Autonomous Vehicle Simulation (AVS) Laboratory, University of Colorado

Basilisk Technical Memorandum

Document ID: Basilisk-dvGuidance

ATTITUDE GUIDANCE DURING ORBIT BURN

Prepared by	H. Schaub

Status: First Release
Scope/Contents
This module creates a time varying attitude reference frame message that allows the orbit correction burn direction to rotate at a constant rate. A message is read in containing the base Δv direction, the burn duration, as well as a nominal rotation axis. A base burn frame is created relative to which a constant rotation about the 3rd frame axis is performed. The output message contains the full reference frame states including the constant angular velocity vector and a zero angular acceleration vector.

Rev	Change Description	By	Date
1.0	Initial Release	H. Schaub	2019-03-28

Contents

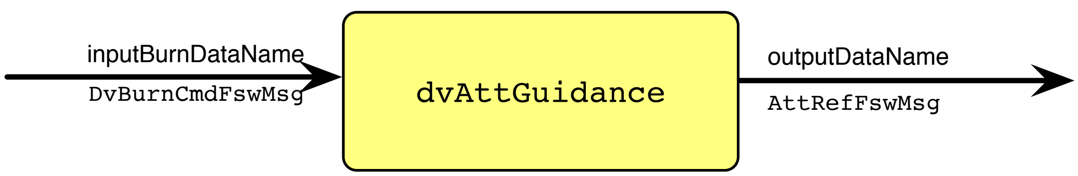

Fig. 1: Illustration of the module input and output messages.

1 Model Description

1.1 General Functionality

The purpose of this module is to create an attitude reference frame suitable for an orbit trajectory correction burn that has a constantly rotating direction. Assume the initial burn direction is given by $\Delta \boldsymbol{v}$ as illustrated in Figure 2. The module assumes that the burn direction is always along the current reference frame 1 axis. If this is not the case, the `attTrackingError` module can be setup to align a different body frame with $\mathcal{R}$.

While the following developments are done in a vectorial manner, all vector components are assumed to be taken with respect to a common inertial frame.

1.2 Base Burn Frame Definition

The current burn frame is developed in a two-stage process. First a base frame is developed which is then rotated about the 3rd axis. Let $\mathcal{B}_{u,b} = \{\hat{\boldsymbol{b}}_{u_b,1}, \hat{\boldsymbol{b}}_{u_b,2}, \hat{\boldsymbol{b}}_{u_b,3}\}$ be the inertially fixed base burn frame. The DCM of $\mathcal{B}_{u,b}$ relative to an inertial frame $\mathcal{N}$ is defined as

$$[B_{u,b}N] = \begin{bmatrix} {}^{\mathcal{N}}\hat{\boldsymbol{b}}^T_{u_b,1} \\ {}^{\mathcal{N}}\hat{\boldsymbol{b}}^T_{u_b,2} \\ {}^{\mathcal{N}}\hat{\boldsymbol{b}}^T_{u_b,3} \end{bmatrix} \tag{1}$$

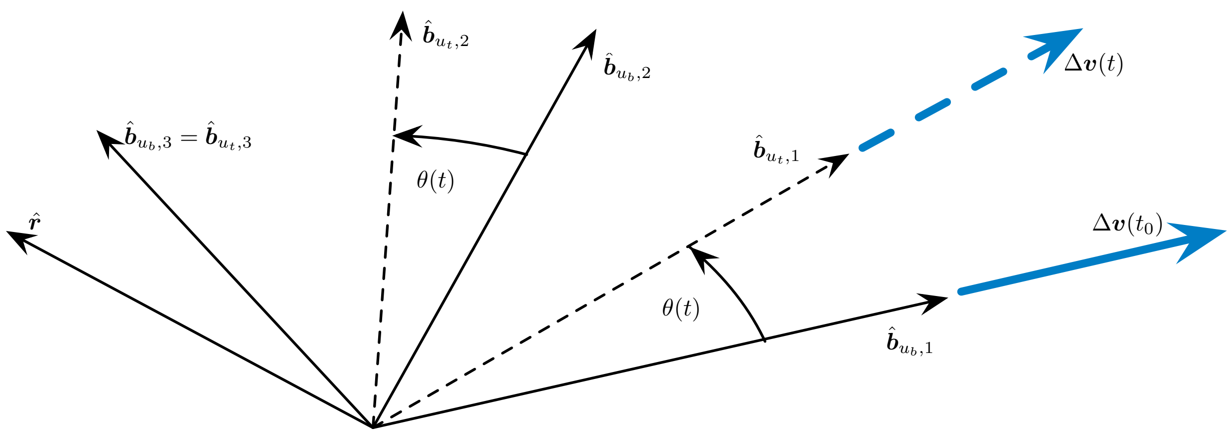

Fig. 2: Burn frame unit vector Illustration.

The first base vector is defined as the normalized $\Delta \boldsymbol{v}$ direction using

$$\hat{\boldsymbol{b}}_{u_b,1} = \frac{\Delta \boldsymbol{v}}{|\Delta \boldsymbol{v}|} \tag{2}$$

To create a full three-dimensional reference frame, a vector $\hat{\boldsymbol{r}}$ is provided in the input message. The second base Burn frame vector is then defined as

$$\hat{\boldsymbol{b}}_{u_b,2} = \frac{\hat{\boldsymbol{r}} \times \Delta \boldsymbol{v}}{|\hat{\boldsymbol{r}} \times \Delta \boldsymbol{v}|} \tag{3}$$

The final base frame vector is then defined as

$$\hat{\boldsymbol{b}}_{u_b,3} = \frac{\hat{\boldsymbol{b}}_{u_b,1} \times \hat{\boldsymbol{b}}_{u_b,2}}{|\hat{\boldsymbol{b}}_{u_b,1} \times \hat{\boldsymbol{b}}_{u_b,2}|} \tag{4}$$

Note that if $\hat{\boldsymbol{r}}$ and $\Delta \boldsymbol{v}$ are orthogonal to begin with, then $\hat{\boldsymbol{r}} = \hat{\boldsymbol{b}}_{u_b,3}$. In this case the $\hat{\boldsymbol{r}}$ vector defines the axis about which the $\Delta \boldsymbol{v}$ vector will rotate.

1.3 Burn Time

The input message contains a time tag t_{start} when the $\Delta \boldsymbol{v}$ burn is to begin. The time since this start time is thus evaluated using

$$\Delta t = t - t_{\text{start}} \tag{5}$$

where t is the current time. A negative signed Δt is a valid burn duration and corresponds to a rotation towards the nominal attitude at the start of the burn.

1.4 Current Burn Frame

The current burn frame is defined as $\mathcal{B}_{u,t} = \{\hat{\boldsymbol{b}}_{u_t,1}, \hat{\boldsymbol{b}}_{u_t,2}, \hat{\boldsymbol{b}}_{u_t,3}\}$. It differs from the base burn frame through a third base-frame axis rotation. The rotation rate $\dot{\theta}$ is given in the input message as `dvRotVecMag`. The current angle θ is

$$\theta(t) = \dot{\theta} \Delta t \tag{6}$$

The DCM going from the base to the current burn frame is

$$[B_{u,t} B_{u,b}] = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{7}$$

The final output reference frame is then computed as

$$[RN] = [B_{u,t}N] = [B_{u,t}B_{u,b}][B_{b,t}N] \tag{8}$$

which is mapped into the equivalent $\boldsymbol{\sigma}_{R/N}$ MRP set for the output message.

The reference frame angular velocity vector is computed as follows. Note that because $\mathcal{B}_{u,b}$ is inertially fixed then $\boldsymbol{\omega}_{B_{u,b}/N} = \mathbf{0}$. The angular velocity vector between the current and the base burn frame is

$$\boldsymbol{\omega}_{B_{u,t}/B_{u,b}} = \dot{\theta}\hat{\boldsymbol{b}}_{u_b,3} = \dot{\theta}\hat{\boldsymbol{b}}_{u_t,3} \tag{9}$$

The desired inertial reference frame vector is then given by

$$\boldsymbol{\omega}_{R/N} = \boldsymbol{\omega}_{B_{u,t}/N} = \boldsymbol{\omega}_{B_{u,t}/B_{u,b}} + \boldsymbol{\omega}_{B_{u,b}/N} = \dot{\theta}\hat{\boldsymbol{b}}_{u_t,3} \tag{10}$$

As $\dot{\theta}$ is constant and $\hat{\boldsymbol{b}}_{u_t,3}$ is inertially fixed, the reference angular acceleration is zero.

$$\dot{\boldsymbol{\omega}}_{R/N} = \dot{\boldsymbol{\omega}}_{B_{u,t}/N} = \mathbf{0} \tag{11}$$

2 Module Functions

- **Read in Δv information**: The nominal Δv maneuver information is read in to establish a base burn reference frame
- **Allow for a constant rotation**: The reference frame is rotated at a constant rate during the burn duration.

3 Module Assumptions and Limitations

The module assumes the rotation rate is constant. Further, the burn direction is assumed to be along the first reference frame axis.

4 Test Description and Success Criteria

The unit test computes setups up a sample Δv maneuver message and runs the module for 3 time steps. This ensures that the $\theta(t)$ angle updates are occurring correctly.

5 Test Parameters

The test sets up ${}^{\mathcal{N}}\Delta\boldsymbol{v} = [5, 5, 5]$ m/s while ${}^{\mathcal{N}}\hat{\boldsymbol{r}} = [1, 0, 0]$. The commanded reference frame rotation rate is 0.5 rad/sec, and the burn start time is set to 0.5 seconds.

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

Table 2: Error tolerance for each test.

Output Value Tested	Tolerated Error
sigma_RN	1e-09
omega_RN_N	1e-09
domega_RN_N	1e-09

6 Test Results

All of the tests passed.

Table 3: Test results

Check	Pass/Fail
1	PASSED

7 User Guide

This section contains information directed specifically to users. It contains clear descriptions of what inputs are needed and what effect they have. It should also help the user be able to use the model for the first time.