Trajectory Tracking for Aggressive Quadrotor Flight using $\mathcal{L}1$-Adaptive Control

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Motivation

- Aggressive quadcopter flight has applications in surveying, delivery and wildlife photography
- Goal of the controller synthesis is to accommodate **autonomy and agility** of small quadrotors
- Many control models **disregard the disturbances and the uncertainties** for simplicity which results in poor control over the system
- A common way to deal with uncertainties is gain scheduling which is **time consuming**
- **L1 Adaptive control** (L1-AC) is a recent advancement in the field of adaptive control systems

Methodology

- **Baseline Controller**
    - System dynamics matrix (**A**m) is generated using K_{pp}, which is a gain by Pole-Placement method
    - Controller cost is optimized to find the trim point
    - System is linearized around the trim point
    - The baseline gain ($K_{baseline}$) is calculated using LQR
- **L1-AC:**
    - System model is updated to contain bounded unmodeled disturbance.
    - The state predictor works in conjunction with the measured states to estimate the state uncertainty.
    - The adaptation law uses the state uncertainty to update the system and control parameters.
    - Finally, the control law uses the updated parameters to synthesize the control input for the uncertain system.

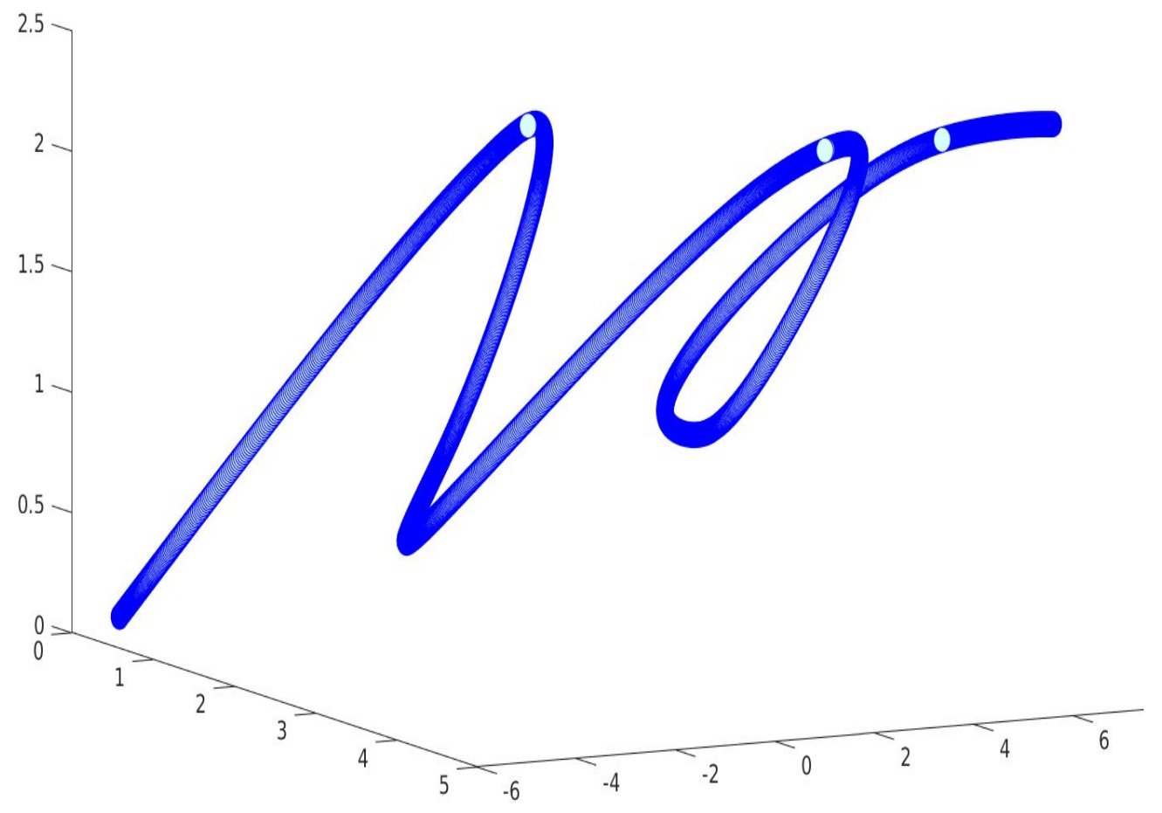

Fig.(1) Sample trajectory of an aggressive quadrotor flight

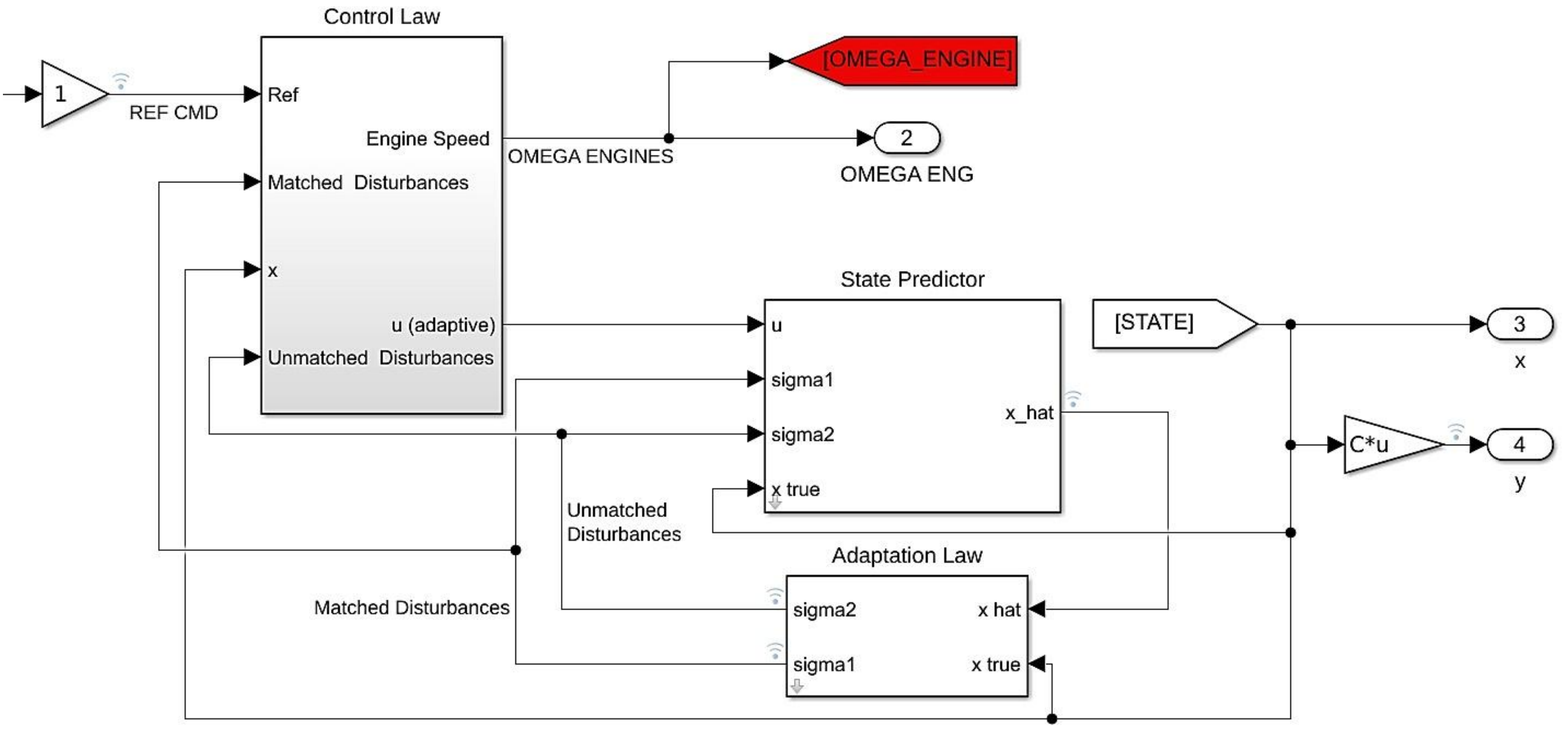

Fig. (2) Simulink Model of L1 - Adaptive Controller containing the blocks for **Control, State Prediction and Adaptation**

Results

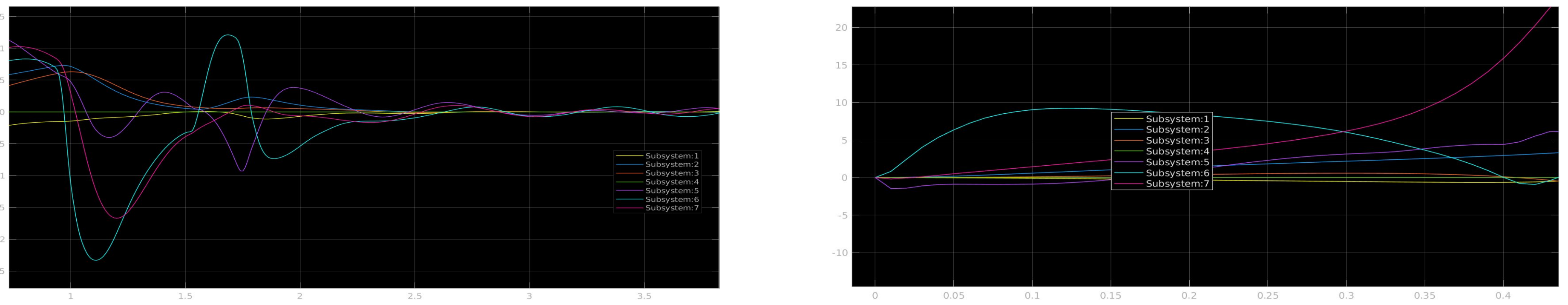

Fig.(3) Comparison of control analysis around a constant state (figure on left) and around aggressive flight (figure on right)

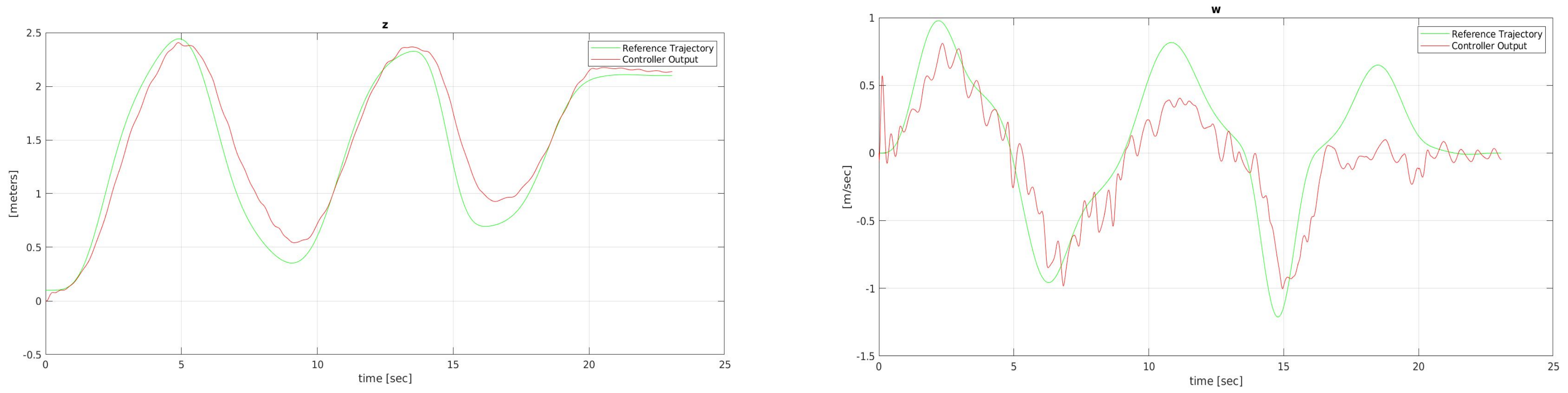

Fig.(4) For the given aggressive trajectory, position and velocity control in the earth and body frame respectively

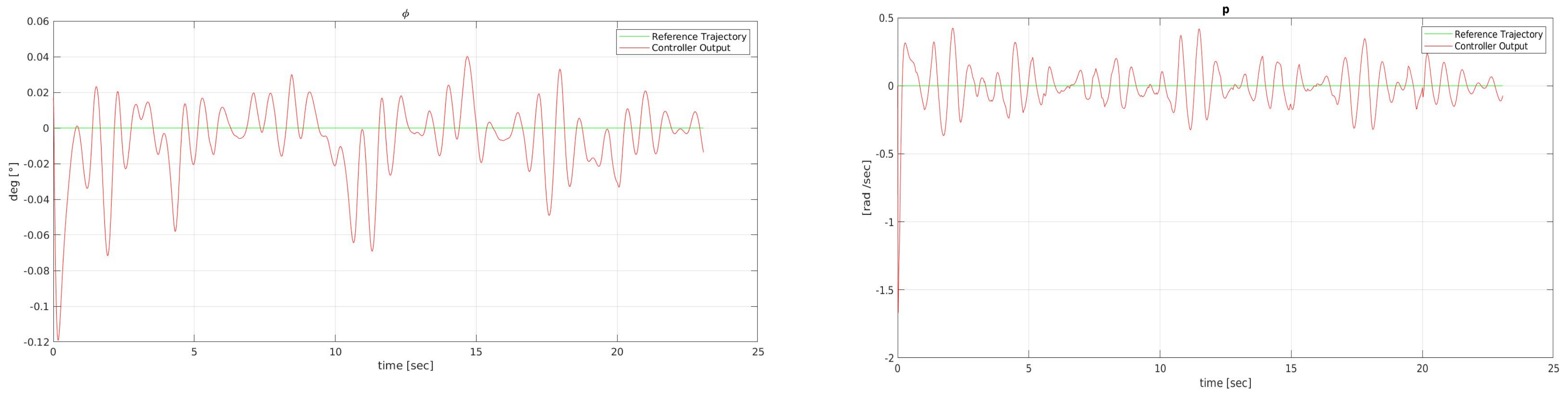

Fig.(5) For the given aggressive trajectory, attitude and angular velocity control in the earth and body frame respectively

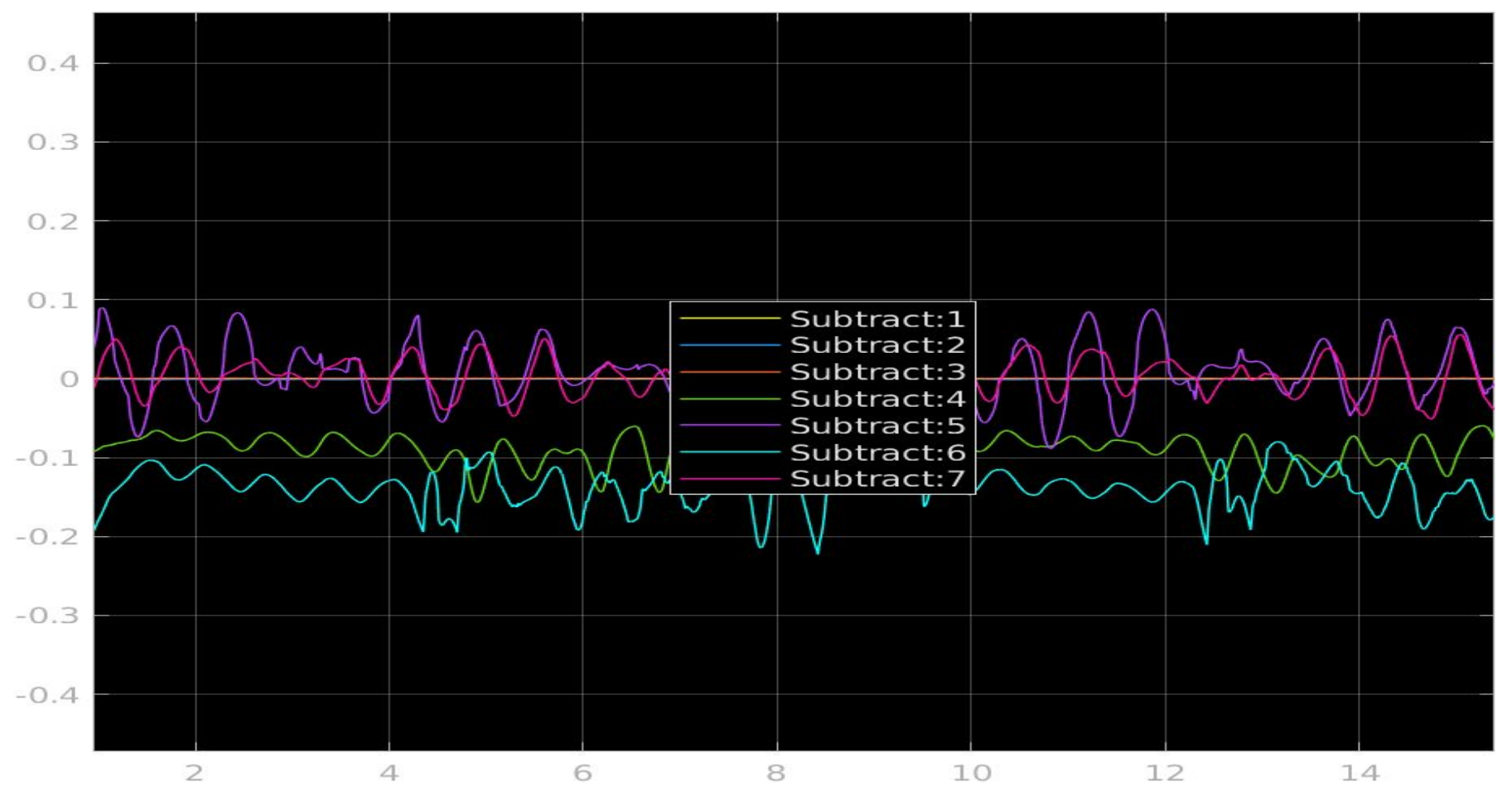

Fig.(6) Error variation

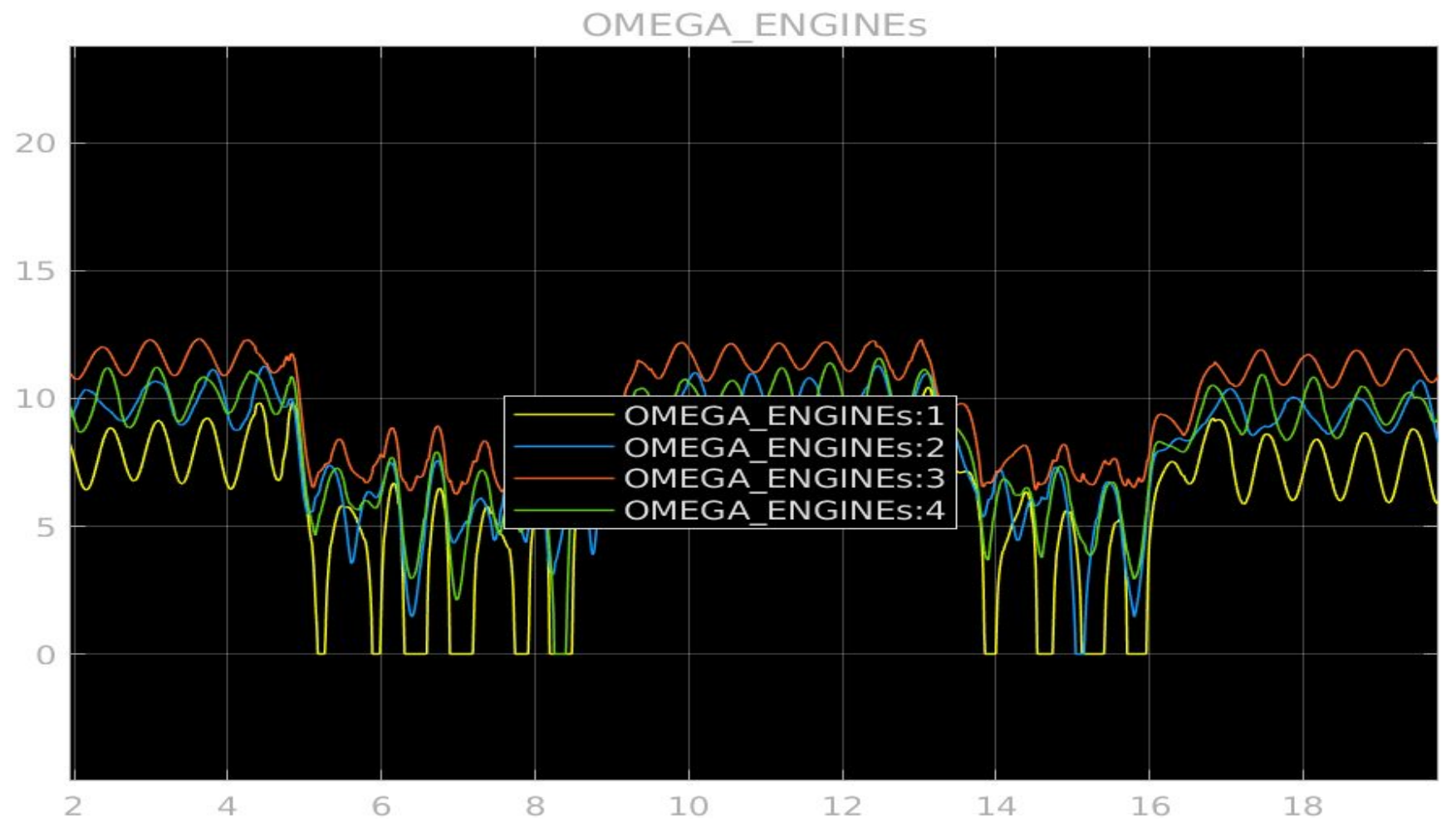

Fig.(7) Rotational speed of individual motors of quadrotor

- The time step used in this experiment was 0.01 seconds
- Larger adaptive gains (of the order $\Gamma = 10^6$) leads to numerical instability
- In the absence of projection all signals in the closed-loop system go unbounded
- Non-zero steady state tracking error remains but the high frequency oscillations are gone due to smaller step size

Conclusion

- Controller guarantees that in presence of bounded uncertainties the system remains stable
- L1-AC tries to **compensate for the uncertainties** within the control bandwidth of the actuator
- Guarantees **good transient performance and robustness**

Future Work

- Compare this controller response with baseline **PID and MPC** for same trajectory
- Implement L1-AC for trajectory optimization experiments on aggressive flights
- Integrate **H2/ H-∞ Controller** with L1-AC to guarantee the robustness of system

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