Autonomous Vehicle Simulation (AVS) Laboratory, University of Colorado

Basilisk Technical Memorandum

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SUN POINTING USING A BODY-RELATIVE SUN DIRECTION VECTOR AND RATE GYRO INFORMATION

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Status: Released

Scope/Contents

This module provides the attitude guidance output for a sun pointing mode. This could be used for safe mode, or a power generation mode. The input is the sun direction vector which doesn't have to be normalized, as well as the body rate information. The output is the standard BSK attitude reference state message. The sun direction measurement is cross with the desired body axis that is to point at the sun to create a principle rotation vector. The dot product between these two vectors is used to extract the principal rotation angle. With these a tracking error MRP state is computer. The body rate tracking errors relative to the reference frame are set equal to the measured body rates to bring the vehicle to rest when pointing at the sun. Thus, the reference angular rate and acceleration vectors relative to the inertial frame are always set to zero.

Rev	Change Description	By	Date
1.0	First Documentation of this module, even though the module was one of the first BSK modules drafted.	H. Schaub	2018-04-28

Contents

1 Model Description

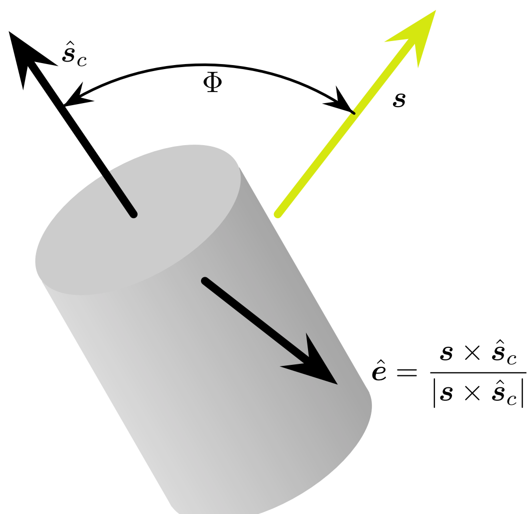

Fig. 1: Body Vector Illustrations.

1.1 Module Goal

This attitude guidance module has the goal of aligning a commanded body-fixed spacecraft vector $\hat{s}_c$ with another input vector s. If $\hat{s}_c$ is for example the solar panel normal vector, and s is the current sun heading vector, this module will compute the attitude tracking errors to align the solar panels towards the sun, i.e. achieve sun pointing. Sun pointing is a mode for general recharging the spacecraft, but is also a common guidance scenario with Safe Mode.

Besides $\boldsymbol{s}$, the second input vector is the inertial body angular velocity vector $\boldsymbol{\omega}_{B/N}$. The sun pointing frame is assumed to be at rest, thus the attitude rate tracking error is set equal to the body rates.

As the desired sun pointing orientation is inertial, the inertial reference frame rate $\boldsymbol{\omega}_{R/N}$ and acceleration $\dot{\boldsymbol{\omega}}_{R/N}$ are set to zero.

Note that this module does not establish a unique sun-pointing reference frame. Rather, the pointing condition, align $\hat{\boldsymbol{s}}_c$ with $\boldsymbol{s}$ is an under-determined 2 degree of freedom condition. Thus, the rotation angle about $\boldsymbol{s}$ is left to be arbitrary in this sun pointing module. For the sun pointing applications this is a very practical result as the power generation does not depend on the orientation about $\boldsymbol{s}$.

1.2 Equations

In the following mathematical developments all vectors are assumed to be taken with respect to a body-fixed frame $\mathcal{B}$. The attitude of the body $\mathcal{B}$ relative to the reference frame $\mathcal{R}$ is written as a principal rotation from $\mathcal{R}$ to $\mathcal{B}$. Thus, the associated principal rotation vector $\hat{\boldsymbol{e}}$ is

$$\hat{\boldsymbol{e}} = \frac{\boldsymbol{s} \times \hat{\boldsymbol{s}}_c}{|\boldsymbol{s} \times \hat{\boldsymbol{s}}_c|} \tag{1}$$

Note that the sun direction vector $\boldsymbol{s}$ does not have to be a normalized input vector.

The principal rotation angle between the two vectors is given through

$$\Phi = \arccos(\boldsymbol{s} \cdot \hat{\boldsymbol{s}}_c) \tag{2}$$

Next, this rotation from $\mathcal{R}$ to $\mathcal{B}$ is written as a set of MRPs through

$$\boldsymbol{\sigma}_{B/R} = \tan\left(\frac{\Phi}{4}\right)\hat{\boldsymbol{e}} \tag{3}$$

The set $\boldsymbol{\sigma}_{B/R}$ is the attitude error of the output attitude guidance message.

The tracking error angular velocity vector is set equal to the measure body rates to bring the spacecraft to rest when pointing in the desired direction.

$$\boldsymbol{\omega}_{B/R} = \boldsymbol{\omega}_{B/N} \tag{4}$$

Finally, the attitude guidance message must specify the inertial reference frame rates and acceleration vectors. These are all set to zero.

$$\boldsymbol{\omega}_{R/N} = \mathbf{0} \tag{5}$$

$$\dot{\boldsymbol{\omega}}_{R/N} = \mathbf{0} \tag{6}$$

2 Module Functions

- **Compute the attitude tracking error**: Determines the shortest rotation to align $\boldsymbol{s}$ and $\hat{\boldsymbol{s}}_c$, and computes the corresponding three-dimensional attitude difference

- **Bring spacecraft to rest**: The reference frame is assumed to be at rest and non-accelerating.

3 Module Assumptions and Limitations

The module input vector $\boldsymbol{s}$ can be a vector of any length except for a zero-length vector. The commanded body-relative unit direction vector $\boldsymbol{s}_c$ is assumed to be fixed relative to the body.

4 Test Description and Success Criteria

The mathematics in this module are straight forward and can be tested in a series of input and output evaluation tests.

4.1 Check 1

Here a check is performed where the sun vector measurement $\boldsymbol{s}$ has a non-zero length and is not aligned with $\hat{\boldsymbol{s}}_c$.

5 Test Parameters

The unit test verify that the module output guidance message vectors match expected values.

Table 2: Error tolerance for each test.

Output Value Tested	Tolerated Error
$\boldsymbol{\sigma}_{B/R}$	1e-12
$\boldsymbol{\omega}_{B/R}$	1e-12
$\boldsymbol{\omega}_{R/N}$	1e-12
$\dot{\boldsymbol{\omega}}_{R/N}$	1e-12

The nominal module test input values are $\hat{\boldsymbol{s}}_c = (0, 0, 1)$, $\boldsymbol{s} = (1, 0, 0)$ and ${}^{\mathcal{B}}\boldsymbol{\omega}_{B/N} = (0.01, 0.50, -0.20)$ rad/sec.

6 Test Results

All of the tests passed:

Table 3: Test results

Check	Pass/Fail
1	PASSED

7 User Guide

The module has 2 required input messages:

- `inputSunVecName` – This message, of type `NavAttIntMsg`, received the sun heading vector $\boldsymbol{s}$
- `inputIMUDataName` – This message, of type `IMUSensorBodyFswMsg`, received the inertial angular body rates $\boldsymbol{\omega}_{B/N}$

The module has the following parameter that can be configured:

- `sHatBdyCmd` – [REQUIRED] This 3x1 array contains the commanded body-relative vector $\hat{\boldsymbol{s}}_c$ that is to be aligned with the sun heading $\boldsymbol{s}$
- `minUnitMag` – This double contains the minimum norm value of $\boldsymbol{s}$ such that a tracking error attitude solution $\boldsymbol{\sigma}_{B/R}$ is still computed. Default value is zero.