



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

Basilisk Technical Memorandum

Document ID: Basilisk-imu_sensor

TESTING IMU SENSOR MODEL

Prepared by	J. Alcorn
-------------	-----------

Status: Initial document draft
Scope/Contents
This unit test validates the internal aspects of the Basilisk IMU module <code>test_imu_sensor.py</code> by comparing module output to expected output. The Basilisk IMU module is responsible for producing sensed body rates and acceleration from simulation truth values. The IMU module applies Gauss-Markov process noise to the true body rates and acceleration. The unit test validates MRP switching, static bias, process noise, discretization, saturation, spacecraft center of mass (CoM) offset, sensor misalignment, and bias walk bounds for both the gyroscope and accelerometer.

Rev:	Change Description	By
Draft	Initial document creation	J. Alcorn

Contents

1	Introduction	1
2	test_imu_sensor Test Description	1
3	Test Parameters	2
4	Test Results	2

1 Introduction

The Basilisk IMU module `imu_sensor.cpp` is responsible for producing sensed body rates and acceleration from simulation truth values. Each check within `test_imu_sensor.py` sets initial attitude MRP, body rates, and accumulated Delta V and validates output for a range of time.

2 test_imu_sensor Test Description

This test is located in `SimCode/sensors/imu_sensor/_UnitTest/test_imu_sensor.py`. In order to get good coverage of all the aspects of the module, the test is broken up into several parts:

1. Gyro/Accelerometer I/O The check verifies basic I/O of body rates and acceleration. Initial attitude MRP, body rates, and Delta V are propagated and corresponding body rates, acceleration, DR, and DV are compared to module output.
2. MRP Switch The check validates that the module accounts for attitude MRP switching in calculation of body rates. Initial attitude MRP and body rates are propagated for a sufficient amount of time for the MRP to switch to the shadow set. The test verifies that the module sets the MRP switch flag to TRUE.
3. Static Bias The check validates static bias in gyro/accel measurements. Gyro and accelerometer static bias are set to nonzero values. Initial MRP, body rates, and DV are propagated. Module output is verified to contain data with static bias.
4. Process Noise The check verifies that the Gauss-Markov model applies noise of appropriate mean and standard deviation to the attitude coordinate output. This check does not consider bias random walk. Accelerometer and gyro noise standard deviations are set to nonzero values for each axis. Module output is verified by taking the standard deviation of output data and comparing to specified values.
5. Discretization The check verifies that the module correctly discretizes the gyro/accel data according to the specified least significant bit (LSB). LSB of gyro and accelerometer are set to nonzero values. Output is verified to round input to nearest multiple of LSB.
6. Saturation The check verifies that the module saturates the output according to specified values. Gyro and accelerometer maximum output are set to nonzero values. Output is verified to not exceed specified saturation values for both negative and positive cases.

7. Accelerometer Center of Mass Offset The check validates that the accelerometer will give appropriate output based on an offset in center of mass from accelerometer. Sensed acceleration is given by the equation

$$\ddot{\mathbf{r}}_{\text{sensed}} = \boldsymbol{\omega} \times (\boldsymbol{\omega} \times (\mathbf{r}_{\text{imu}/S} - \mathbf{r}_{\text{CoM}/S})) + \dot{\boldsymbol{\omega}} \times (\mathbf{r}_{\text{imu}/S} - \mathbf{r}_{\text{CoM}/S}) + \ddot{\mathbf{r}}_{B/N} \quad (1)$$

where $\boldsymbol{\omega}$ is the spacecraft angular velocity vector, $\mathbf{r}_{\text{imu}/S}$ is the position vector of the IMU with respect to the structure origin, $\mathbf{r}_{\text{CoM}/S}$ is the position vector of the CoM with respect to the structure origin, and $\ddot{\mathbf{r}}_{B/N}$ is the actual inertial acceleration of the spacecraft.

8. IMU Misalignment The check validates measurements taken when the IMU is not correctly aligned (i.e. the IMU measurements are taken in a frame with constant rotational offset from assumed IMU orientation).
9. Bias Random Walk Bounds The check verifies that the Gauss-Markov model correctly applies bias random walk to the gyro and accelerometer output. Specified walk bounds are validated.

3 Test Parameters

This section summarizes the test input/output for each of the checks.

- Error Tolerance

There are specific error tolerances for each test. Error tolerances are determined based on whether the test results comparison should be exact or approximate due to integration or other reasons. Error tolerances for each test are summarized in table 2.

Table 2: Error tolerance for each test.

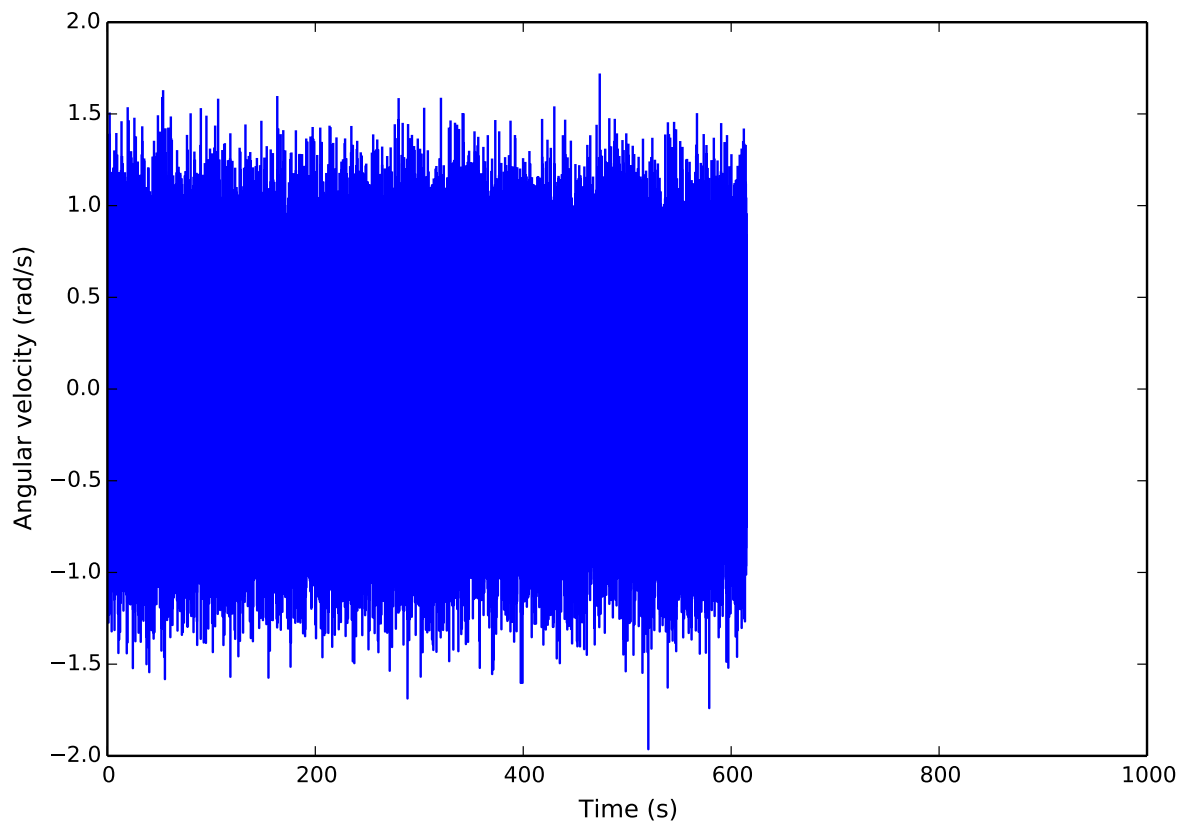
Test	Tolerated Error	Digits of Precision
Gyro/Accelerometer I/O	1E-13	
MRP Switching	-	-
Static Bias	1E-13	
Process Noise	1E-1	
Discretization	1E-5	
Saturation	1E-13	
Accelerometer Center of Mass Offset	1E-5	
IMU Misalignment	1E-4	
Bias Walk Bounds	-	-

4 Test Results

All checks within test_imu_sensor.py passed as expected. Table 3 shows the test results. Figures 4 and 4 show the module output for the process noise and walk bounds checks, respectively.

Table 3: Test results.

Test	Pass/Fail	Notes
Gyro/Accelerometer I/O	—	
MRP Switching	Passed	
Static Bias	Passed	
Process Noise	Passed	
Discretization	Passed	
Saturation	Passed	
Accelerometer Center of Mass Offset	Passed	
IMU Misalignment	Passed	
Bias Walk Bounds	Passed	

**Fig. 1:** Module output of noise standard deviation check

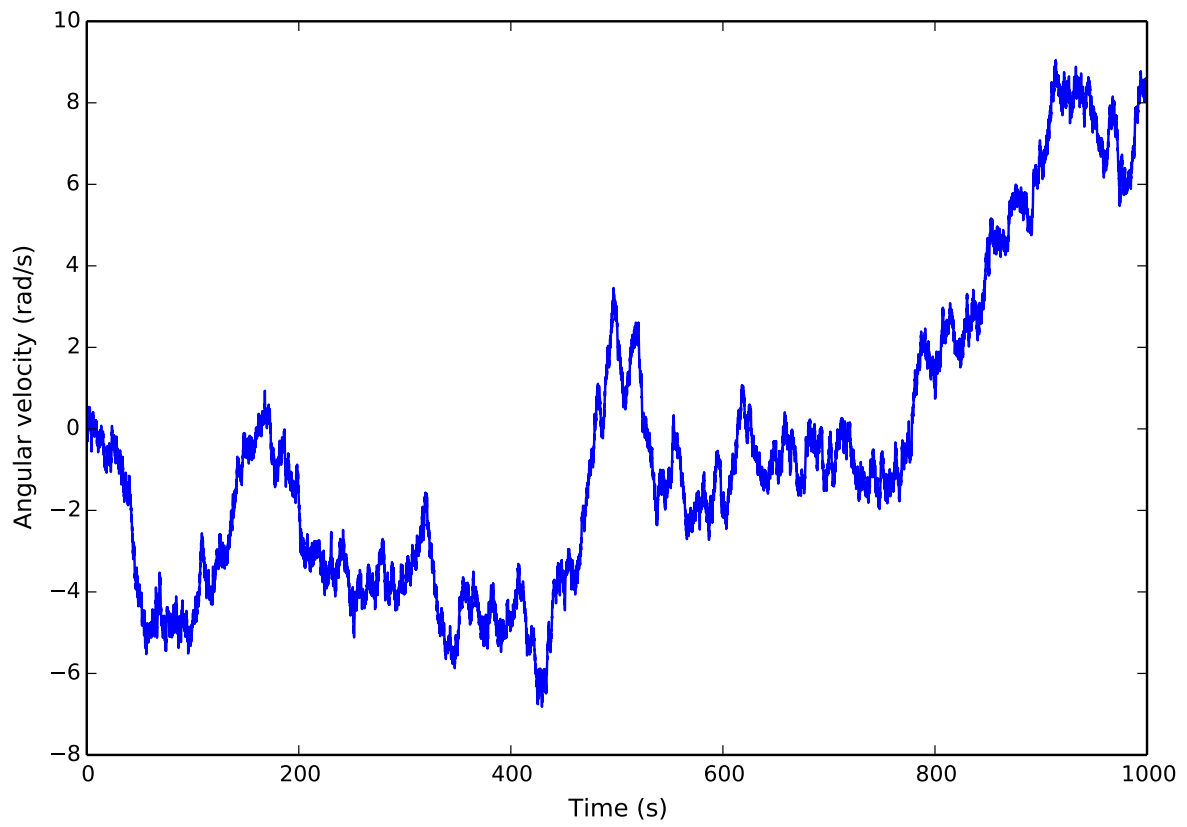


Fig. 2: Module output for random walk bounds check