Autonomous Vehicle Simulation (AVS) Laboratory, University of Colorado

Basilisk Technical Memorandum
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REACTION WHEEL MOTOR TORQUE

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Status: Tested
Scope/Contents
This module takes a desired torque vector and maps it to available reaction wheel torques. The optional wheel availability message is used to include or exclude particular reaction wheels from the torque solution. The desired control torque can be mapped onto particular orthogonal control axes to implement a partial solution for the overall attitude control torque.

Rev:	Change Description	By
v1.0	Initial Document	J. Martin
v1.1	Revision with enhanced module description	H. Schaub

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1 Model Description

1.1 Module Input and Output Behavior

As illustrated in Figure **??**, this module takes an attitude control torque $^{\mathcal{B}}\boldsymbol{L}_r$ and maps the vector onto the specific control axes, $\hat{\boldsymbol{c}}_i$. This allows only a subset of $^{\mathcal{B}}\boldsymbol{L}_r$ to be implemented with the Reaction Wheels (RWs). The next step is to map reduced control torque onto the available RW spin axes,$\hat{\boldsymbol{g}}_{s_j}$. The module accounts for the availability of the reaction wheels in the case that not all wheels are functioning appropriately or are undergoing independent analysis.

Assume in this documentation that the number of available RWs is m, while the number of desired control axes $\hat{\boldsymbol{c}}_i$ is n. The number of installed RWs is N.

The commanded torque message is a required input message and is read in every time step. The RW configuration message is also required, but only read in during reset. If the RW spin axes $\hat{\boldsymbol{b}}_{s_i}$ change then reset() must be called again. The RW availability message is optional. If the availability message is not used, then all installed RWs are assumed to be available. The output message is always the array of RW motor torques.

1.2 Torque Mapping

The `rwMotorTorque` module receives a desired attitude control torque in the body frame $^{\mathcal{B}}\boldsymbol{L}_r$. This torque is the net control torque that should be applied to the spacecraft. Let $\hat{\boldsymbol{g}}_{s_i}$ be the individual RW spin axis, while $\boldsymbol{u}_s$ is the m-dimensional array of motor torques. The $3 \times m$ projection matrix $[G_s]$ then maps the control torque on motor torques using

$$[G_s]\boldsymbol{u}_s = (-^{\mathcal{B}}\boldsymbol{L}_r) \tag{1}$$

The project matrix is defined as

$$[G_s] = \begin{bmatrix} \hat{\boldsymbol{g}}_{s_1} & \cdots & \hat{\boldsymbol{g}}_{s_m} \end{bmatrix} \tag{2}$$

Note that here $\boldsymbol{u}_s$ is the array of available motor torques. The installed set of RWs could be larger than m.

The projection matrix to map a vector in the body frame $\mathcal{B}$ onto the set of control axes $\hat{c}_i$ is given by

$$[CB] = \begin{bmatrix} {}^{\mathcal{B}}\hat{c}_1^T \\ \vdots \\ {}^{\mathcal{B}}\hat{c}_n^T \end{bmatrix} \tag{3}$$

where $n \leqslant 3$.

To map the requested torque onto the control axes, Eq. (1) is pre-multifplied by $[CB]$ to yield

$$[CB][G_s]\boldsymbol{u}_s = [CG_s]\boldsymbol{u}_s = [CB](-{}^{\mathcal{B}}\boldsymbol{L}_r) = {}^{\mathcal{C}}\boldsymbol{L}_r \tag{4}$$

Note that $[CG_s]$ is a $n \times m$ matrix.

The module assumes that $m \geqslant n$ such that there are enough RWs available to implement ${}^{\mathcal{C}}\boldsymbol{L}_r$. If not, then the output motor torques are set to zero with $\boldsymbol{u}_s = \boldsymbol{0}$.

To invert Eq. (4) a minimum norm solution is used yielding:

$$\boldsymbol{u}_s = [CG]^T \left([CG][CG]^T\right)^{-1} {}^{\mathcal{C}}\boldsymbol{L}_r \tag{5}$$

The final step is to map the array of available motor torques $\boldsymbol{u}_s$ onto the output array of installed RW motor torques.

1.3 RW Availability

If the input message `rwAvailInMsg` is linked, then the RW availability message is read in. The torque mapping is only used for RW's whose availability setting is `AVAILABLE`. If it is `UNAVAILABLE` then that RW output torque is set to zero.

2 Model Functions

The code performs the following functions:

- **Maps control torque vector onto available reaction wheels**: Takes a desired body-frame torque from `CmdTorqueBodyIntMsg` and maps it onto the RW axes.

- **Removes torque from unavailable reaction wheels**: The module observes the availability of the RWs and maps the torques to only available reaction wheels.

3 Model Assumptions and Limitations

This code makes the following assumptions:

- The number of available wheels must be equal or larger than the number of control axes. If this is not the case a zero output motor torque message is produced.

4 Test Description and Success Criteria

The unit test checks for proper functionality of the module for various numbers of control axes and reaction wheel configurations, both within and outside expected bounds. The test cases include permutations of:

1. Number of control axes set to 1, 2 or 3

2. Number of RW set to 2, 4 or the maximum allowable device number

3. The optional RW availability message set to:

- ("NO") – Message not provided
- ("ON") – Message is provided and all RWs are set to AVAILABLE
- ("OFF") – Message is provided and all RWs are set to UNAVAILABLE
- ("MIXED") – Message is provided and half of all RWs are set to UNAVAILABLE and the remainder are AVAILABLE.

5   Test Parameters

The unit test verify that the module's output reaction control torques match expectation.

Table 2: Error tolerance for each test.

Output Value Tested	Tolerated Error
rwMotorTorques	1e-08

6   Test Results

The unit test results are shown in Table 3. All tests should be passing.

Table 3: Test results

numControlAxes	numWheels	RWAvailMsg	Pass/Fail
1	2	NO	PASSED
2	2	NO	PASSED
3	2	NO	PASSED
1	4	NO	PASSED
2	4	NO	PASSED
3	4	NO	PASSED
1	MAX_EFF_CNT	NO	PASSED
2	MAX_EFF_CNT	NO	PASSED
3	MAX_EFF_CNT	NO	PASSED
1	2	ON	PASSED
2	2	ON	PASSED
3	2	ON	PASSED
1	4	ON	PASSED
2	4	ON	PASSED
3	4	ON	PASSED
1	MAX_EFF_CNT	ON	PASSED
2	MAX_EFF_CNT	ON	PASSED
3	MAX_EFF_CNT	ON	PASSED
1	2	OFF	PASSED
2	2	OFF	PASSED
3	2	OFF	PASSED
1	4	OFF	PASSED
2	4	OFF	PASSED
3	4	OFF	PASSED
1	MAX_EFF_CNT	OFF	PASSED
2	MAX_EFF_CNT	OFF	PASSED
3	MAX_EFF_CNT	OFF	PASSED
1	2	MIXED	PASSED
2	2	MIXED	PASSED
3	2	MIXED	PASSED
1	4	MIXED	PASSED
2	4	MIXED	PASSED
3	4	MIXED	PASSED
1	MAX_EFF_CNT	MIXED	PASSED
2	MAX_EFF_CNT	MIXED	PASSED
3	MAX_EFF_CNT	MIXED	PASSED

7   User Guide

Input required:

- `rwMotorTorqueConfigData.rwMotorTorqueOutMsg`: output message which contains RW motor torque information.

- `rwMotorTorqueConfigData.vehControlInMsg`: input message which contains the required attitude control vector.

- `rwMotorTorqueConfigData.rwParamsInMsg`: input message which contains information on RW spin axes.

- `rwMotorTorqueConfigData.controlAxes_B`: Set the control axes into a single array.

- `rwMotorTorqueConfigData.rwAvailInMsg`: optional message which contains information on which RW can be used to apply the desired torque.