



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

**Basilisk Technical Memorandum**

**SIMPLENAV**

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## 1 Model Description

The Simple Navigation model in the AVS Basilisk simulation is used to generate a stand-in for the real navigation system. Its use-case is to provide realistic navigation signals that are right at the spec of what ADCS claims for navigation system performance. For a typical spacecraft navigation system, the spec will almost always be at least a factor of two lower in performance than the expected nominal capabilities of the on-board navigation system. Therefore, we require the existence of a model that can provide spec-level navigation errors so that the functionality of the guidance and control subsystems can be verified as acceptable in the presence of navigation errors that are right at the spec.

The noise present in the simple navigation is designed to mimic the error signals that will be observed in the real navigation system. The true "noise" present in a vehicle's navigation system is always a combination of bias, white noise, and brown noise (or random walk). In order to provide this, a second-order Gauss-Markov process model was added to the simulation utilities that allows the user to configure a random walk process. The output of this model when applied to the vehicle position can be observed in Figure 1, and the attitude can be observed in Figure 2.

In this figure, the nominal position that the error was being distributed about was [10000.0, 0.0, 0.0] in meters and the error was bounded such that the absolute value of the error was less than 1000 m. The random walk had a white noise standard deviation of 5 meters.

In the model, the vehicle position, velocity, attitude, attitude rate, accumulated delta-velocity, and sun-pointing vector have errors applied separately. Arguably the sun-pointing vector should just use the vehicle attitude and the Sun position to get its pointing accuracy, but the Sun can be sensed independently of this and that is why there is a separate error source used for it.

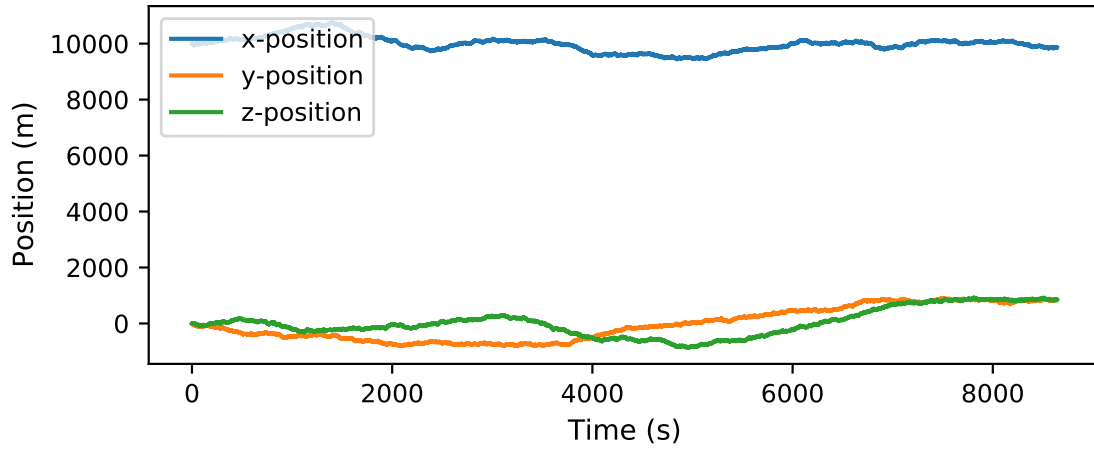


Fig. 1: Simple Navigation Position Signal

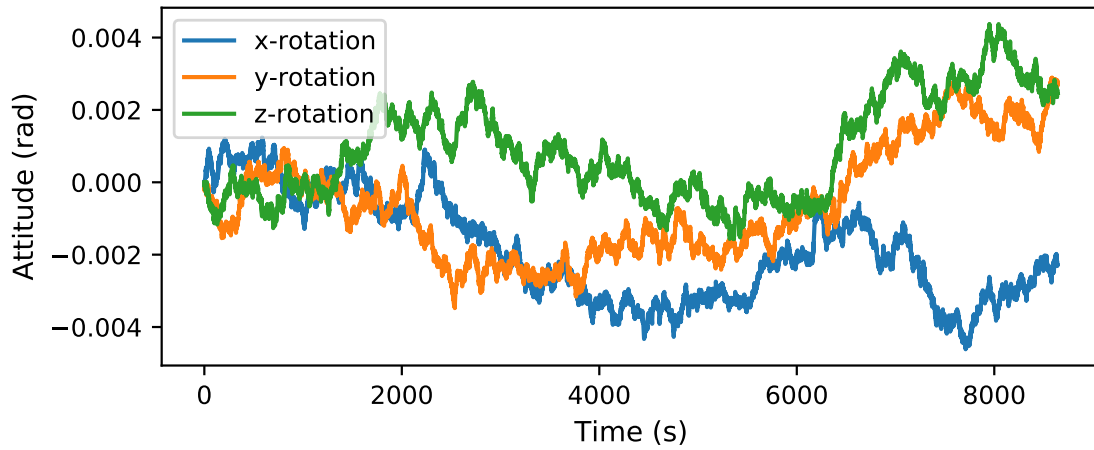


Fig. 2: Simple Navigation Att Signal

The top-level model relies on a lower-level utility module called GaussMarkov that supplies the random walk process that is added to the truth states. Since the simpleNav model exercises this utility completely, the unit test documented here was also used to test the GaussMarkov model both in terms of functionality and in terms of code coverage. The coverage results are included in a table in the results.

## 2 Model Functions

This module allows the user to set the bounds, and the standard deviations for:

- The spacecraft's position
- The spacecraft's velocity
- The spacecraft's attitude
- The spacecraft's attitude rate
- The sun direction
- The  $\Delta V$

The user can set the noise levels on each of these parameters independently.

## 3 Model Assumptions and Limitations

The direct assumption behind the simple nav module, is that the random walk produced by a Gauss-Markov process can accurately model the uncertainties of a real sensor. Generally, real sensor noise is a combination of bias, white noise, and brown noise. In order to provide this, a second-order Gauss-Markov process model was added to the simulation utilities that allows the user to configure a random walk process.

## 4 Test Description and Success Criteria

### 4.1 Test location

The unit test for the simple\_nav module is located in:

```
simulation/navigation/simpleNav/UnitTest/test_simpleNav.py
```

### 4.2 Subtests

This unit test is designed to functionally test the simulation model outputs as well as get complete code path coverage. The test design is broken up into three main parts:

1. Error Bound Enforcement: The simulation is run for 2.4 hours and the error bounds for all of the signals are tested. This test length is long enough to see both the walk in the signal and the noise, all the while not being so long as to slow down the test. The test ensures that the bounds are crossed no more than 30% of the time.
2. Error Bound Usage: The error signals are checked for all of the model parameters over the course of the simulation to ensure that the error gets to at least 80% of its maximum error bound at least once, ensuring that noise is indeed properly introduced.

3. Corner Case Check: The simulation is intentionally given bad inputs to ensure that it alerts the user and does not crash.

### 4.3 Test success criteria

These tests are considered to pass if during the whole simulation time of 144 minutes, all the variables need to stay within an allowable statistical error. This means that they must stay within their bounds 30% of the time.

At the same time, we want each of the errors to get to 80% of their respective error bounds at least once during the run.

These sigma bounds are defined in Table 2. These are chosen in regard to the simulation's parameters and their orders of magnitude, while the bounds are defined in Table 3

**Table 2:** Sigma Values

Variable	Position	Velocity	Attitude	Rates	$\Delta V$	Sun Position
Associated $\sigma$	5 (m)	0.035 (m/s)	$\frac{1}{360}$ (deg)	0.05 (deg/s)	1 (deg)	0.1 (deg)

**Table 3:** Upper bound Values

Variable	Position	Velocity	Attitude	Rates	$\Delta V$	Sun Position
Associated bounds	1000 (m)	1 (m/s)	0.29 (deg)	1.15 (deg/s)	5 (deg)	3.03 (deg)

These values were set to make the statistics visible in one test. They are also sometimes set as radians which explains why some values are not round.

## 5 Test Parameters

The test used for the simple navigation tests the statistics of the Gauss Markov process, making sure that we are getting the variability we want. In order to do so, no specific scenario is necessary. Therefore the position of the spacecraft and the sun were set generically:

- The vehicle position is  $[10000 \ 0 \ 0]^T$
- The Sun position is  $[10000 \ 10000 \ 0]^T$

## 6 Test Results

### 6.1 Pass/Fail

The test results are explained below and summarized in Table 4.

1. Error Bound Enforcement: We only want to violate the error bound a statistically small number of times as most bounds are specified 3-sigma. All signals remained inside their bounds more than 1-sigma ( 70%) of the time.
2. Error Bound Usage: As stated above, we want to ensure that the random walk process is effectively utilizing the error bound that it has been given and not remaining mired near zero. All error signals cross up above 80% of their error bound at least once.

### 6.2 Corner case test

Corner Case Usage: All errors/warnings were stimulated and the simulation still ran without incident. The expected error message is not automatically validated within pytest, but the test can not pass if the corner case test did break the simulation. In that way it is a partially automated test.

### 6.3 Summary of Test Results

**Table 4:** Test Results

SubTest	Result
Bound Enforcement	Passed
Bound Usage	Passed
Corner Case	Passed

As said in the previous part, the expected error message of the corner case is not tested automatically, but the test passes, meaning that the corner case does not break the simulation. It is therefore said to pass.

### 6.4 Test Coverage

The method coverage for all of the methods included in the simple\_nav module are tabulated in Tables 5 and 6.

**Table 5:** Simple Navigation Test Analysis Results

Method Name	Unit Test Coverage (%)	Runtime Self (%)	Runtime Children (%)
UpdateState	100.0	0.08	15.0
SelfInit	100.0	0.0	0.0
CrossInit	100.0	0.0	0.0
computeOutput	100.0	0.0	0.0

**Table 6:** GaussMarkov Test Analysis Results

Method Name	Unit Test Coverage (%)	Runtime Self (%)	Runtime Children (%)
computeNextState	100.0	0.71	12.4
setRNGSeed	100.0	0.0	0.0
setPropMatrix	100.0	0.0	0.0
getCurrentState	100.0	0.0	0.0
setUpperBounds	100.0	0.0	0.0
setNoiseMatrix	100.0	0.0	0.0
setPropMatrix	100.0	0.0	0.0

For all of the code this test was designed for, the coverage percentage is 100%. The CPU usage of the model is higher than would be ideal although this might just be a symptom of the level of simplicity present in the overall simulation. The majority of the computations are coming from two pieces of the GaussMarkov code.

The first is the random number generator. The model is using one of the simplest random number generators in the standard template library. That is still a relatively expensive operation as random numbers are costly and we generate a new random number for each state. The second factor is in the state and noise propagation. Those are being performed with a matrix multiplication that is an  $n^2$  operation. We could save some computations here in the future if we took away the cross-correlation capability from some of the states which would definitely be easy and accurate. It would just take some more code.

## 7 User Guide

The nominal set-up for the ephemeris converter is done as follows:

- `sNavObject = simpleNav.SimpleNav()`: Construct simple nav
- `sNavObject.walkBounds = sim_model.DoubleVector(errorBounds)`: add desired error bounds for the position, attitude....

- `sNavObject.PMatrix = sim_model.DoubleVector(pMatrix)`: Add the matrix of standard deviation values
- `sNavObject.crossTrans = True`
- `sNavObject.crossAtt = False`