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ASE 376D Rocket Engineering Practicum II
04/21/2025

In-Space Quidditch Controller Simulation

Link to code repository

The purpose of this project is to simulate a zero-gravity Quidditch match. To this end a Guidance and Control algorithm is designed, which brings the seeker into a 30-cm capture radius from the snitch within a five-minute window.

The following constraints are applied to this model:

1. The seeker can have a maximum acceleration of $1.5g$ and maximum gimbal angle of $\pm 50°$.
2. The snitch travels counter-clockwise at a constant altitude in an elliptical path centered at (9.144, 0, 15.24) meters, with a period of 5 minutes.
3. The seeker starts at the origin and must remain within a 15.24 m sphere from the center-point of the snitch's trajectory.

The G&C algorithm first implements three-dimensional Pure Proportional Navigation (PPN) to determine the desired seeker acceleration based on the position and velocity of the snitch. Because the snitch is a moderately maneuvering target with a non-chaotic trajectory, PPN is chosen as an appropriate guidance law. The first kinematic constraint is also applied, clipping the seeker to $1.5g$ of acceleration if necessary. The navigation gain N is selected in an effort to smoothen the chasing trajectory.

The resulting seeker acceleration is then ingested by a Proportional-Integral-Derivative (PID) controller which applies gimbal steering to the seeker's velocity. A PID scheme is selected over a Linear Quadratic Regulator (LQR) due to well-defined system dynamics, lower computational cost, and relative ease of parameter tuning. Here, the seeker's steering is restricted to $\pm 50°$ as necessary per the second kinematic constraint. The gimbal input is defined as

$$u(t) = K_p e(t) + K_I \int_0^t e(t)\mathrm{d}t + K_D \frac{\mathrm{d}e(t)}{\mathrm{d}t}$$

where $e(t)$ is the angular error between the desired acceleration direction and current seeker velocity. The PID gains K_p, K_I, and K_D are chosen by trial-and-error to minimize time required for the seeker to capture the snitch. Note that the above continuous gimbal input relation is discretized for this application.

The main simulation runs until the five-minute window is exceeded or the snitch is captured, and yields the following results (Table 1 and Figures 1, 2, 3).

PID/PPN Gains	Capture Time (s)	Capture Distance (m)	Capture Position (m)
$K_p = 3.0$ $K_I = 0.5$ $K_D = 0.1$ $N = 5$	147.900	0.247	(-0.213, 0.046, 15.131)

Table 1: Controller gains and simulation results

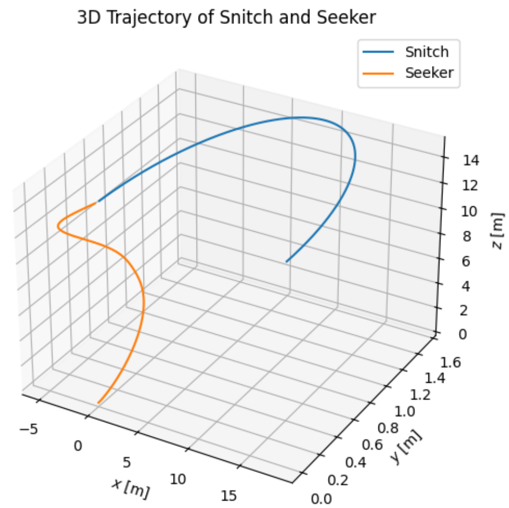

Figure 1: 3D trajectory of seeker and snitch until capture

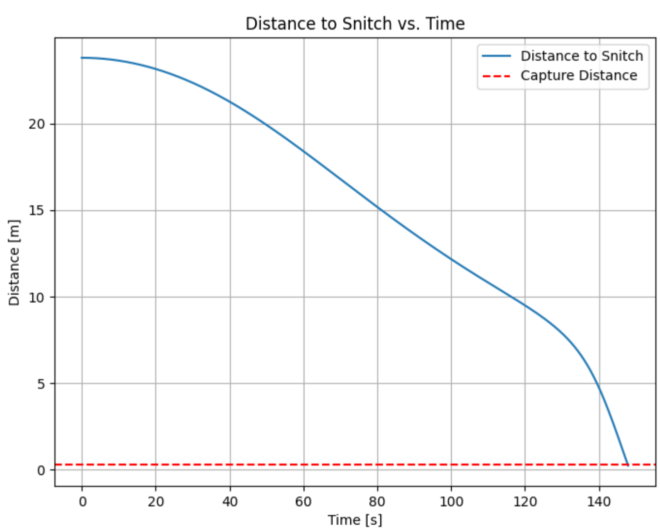

Figure 2: Distance to Snitch vs. Time

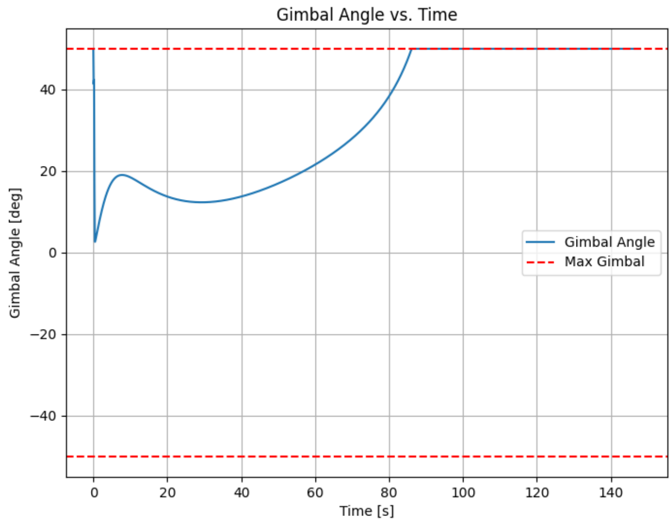

Figure 3: Gimbal Angle vs. Time

As the seeker's allowable gimbal range is increased beyond $\pm 50°$, capture time and distance increase for the same PID and PN gains. The proportional gain K_p is high in relation to the integral and derivative gains, which reduces the seeker's present error – eventually bringing it closer to the snitch at capture – but may also result in larger overshoots. Within the PID controller, the broom axis (i.e., seeker velocity) is also steered correspondingly to the maximum gimbal angle. This can induce sharper turning as gimbal range increases, making the snitch's trajectory less efficient. For larger gimbal angles, the simulation can be optimized by increasing the derivative and integral gains $(K_D,\ K_I)$ so as to predict future error more accurately and minimize capture distance to the snitch.