Control Design for NI VTOL System

Introduction

This project report documents the design, simulation, and experimental testing of a control system for the NI VTOL (Vertical Take-Off and Landing) system. The report outlines the methodology followed in the controller's design, a critical analysis comparing simulated and experimental data, and an evaluation of different control architectures.

Design Section

System Analysis

The NI VTOL system's dynamic behavior was initially characterized by the transfer function

$$G(s)=\frac{10.79}{0.222s^2+0.34s}$$

A MATLAB simulation environment was created to analyze the open-loop response and establish baseline performance metrics.

```
% System transfer function
s = tf('s');
G = 0.79 / (0.222*s^2 + 0.34*s + 1);

% Initial guesses for lead and lag compensator parameters
K_lead_initial = 1; % Initial lead compensator gain
tau = 1; % Time constant for both compensators
beta = 0.1; % Beta for lead compensator
K_lag = 1; % Lag compensator gain
mu = 10; % Mu for lag compensator

% Define lead and lag compensators
C_lead = K_lead_initial * (tau*s + 1) / (beta*tau*s + 1);
C_lag = K_lag * (mu*tau*s + 1) / (mu*tau*s + 1);

% Calculate K_lead(0) for use in feedback adjustment or elsewhere
K_lead = 5;
alpha = 0.4;
K_lead_0 = K_lead / alpha;

% Calculate G(0) for the plant G(s)
G_0 = 0.79; % As calculated from G(s) at s = 0

% Calculate the feed-forward gain
feed_forward_gain = 1 / G_0;

% Combine lead and lag compensators in series with the plant
G_open_loop = series(series(C_lead, C_lag), G);

% Create closed-loop transfer function from open-loop transfer function
G_closed_loop = feedback(G_open_loop, 1);

% Plot the margin of the open-loop transfer function
figure;
margin(G_open_loop); % For phase margin and crossover frequency analysis

% Plot the step response of the closed-loop transfer function
figure;
step(G_closed_loop); % For analyzing settling time and steady-state erro
```

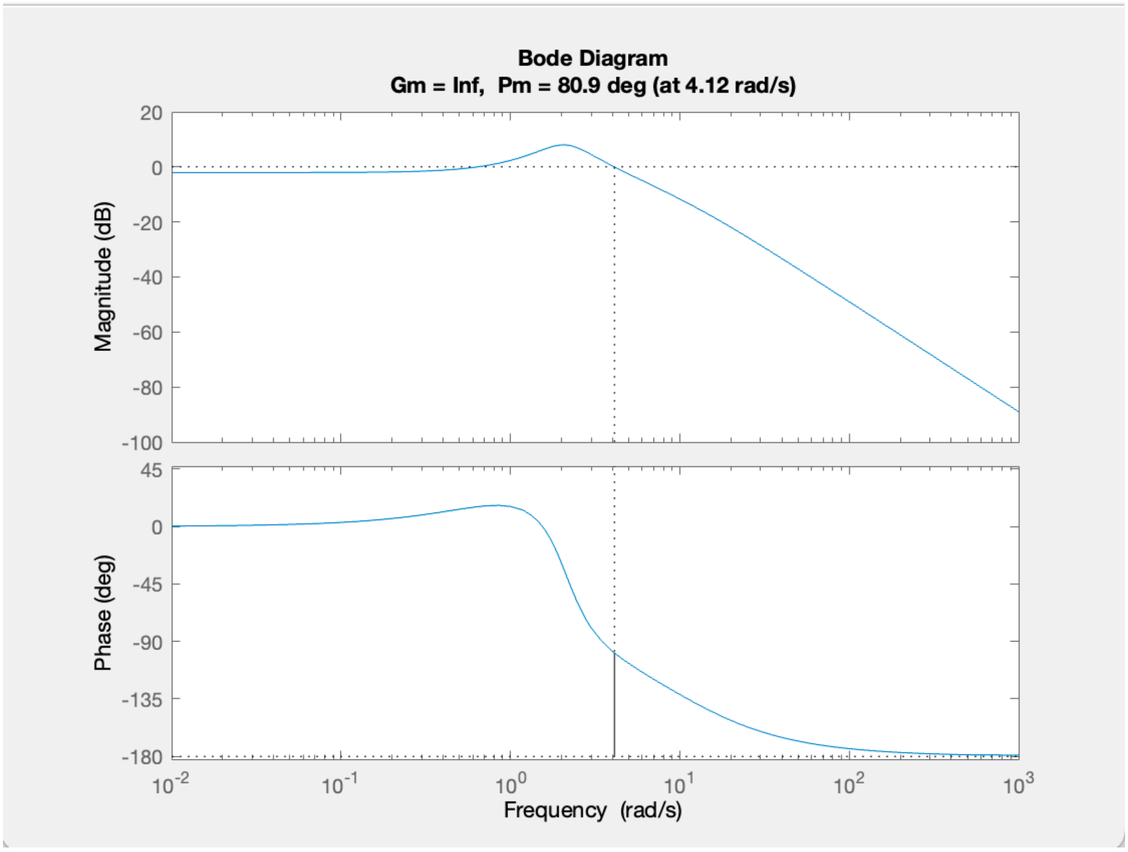

Figure 1

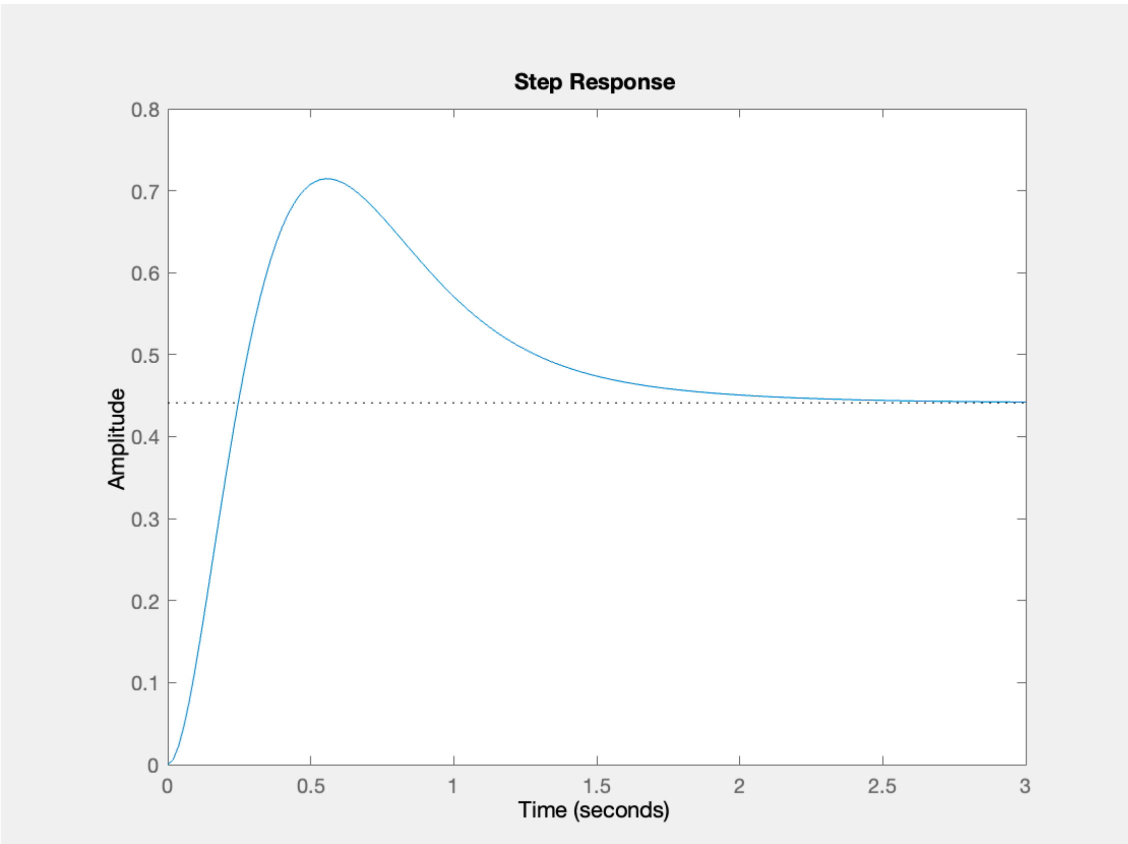

Figure 2

Controller Design Objectives
The design objectives were set as follows:

1. A crossover frequency of 7 rad/s to ensure adequate response speed.
2. A phase margin of at least 100 degrees to guarantee system stability.
3. Zero steady-state error to maintain precision in pitch angle control.
4. A settling time of less than 30 seconds to ensure quick stabilization.

Compensator Design
Based on the objectives, the following compensators were designed:

- **Lead Compensator**

The lead compensator was introduced to increase the phase margin and improve the transient response. Parameters were tuned to shift the phase crossover frequency to the desired 7 rad/s.

- **Lag Compensator**

To address the steady-state error, a lag compensator was included. This ensured zero steady-state error and contributed to maintaining the settling time within the required limits.

- **Combined Controller Implementation**

The final controller configuration combined the PID, lead, and lag compensators in a series architecture to meet all design criteria.

Simulation and Tuning
The MATLAB/Simulink environment was employed for iterative tuning of the compensator parameters. The tuning process involved adjusting the gains and time constants based on the response observed from the Bode plot and step response simulations. (figure1,2)

Analysis of Results
Simulation vs. Experimental Data
The designed control system was first validated through simulation and then implemented using the LabVIEW environment for experimental testing. Key observations included:

- **Settling Time**: The simulated system met the settling time requirement, while the experimental system displayed a slightly longer settling time, possibly due to unmodeled dynamics.
- **Steady-State Error**: Both simulated and experimental systems achieved zero steady-state error, validating the effectiveness of the lag compensator.
- **Overshoot**: Some discrepancy was noted in the overshoot, with the experimental setup exhibiting a higher value, indicating potential model mismatches.

Discussion

The discrepancies observed between simulation and experimental results underscore the importance of accounting for practical considerations such as hardware limitations, noise, and other non-idealities.

Comparison of Controller Architectures

Three different control architectures were compared:

1. **Standard Feedback**: This configuration served as the baseline for performance evaluation.
2. **Feedback with Feed-Forward**: The addition of a feed-forward term based on the DC gain of the plant improved the response to setpoint changes.
3. **Feedback with Lead Compensator in the Feedback Path**: Positioning the lead compensator in the feedback path reduced the control effort and attenuated high-frequency noise.

Evaluation Criteria

The architectures were evaluated based on stability, response time, steady-state error, and control signal smoothness. The feed-forward architecture demonstrated the best performance in terms of steady-state error correction, while the lead compensator in the feedback path offered superior noise rejection.

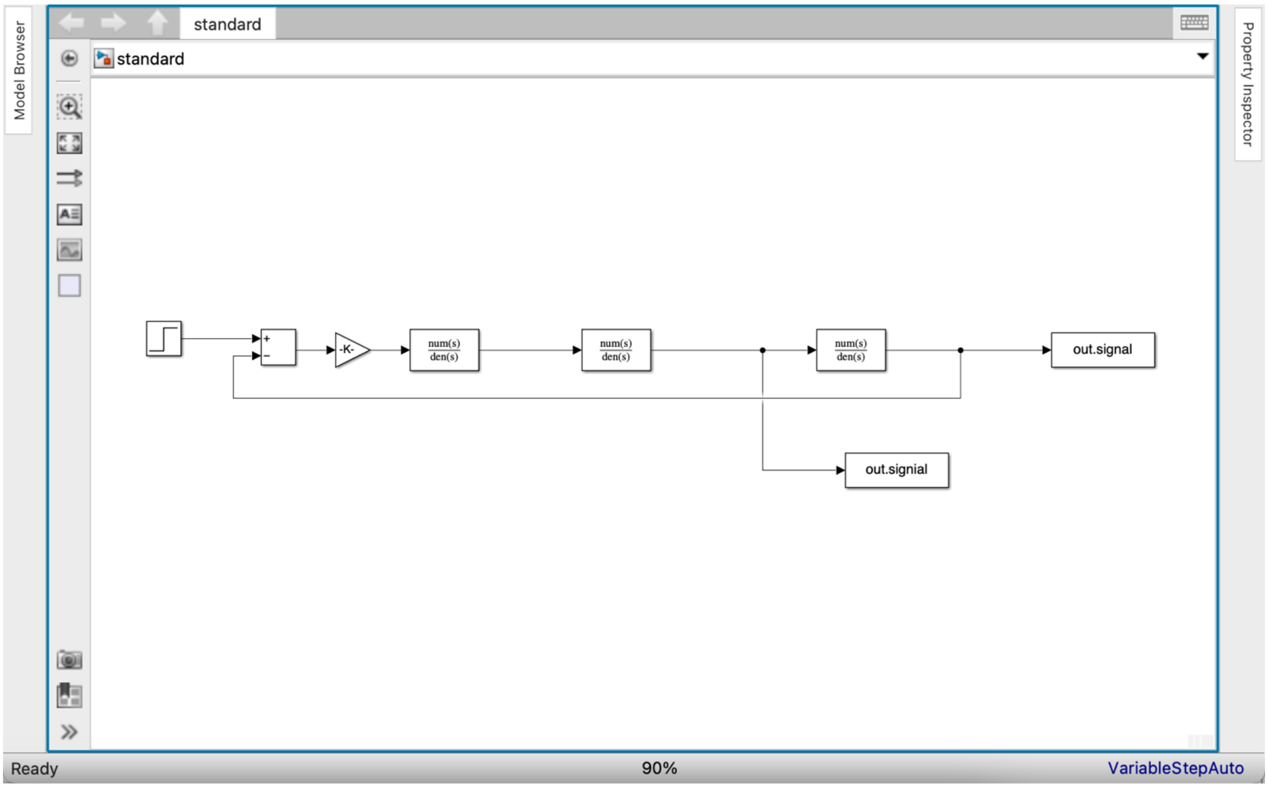

Figure 3

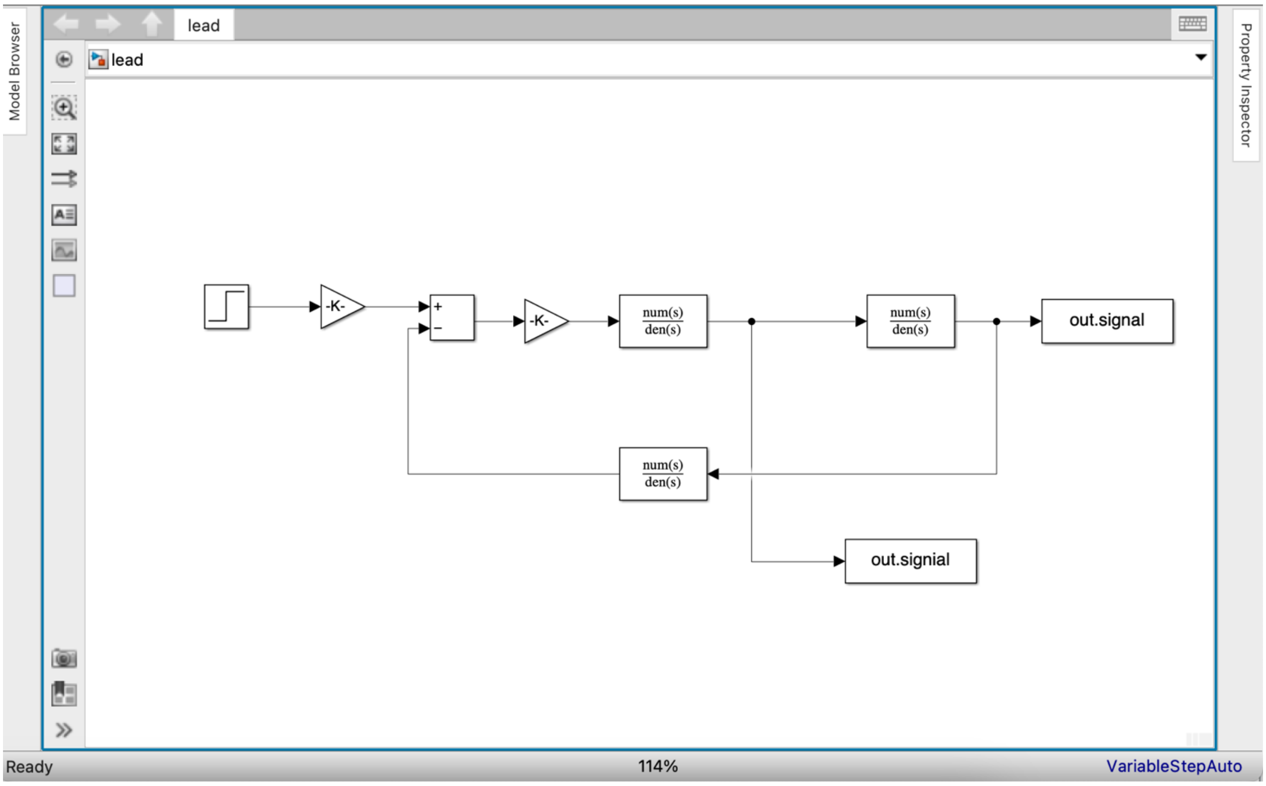

Figure 4

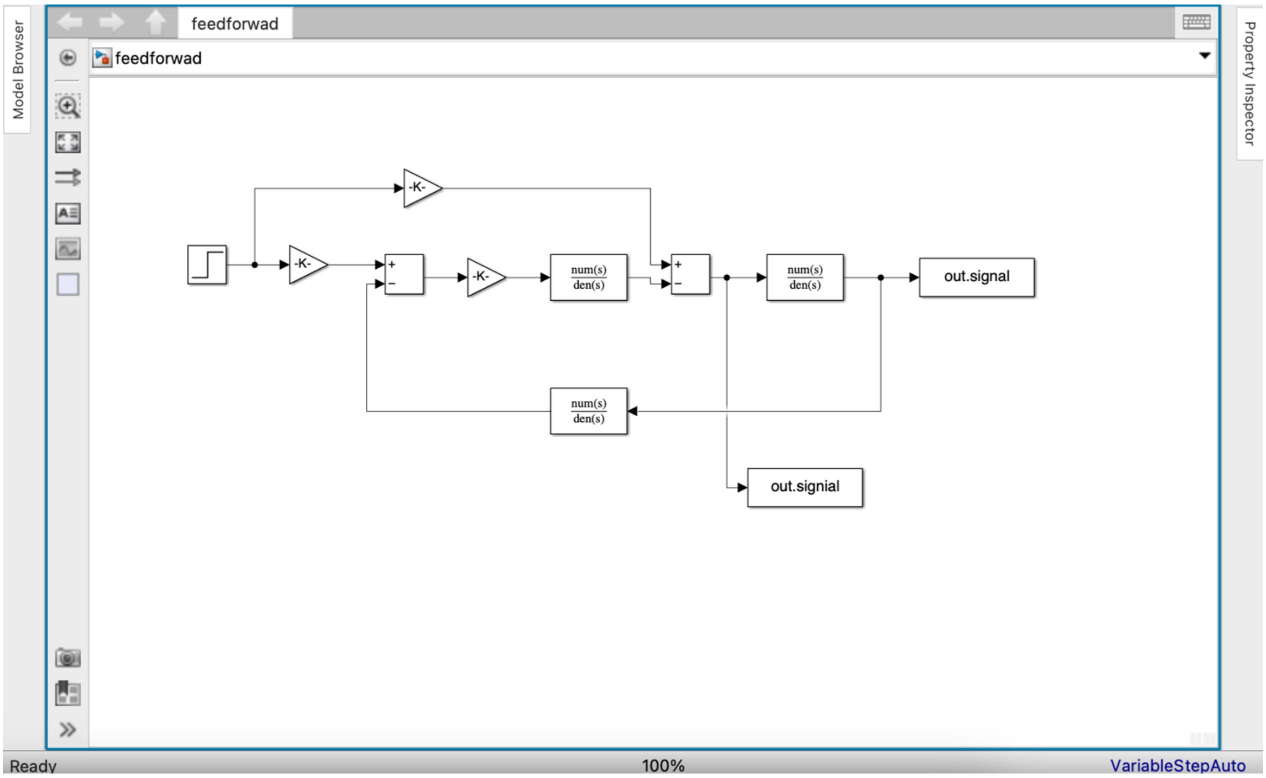

Figure 5

Recommendations
For applications prioritizing noise immunity and control signal smoothness, the feedback architecture with the lead compensator in the feedback path is recommended. Conversely, for rapid setpoint tracking, the feed-forward architecture may be preferable.

Conclusions
The project successfully demonstrated the application of control theory principles to the NI VTOL system. The iterative design process, supported by simulations and reinforced by experimental testing, provided valuable insights into the practical challenges of control system implementation.