Software Design for an Intelligent Attitude Determination and Control System

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Overview

Space exploration and satellite missions often carry equipment that must be accurately pointed towards distant targets, therefore making an effective attitude determination and control system (ADCS) a vital component of almost every spacecraft. However, the effectiveness of the ADCS could decrease drastically if components shift during launch, degrade in efficiency over the course of the mission, or simply fail. Prior work [0] has presented a concept for a adaptive ADCS which can respond to changing spacecraft conditions and environmental factors. This poster presents an implementation for a lazy learning ADCS is presented that uses past maneuver data to construct and refine a model of the spacecraft's movement.

Background

The development of autonomous learning attitude control systems is an open problem in the area of autonomous control. One approach [1] uses of fuzzy logic controllers to replace the standard linear controllers in an ADCS for a small satellite to improve the system's performance. Another study [2] examined using fuzzy logic controllers to reduce the limit cycle of an attitude control system, using a reinforcement learning to tune the relationship between system parameters and potential actions. A slightly different application of autonomous control techniques has also been investigated to create a fault-tolerant ADCS capable of detecting and adapting to degradation in actuator performance without prior knowledge of the spacecraft's specific systems as described in [3] and [4].

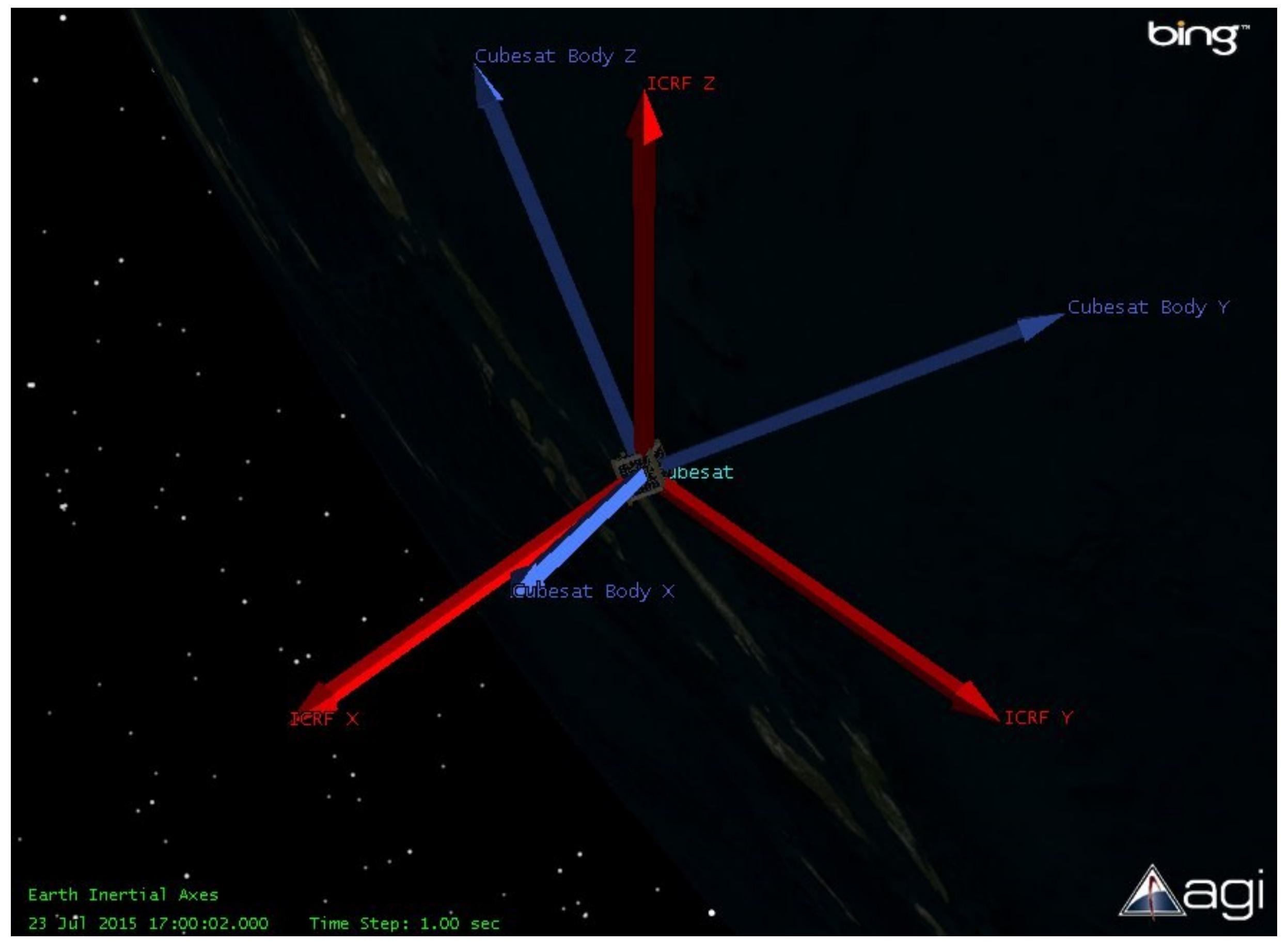

Figure 1. Screenshot of STK animation of attitude maneuver

Work To Date

Initial efforts in developing the intelligent ADCS focused on creating a system capable of learning its own movement model. This movement model defines how a given action, such as altering the speed of reaction wheels, affects certain sensor data, such as gyroscope readings. Action-result pairs from previous maneuvers are stored. When the ADCS is required to perform a given action, a lazy learning approach is used to analyze the point data to generate possible actions that are likely to achieve the goal. Since potentially multiple actions could yield the same result, the candidate actions are evaluated using a heuristic to select the most power efficient option.

To demonstrate the effectiveness of this concept, a control loop was constructed that utilized the action generation algorithm to reorient a CubeSat spacecraft from one attitude to another. An overview of this control loop is presented in Figure 2.

Experimental Testing

To verify the effectiveness of the action generation algorithm, a set of tests were developed to evaluate the system's performance across a range of scenarios. The system was tested with five different training sets and five different target attitudes (see Table 1). To identify how the system responded to sensor and actuator error, five different error levels (see Table 2) and five different error drift rates (see Table 3) were simulated for the attitude sensor, gyroscope sensor, and actuator output. Varying these parameters resulted in 1875 tests and five training runs for a total of 1880 simulations.

Table 1. Target attitude conditions

Condition	1	2	3	4	5
Yaw	90°	0°	0°	45°	135°
Pitch	0°	90°	0°	-45°	70°
Roll	0°	0°	-90°	45°	180°

Table 2. Error conditions

Condition	1	2	3	4	5
Error Level	-5%	-1%	0%	1%	5%

Table 3. Error drift conditions

Condition	1	2	3	4	5
Error Drift/Sec	-0.05%	-0.02%	0%	0.02%	0.05%

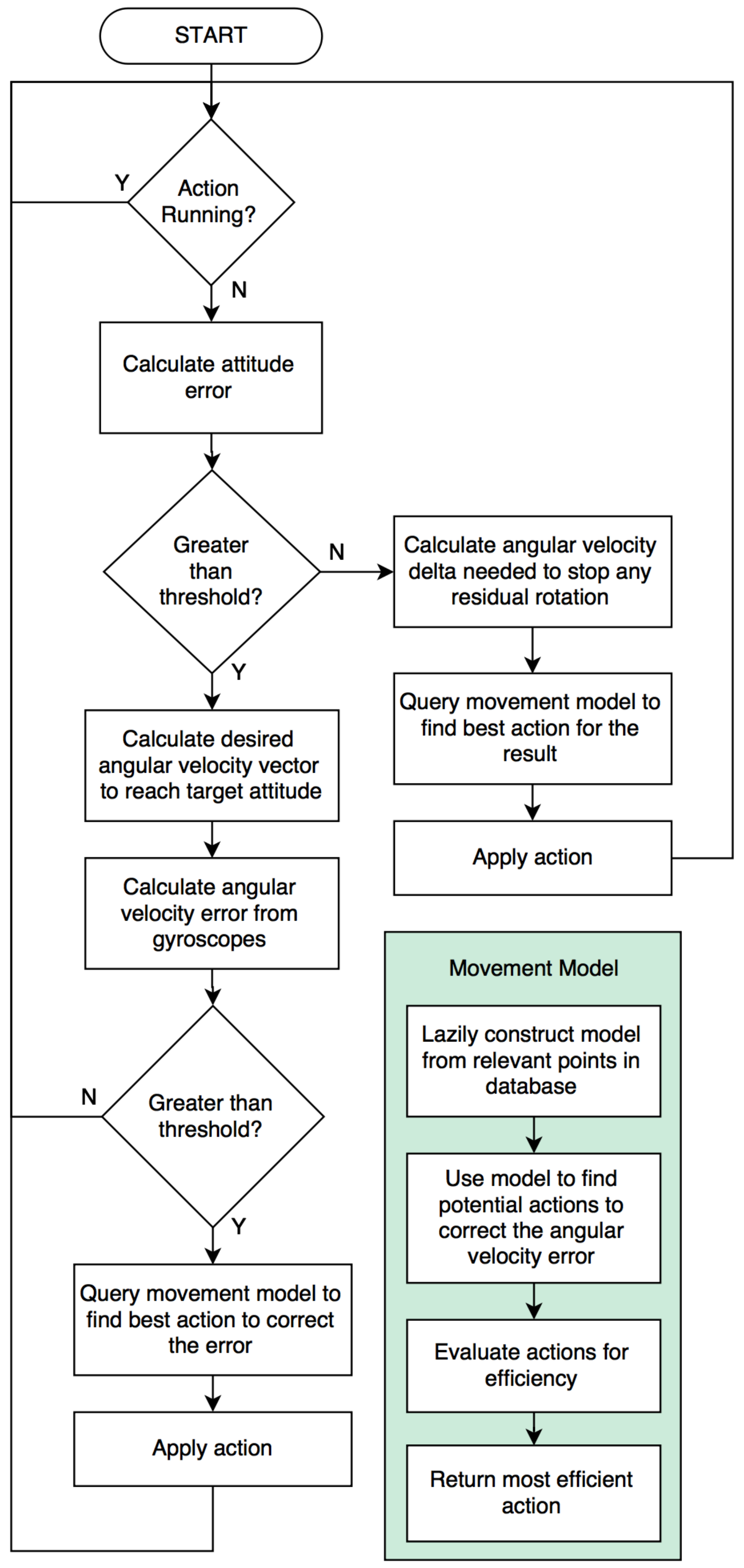

Figure 2. Control loop flowchart

Table 4. Summary of results

Total Maneuvers	1875
Successful Maneuvers	1267
Success Rate	67.6%
Avg. Successful Maneuver Time	8.33 sec
Avg. Successful Maneuver Final Error	0.00498 rad
Success Rate w/ Attitude Error	0.83%
Success Rate w/ Gyroscope/Actuator Error	98.9%
Success Rate w/ No Error	100%

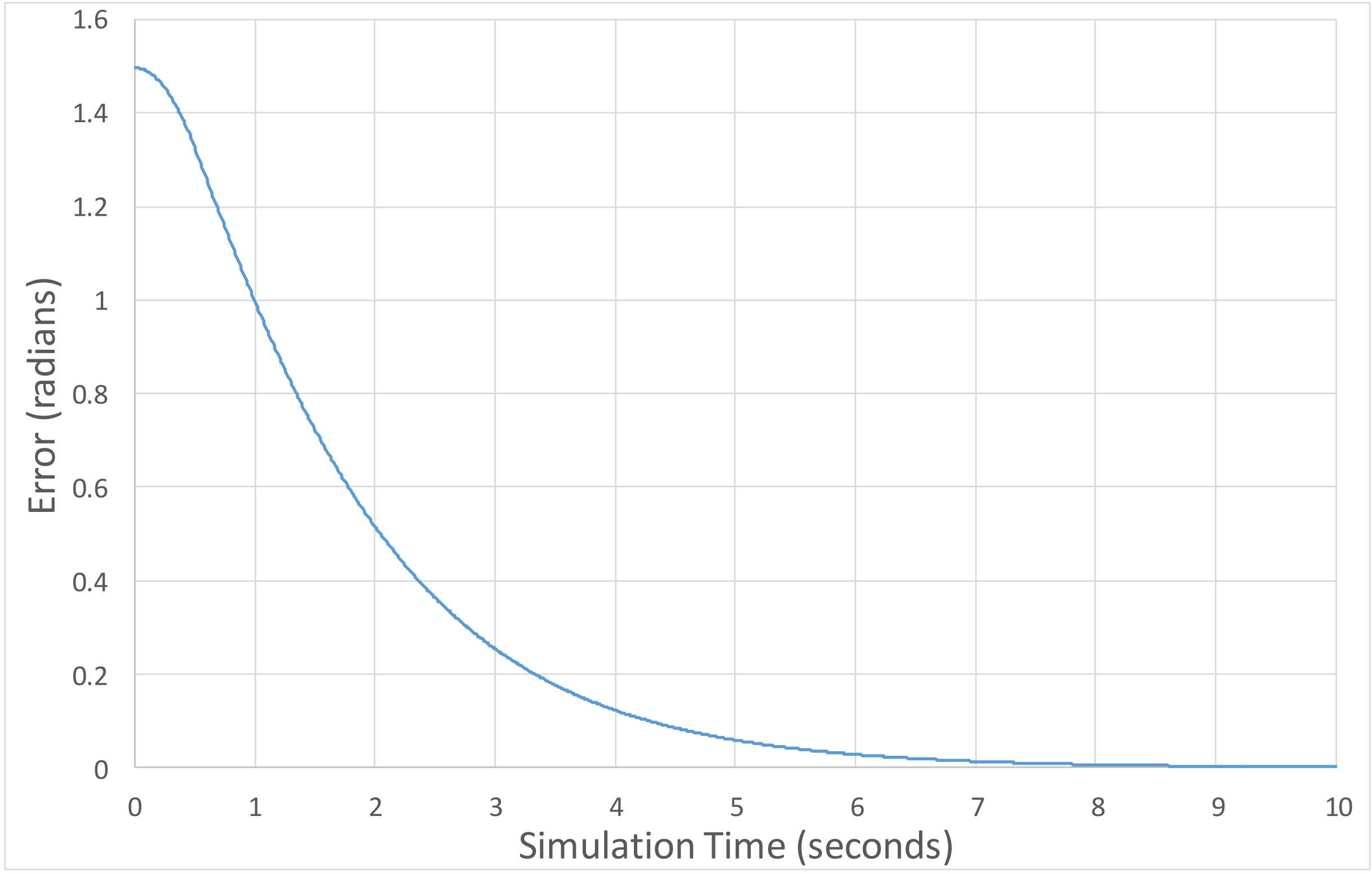

Figure 3. Example graph of error throughout a successful maneuver

Analysis

The data presented in Table 4 shows that the ADCS was successfully able to populate a database of training points through a sequence of training maneuvers and use those points to orient to a target attitude. The overall success rate for all 1875 tests was 67.6%. A more detailed analysis of the situations which led to a maneuver failure reveals that virtually all of the failures occurred when the system was subjected to some amount of attitude error. This result is easily explainable given that the ADCS relies on the attitude reading to evaluate its own success. If the reading is off by even a few fractions of a percent, the system may stabilize far enough away from the target attitude to be considered a failure.

A very different set of results occurred when the ADCS dealt with varying levels of either gyroscope or actuator error. The system successfully reached and stabilized at the target attitude for 98.9% of the tests. This seems to indicate that the system is robust when exposed to small errors and drifting values in gyroscope readings as well as variations in actuator performance.

Conclusions and Future Work

In this study the use of lazy machine learning techniques in an adaptive attitude control system was investigated. Prototype ADCS software was developed that utilized a database of previous maneuver information to accurately generate actions that would produce a desired set of sensor deltas. Using this intelligent movement model, basic attitude maneuvers were tested using AGI's Systems Toolkit. From this, a set of training points was gathered and used to both accurately and precisely rotate the spacecraft to a target attitude in multiple experimental conditions with various levels of simulated sensor and actuator error.

References

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