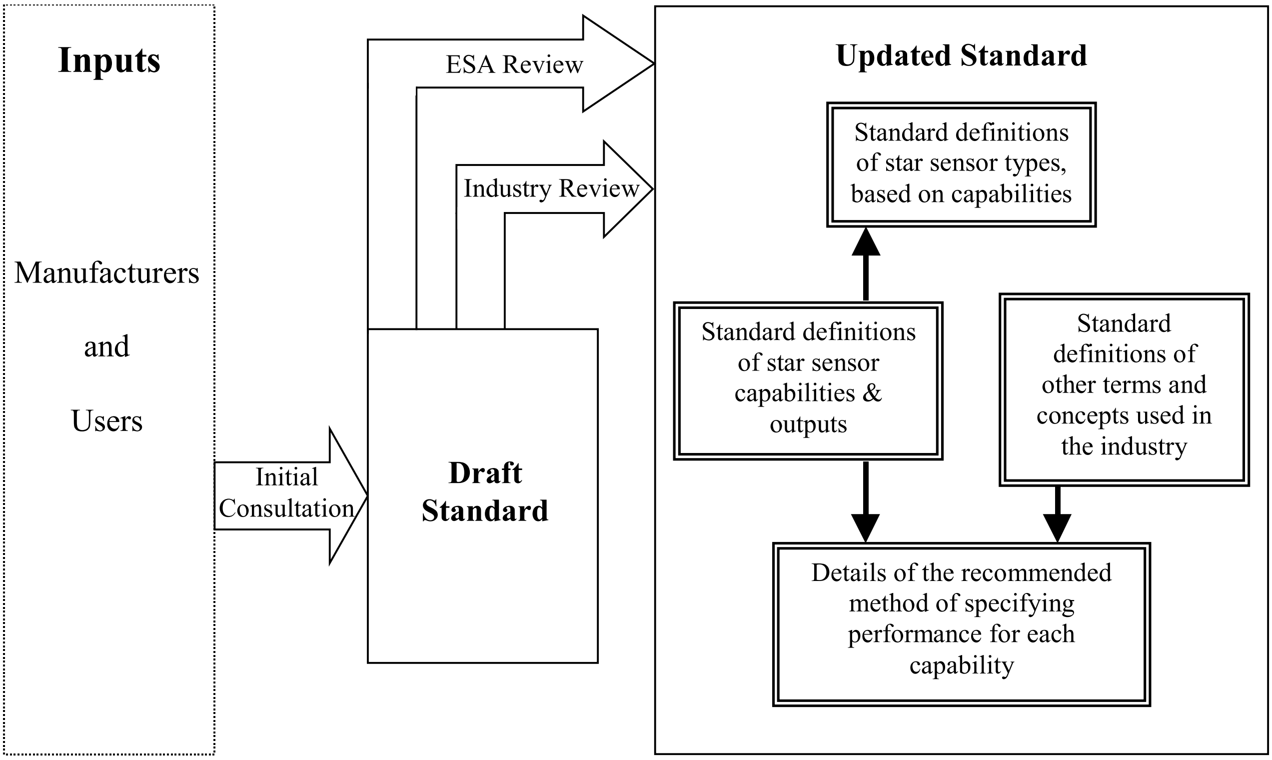

Figure 1: Summary of Star Sensor Specification Standard

nomenclature, where available, for existing sensors and for previous ESA missions. Manufacturers and users of star sensors were consulted in order to determine which terms were in current use and to identify existing common ground and areas of contention. This was considered essential since, in order to achieve widespread uptake within industry, the standard should reflect not only the desires of the users but also provide a framework that provides a specification verifiable by manufacturers with their current in-house test capabilities.

A first draft of the standard was then created with the intention to be flexible enough to allow past, present and future star sensor developments to be easily described and categorised within the new framework. This draft document was made available to companies that took part in the study and also published on the ESA web site. A period of industry review followed, where manufacturers and users were invited to comment on the draft specifications. After completion of this process an updated document was produced which included the ideas and comments made during the review.

3 Areas Covered by the Standard

The Star Sensor Specification Standard includes standardised definitions in the following areas:

3.1 Definition of Sensor Outputs

A standard set of outputs which might be generated by a star sensor are defined. These outputs, such as the attitude quaternion, are then used as the basis for defining star sensor capabilities and types.

3.2 Definition of Capabilities

A standard set of potential capabilities applicable to star sensors is defined. For each capability, the mandatory and optional sensor outputs are listed. This set of standardised capabilities (which are summarised as part of Table 1) attempts to cover the functionality of both present and perceived future star sensor developments, and provides a basis for the definition of standardised sensor types.

3.3 Definition of Sensor Types

A number of standard types of star sensor are defined, each with a standard nomenclature. The classification of star sensors into different types is based on the definition of a set of mandatory capabilities and a set of optional capabilities for each type.

Table 1 summarises the defined set of capabilities, together with the standard star sensor types and the mandatory and optional capabilities required by a sensor of each type.

	Cartography	Star Tracking	Autonomous Star Tracking	Autonomous Attitude Determination	Autonomous Attitude Tracking	Independent Rate measurement	(Partial) Image Download
Star Camera	X						(X)
Star Tracker	X	X	(X)				(X)
Autonomous Star Tracker	X	(X)	(X)	X	X	(X)	(X)

Key: X = Mandatory, (X) = Optional

Table 1: Capabilities of Different Star Sensor Types

3.4 Definition of Other Terms

Standard definitions are also provided for other terms and concepts that are used in characterising sensor performance, such as standardised reference frame definitions, component parts of the star sensor, and standard time definitions (e.g. measurement time, integration time and latency) – even these types of definition are currently highly non-standard across industry.

3.5 Definition of Generalised Performance Metrics

Standard generalised measurement error metrics are introduced, based on (and consistent with) concepts defined in the ESA Pointing Error Handbook [1]. Furthermore, following the approach of the Pointing Error Handbook, the statistical interpretations to be applied in using these metrics are also defined. The new definitions are perhaps more abstract than previously, and so the link between the new definitions and traditional metrics (such as bias, noise equivalent angle etc.) is also discussed in the standard.

Schematically, for the case of a fixed true attitude, the meaning of the following metrics is illustrated in Figure 2 for the case of a rotation about a single axis (with a typical traditional equivalent metric also indicated):

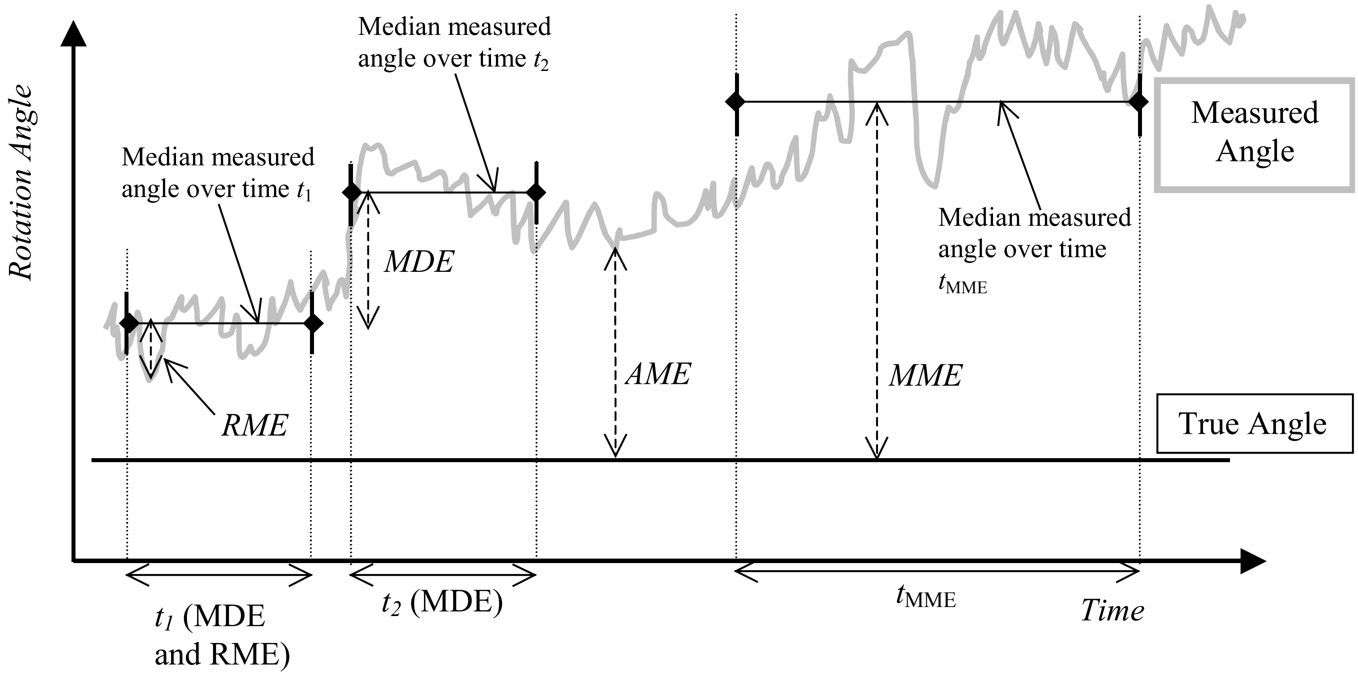

Figure 2: Schematic Definition of Generalised Performance Metrics

- Absolute Measurement Error (AME) – “Total Accuracy”.
- Median Measurement Error (MME) – “Bias”.
- Measurement Drift Error (MDE) – “Bias stability”.
- Relative Measurement Error (RME) – “Noise equivalent angle”

Some of these metrics are defined with associated time periods. In these cases, the errors are defined relative to a median rotation over the relevant period, as illustrated in the figure.

The application of the measurement error metrics to star sensor measurements is defined in the standard, and is applied to both star position measurements (in sensor frames) and inertially referenced attitude quaternion measurements.

3.6 Recommendations for Specifying Performance

For each star sensor capability and for each output (where appropriate), a detailed description of the recommended metrics used to specify sensor performance is given, for use by users when formulating mission-specific specifications. The description typically consists of the following:

- A detailed description of the sensor outputs for the capability, including the recommended parameterisation.

Capability:	**Autonomous Attitude Determination**
Mandatory Outputs:	1. Attitude quaternion between the Boresight Reference Frame and the Inertial Reference Frame 2. Measurement Time 3. Validity Index
Performance Metrics	1. Attitude AME_q, MME_q, RME_q and MDE_q 2. Attitude Determination Probability 3. Attitude Determination Time 4. Measurement Time Error 5. Measured Output Bandwidth
Examples of conditions **(for AME_q as an example metric)**	• *Conditions assumed as worst case:* 1. Worst-case direction in celestial sphere 2. Worst-case baseplate temperature within specified range 3. Worst-case straylight from solar, lunar, Earth, planetary or other sources
	• *Conditions defined in specification:* 1. Maximum body rates about the sensor boresight reference frame 2. Whether the moon is in the field of view 3. Whether planetary objects are in the field of view
Examples of conditions **(for Attitude Determination Probability as an example metric)**	• *Conditions assumed as worst case:* 1. Worst-case baseplate temperature within specified range 2. Worst-case straylight from solar, lunar, Earth, planetary or other sources
	• *Conditions defined in specification:* 1. The maximum body rates about the sensor boresight reference frame 2. Whether the moon is in the field of view 3. Whether planetary objects are in the field of view 4. The maximum number of false stars in the field of view for which the specification must be satisfied

Table 2: Example Outputs, Metrics and Conditions

- The performance metrics to be used to specify performance for each output and, where appropriate, the confidence levels and statistical interpretation to be used.
- The conditions for which performance should be specified. This consists both of conditions which should be taken as ‘worst-case’ and conditions which should be explicitly defined within the standard.
- A description, where applicable, of the error sources that are expected to contribute to performance in that area.
- Types of test and analysis recommended in order to verify performance against the specification.
- An example of the recommended requirement specification.

An example capability, together with the associated outputs and performance metrics, is shown in Table 2 This table also shows examples of the definition of conditions, both those taken as ‘worst-case’ and those to be defined in the specification. By way of illustration, example requirement specifications for the cases in the table are as follows:

- The star sensor shall have an AME_q (X, Y axes rotation) of less than 10 arcsec at rates about any axis of up to 10 deg/s at end of life with the Moon in the field of view.
- The probability of correct attitude determination shall be greater than 99% for random initial pointings within the entire celestial sphere with up to 10 false stars in the field of view, for rates about any axis of up to 100 arcsec/s at end of life.

Conditions not quoted in the specification take worst-case values by default according to the definitions in the standard.

3.7 Example Data Sheet

The Star Sensor Specification Standard also includes an example data sheet giving the recommended method of specifying the type and performance of a star sensor. This is intended to provide a standalone, mission-independent statement of performance that, however, still contains enough information to allow an assessment of performance to be made under varying sets of conditions.

4 Status of the Project and the Way Forward

A formal issue of the Star Sensor Specification Standard has now been produced following industry review of the draft version. It is hoped that the information contained in this standard will enjoy widespread acceptance within industry, and will allow a consistent approach to the performance specification of star sensors to emerge that will yield significant benefits to both users and manufacturers of these sensors.

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References

[1] ‘ESA Pointing Error Handbook’
Produced under ESTEC Contract No.07 WKA
ESA-NCR-502 Issue 1 19 February 1993

[1] The acknowledgement does not imply the endorsement of the document by the companies/organisations mentioned.