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MidTerm Report

Smart Throttle Control for EVS

1. Control Systems

A control system regulates the behavior of other devices or systems. It typically includes a **plant**, which is the device or system that needs to be controlled, and a **controller**, which compares the desired output and actual output and adjust the input to minimize error.

2. Key Concepts in Control Theory

- **Laplace Transform** - It is a mathematical tool to simplify system analysis by transforming the complex differential equations (in time domain) into simpler algebraic expressions (in frequency domain).
- **Transfer Functions** - Represent the system input-output relationship in frequency domain and forms the basis of system analysis.
- **Open-Loop and Closed-Loop System** - Closed-Loop system relies on a feedback system to control error while an open-loop system has no such means.
- **System Modelling** - Mathematical representation of physical systems. Defined using differential equations in time domain and analysed using Laplace transform and transfer function.
- **Performance Metrics** - Rise Time, Settling Time, Overshoot and Steady-State Error.
- **System Stability** - Analysed using pole location in s-plane. Poles in left-half indicate stability while those on the right-half indicate unstable behavior.

- **System Types** - Classified on the basis of no. of integrators. It is used in predicting system accuracy in different types of inputs.

3. PID Control System

A Proportional-Integral-Derivative (PID) controller is the most common control loop feedback mechanism. It calculates an error value as the difference between a desired setpoint and a measured process variable. The controller attempts to minimize this error by adjusting the process control inputs using three terms:

- **P**roportional - responds to current error. Higher Kp leads to a faster rise time but can introduce unwanted overshoots and oscillations.
- **I**ntegral - accumulates past error ultimately driving steady-state error to zero. Improves accuracy but can increase oscillations and settling time.
- **D**erivative - predicts future error based on rate of change thus reducing settling time. Introduces damping which reduces overshoots and oscillations. Highly sensitive to noise in error signals, so filtering is usually necessary.

PID Failure - The PID terms are not independent. Tuning one parameter to fix one issue often degrades other issues. This results in achieving “perfect” control almost impossible with PID alone.

4. Beyond PID Control

4.1. Compensators - Used for fine-tuning after the coarse adjustment is done using PID.

- Lead Compensator increases speed and reduces settling time of the system.
- Lag Compensators eliminates steady-state error with much higher precision.

Depending on the requirements a combination of both compensators can be used.

4.2. Feedforward Controller - Estimates disturbances and immediately adjusts the control input to avoid deviation. Unlike a feedback (closed-loop) controller, which waits for an error to occur before taking corrective action, a feedforward controller attempts to prevent the error entirely.

5. MIMO Systems

MIMO system consists of multiple inputs and multiple outputs which, unlike SISO systems, are coupled, that is an output is affected by a combination of inputs.

6. Contribution to Project

Learned all the concepts and implemented them through assignments. Using MATLAB, i designed, simulated and analysed system to achieve the required specifications, improving both Theoritical understanding of the concepts and real-life implementation.

Drone Altitude and Speed Control System

The drone control system is inherently a Multi-Input Multi-Output (MIMO) system, but the altitude and speed control can often be treated as decoupled or semi-decoupled Single-Input Single-Output (SISO) control loops for simplified design (e.g., controlling vertical thrust for altitude and horizontal thrust/tilt for speed).

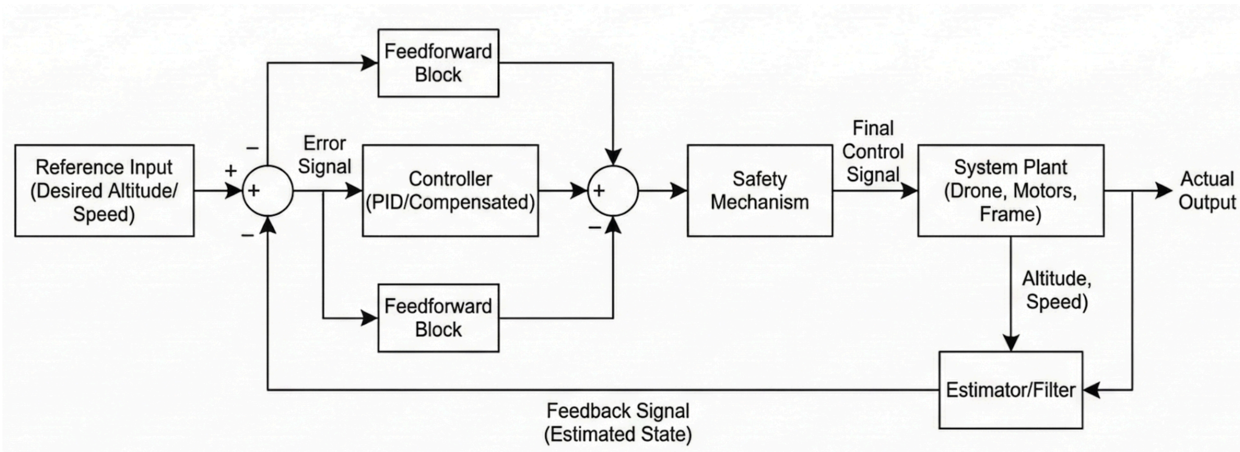
Overall Workflow/Architecture

The system follows a standard closed-loop feedback architecture:

- Sensor Inputs (Measurement):
    - Altitude Control: Barometer/Altimeter (for pressure altitude), Sonar/LIDAR (for ground proximity/low altitude), GPS (for position-based altitude estimation).
    - Speed Control: GPS (horizontal velocity), Inertial Measurement Unit (IMU - Accelerometers for change in velocity).
    - Set Point Input: User input (via remote control) specifies desired altitude and speed.
- Processing (Control Law Calculation):
    - Error Calculation: Compares the desired set point (e.g., target altitude) with the actual measured output (current altitude).
    - Controller Block: The error is fed into the PID or compensated PID controller (the control law) to calculate the required control effort.
    - Safety/Limiting: Ensures the calculated control effort stays within physical limits (e.g., max motor speed).
- Actuator Control (Action):
    - The calculated control signal is translated into specific motor commands (e.g., PWM signals) and distributed to the Electronic Speed Controllers (ESCs) which drive the BLDC motors.

Key Components/Blocks

Module	Function	Action in Control Loop
System Plant	The physical drone, motors, and frame.	Subject to System Modelling (differential equations).
Feedback Loop	Measures the actual output (Altitude, Speed) using sensors and feeds it back.	Essential for Closed-Loop Control, error minimization.
Controller (PID/Compensated)	Calculates the required thrust adjustment based on the error.	Implements PID Control Law, possibly with Lead/Lag Compensators for better performance metrics (Rise Time, Settling Time).
Estimator/Filter	Filters sensor noise (especially in IMU) and estimates unmeasured states (e.g., velocity from position).	Necessary for Derivative term stability and noise reduction.
Feedforward Block	Adjusts control input immediately based on expected changes (e.g., a known headwind, or rapid altitude set-point change).	Improves Response Tracking and disturbance rejection.
Safety Mechanism	Emergency shut-off, altitude limits, failsafe return-to-home logic.	Ensures System Stability and safe operation.



For altitude control specifically, the outer loop calculates the required *vertical thrust* based on altitude error. For speed control, the outer loop calculates the required *pitch/roll angle* to tilt the drone and generate horizontal thrust, which is then fed as a setpoint to the inner loop. This hierarchical structure simplifies the design by separating fast stability concerns from slower navigation concerns.