



**Autonomous Vehicle Simulation (AVS) Laboratory,  
University of Colorado**

**Basilisk Technical Memorandum**

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**REACTION WHEEL MOTOR VOLTAGE C++ MODEL**

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| <b>Status:</b> Tested  |
| <b>Scope/Contents</b>  |
| This module turns FSW commanded torque into a voltage signal to send to the reaction wheels. |

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| v1.0 | Initial Document   | H. Schaub   |
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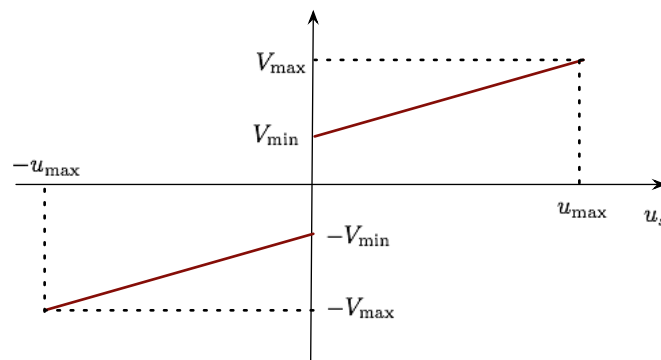
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## 1 Model Description

There two types of RW control torque interfaces, analog and digital. This modules assumes the RW is controlled through a set of voltages sent to the RW motors. This module is developed in a general manner where a voltage deadband is assumed and the module can be run in a pure open-loop manner, or with a closed-loop torque tracking control mode. Finally, if a RW availability message is present, then the RW is set to zero if the corresponding availability is set to UNAVAILABLE.



**Fig. 1:** Illustration of RW motor torque to voltage conversion

## 1.1 Open-loop voltage conversion

This module requires the RW configuration message to contain the maximum RW motor torque values  $u_{\max}$ . The user must specify the minimum and maximum output voltages as shown in Figure 1. The minimum voltage is a voltage below which the motor doesn't apply a torque, i.e. a deadzone.

Let the intermediate voltage value  $V_{\text{int}}$  as

$$V_{\text{int}} = \frac{V_{\max} - V_{\min}}{u_{\max}} u_s \quad (1)$$

The output voltage is thus determined through

$$V = V_{\text{int}} + V_{\min} * \text{sgn}(V_{\text{int}}) \quad (2)$$

## 1.2 RW Availability

If the input message name `rwAvailInMsgName` is defined, then the RW availability message is read in. The voltage mapping is only performed if the individual RW availability setting is `AVAILABLE`. If it is `UNAVAILABLE` then the output voltage is set to zero.

## 1.3 Closed-loop commanded torque tracking

The requested RW motor torque is given by  $u_s$ . The RW wheel speed  $\Omega$  is monitored to see if the actual torque being applied matches the commanded torque. Let  $J_s$  be the RW spin inertia about the RW spin axis  $\hat{g}_s$ . In the following development the motor torque equation is approximated as

$$u_s = J_s \dot{\Omega} \quad (3)$$

where the assumption is made that the spacecraft angular accelerations are small compared to the RW angular accelerations. The  $\dot{\Omega}$  term is digitally evaluated using a backwards difference method:

$$\dot{\Omega}_n = \frac{\Omega_n - \Omega_{n-1}}{\Delta t} \quad (4)$$

Care is taken that the old RW speed information  $\Omega_{n-1}$  is not used unless a history of wheel speeds is available, in particular, after a module reset. Thus, the actual RW torque is evaluated as

$$u_n = J_s \dot{\Omega}_n \quad (5)$$

Finally, the closed loop motor torque value is computed with a proportional feedback component as

$$u_{s,CL} = u_s - K(u_n - u_s) \quad (6)$$

where  $K > 0$  is a positive feedback gain value. Finally, this  $u_{s,CL}$  is fed to the voltage conversion process in Eq. (1).

## 1.4 Saturation and Dead Band

If the calculated voltage is outside of  $\pm V_{\max}$ , then the voltage is saturated at the  $\pm V_{\max}$  value. Note, this corresponds to the reaction wheel torques being saturated. Similarly, if the calculated voltage is inside  $\pm V_{\min}$ , then the voltage is set to  $\pm V_{\min}$ . This simulates the dead band. If the  $V_{\min} = 0$ , then there is no dead band.

## 2 Model Functions

The code performs the following functions:

- **Reset:** Resets the rwMotorVoltage module to original settings.
- **Closed loop:** Evaluates commanded torque based on closed loop controls.
- **Torque to Voltage:** Uses gains to convert a given torque to a voltage output.
- **Saturation:** Checks that calculated output is within min/max bounds.

## 3 Model Assumptions and Limitations

This code makes the following assumptions:

- **Linear:** This code assumes that there is a linear relationship between the torque desired and the voltage required to create that torque.

## 4 Unit Test Description

A series of unit tests are performed to check the validity of this module's operation.

### 4.1 Test 1

The first test uses an input vector of  $\mathbf{u}_s = [0.05, 0.0, -0.15, -0.2]$  Nm. The RW spin inertia is set to  $J_s = 0.1$  kg m<sup>2</sup>, while the maximum RW motor torque is set to  $u_{\max} = 0.2$  Nm. In this test case no RW availability or wheel speed messages are set. The simulation is first run for 1.5 seconds with a 0.5 second control update period. Next, the module is reset and run for another 1.5 sections. With only the open-loop voltage conversion active and the RW motor torque The resulting actual values and differences with hand-computed values are shown in Table 2. The reset of the module should have not impact on the voltage conversion, which is the case.

### 4.2 Test 2

This test repeats the values of test 1, except that the RW motor torque input vector is set to  $\mathbf{u}_s = [0.5, 0.0, -0.15, -0.5]$  Nm. This should saturate the first and last RW voltage output, which is seen in Table 3.

### 4.3 Test 3

This test repeats the values of test 1, except that a RW availability message is created. Here all RWs have a status of AVAILABLE except for the 3rd RW which is UNAVAILABLE. The 3rd RW voltages should thus all be 0.0 in this case, which is seen in Table 4.

### 4.4 Test 4

This test repeats the values of test 1, except that a RW wheel speed message is created. The feedback gain is set to  $K = 1.5$ . For the first 1.0 seconds the RW wheel speeds are set to  $\mathbf{\Omega} = [1.0, 2.0, 1.5, -3.0]$  rad/sec. At 1.0 seconds the RW wheel speeds are set to  $\mathbf{\Omega} = [1.1, 2.1, 1.1, -4.1]$  rad/sec. Then the module is reset at 1.5 seconds and the simulation continued for another 1.5 second for a 3 second total simulation time. The speed message remains the same after the reset. Table 5 shows the results of the actual values, and the differences with the hand-computed values.

## 5 Test Parameters

Test parameters are interspersed with the test description above. For all tests,  $V_{\min} = 1$  and  $V_{\max} = 11$  which correspond to a maximum torque of 0.2 [Nm].

## 6 Test Results

Results for each test are shown in the tables below:

**Table 2:** RW voltage output for case useLargeVoltage = False, useAvailability = False, useTorqueLoop = False.

| time [s] | $V_{s,1}$ | Error | $V_{s,2}$ | Error | $V_{s,3}$ | Error | $V_{s,4}$ | Error |
|----------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| 0        | 3.5       | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 0.5      | 3.5       | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 1        | 3.5       | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 1.5      | 3.5       | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 2        | 3.5       | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 2.5      | 3.5       | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 3        | 3.5       | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |

**Table 3:** RW voltage output for case useLargeVoltage = True, useAvailability = False, useTorqueLoop = False.

| time [s] | $V_{s,1}$ | Error | $V_{s,2}$ | Error | $V_{s,3}$ | Error | $V_{s,4}$ | Error |
|----------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| 0        | 11        | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 0.5      | 11        | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 1        | 11        | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 1.5      | 11        | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 2        | 11        | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 2.5      | 11        | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |
| 3        | 11        | 0     | 0         | 0     | -8.5      | 0     | -11       | 0     |

**Table 4:** RW voltage output for case useLargeVoltage = False, useAvailability = True, useTorqueLoop = False.

| time [s] | $V_{s,1}$ | Error | $V_{s,2}$ | Error | $V_{s,3}$ | Error | $V_{s,4}$ | Error |
|----------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| 0        | 3.5       | 0     | 0         | 0     | 0         | 0     | -11       | 0     |
| 0.5      | 3.5       | 0     | 0         | 0     | 0         | 0     | -11       | 0     |
| 1        | 3.5       | 0     | 0         | 0     | 0         | 0     | -11       | 0     |
| 1.5      | 3.5       | 0     | 0         | 0     | 0         | 0     | -11       | 0     |
| 2        | 3.5       | 0     | 0         | 0     | 0         | 0     | -11       | 0     |
| 2.5      | 3.5       | 0     | 0         | 0     | 0         | 0     | -11       | 0     |
| 3        | 3.5       | 0     | 0         | 0     | 0         | 0     | -11       | 0     |

All of the tests passed:

**Table 6:** Test results

| Test | Pass/Fail |
|------|-----------|
| 1    | PASSED    |
| 2    | PASSED    |
| 3    | PASSED    |
| 4    | PASSED    |

**Table 5:** RW voltage output for case `useLargeVoltage = False`, `useAvailability = False`, `useTorqueLoop = True`.

| time [s] | $V_{s,1}$ | Error        | $V_{s,2}$ | Error        | $V_{s,3}$ | Error | $V_{s,4}$ | Error        |
|----------|-----------|--------------|-----------|--------------|-----------|-------|-----------|--------------|
| 0        | 3.5       | 0            | 0         | 0            | -8.5      | 0     | -11       | 0            |
| 0.5      | 3.5       | 0            | 0         | 0            | -8.5      | 0     | -11       | 0            |
| 1        | 3.5       | 0            | 0         | 0            | -8.5      | 0     | -11       | 0            |
| 1.5      | 5.75      | -1.77636e-15 | -2.5      | -1.33227e-15 | -11       | 0     | -9.5      | -5.32907e-15 |
| 2        | 3.5       | 0            | 0         | 0            | -8.5      | 0     | -11       | 0            |
| 2.5      | 3.5       | 0            | 0         | 0            | -8.5      | 0     | -11       | 0            |
| 3        | 7.25      | 0            | 0         | 0            | -11       | 0     | -11       | 0            |

## 7 User Guide

This section contains conceptual overviews of the code and clear examples for the prospective user.

This module is often called similar to:

```
from Basilisk.fswAlgorithms import rwMotorVoltage
cmd2volt = rwMotorVoltage.rwMotorVoltageConfig()
cmd2voltWrap = sim.setModelDataWrap(cmd2volt)
cmd2voltWrap.ModelTag = "commandToVoltageConverter"
cmd2volt.VMin = -100.
cmd2volt = 100.
cmd2volt.K = 5.
cmd2volt.voltageOutMsgName = "voltageCommands"
cmd2volt.torqueInMsgName = "torquesToBeConverted"
cmd2volt.rwParamsInMsgName = "reactionWheelParameters"
cmd2volt.inputRWSpeedsInMsgName = "reactionWheelSpeeds"
```

where `sim` is the simulation you are running. The wrap is used because this is a `.c` file rather than a `.c++`, so it helps Basilisk to interface with the module routines. The only thing important about the `InMsgNames` is that they match the output message of the appropriate modules that create the messages.