Poznań University of Technology

Faculty of Automatic Control, Robotics and Electrical Engineering

Smart Aerospace and Autonomous Systems

ADAPTIVE CONTROL LAB 4

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Report of Laboratory Task 4

Model-Identification Adaptive Control (MIAC) of Aircraft Roll Dynamics

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I. Contents

II. Introduction

This report presents the design, implementation, and evaluation of a Model-Identification Adaptive Control (MIAC) system for an aircraft's roll dynamics. The objective was to achieve precise tracking of a reference roll rate trajectory under conditions of unknown and possibly time-varying plant parameters. The control system was designed to meet specific performance criteria, including zero steady-state error and a prescribed settling time. The effectiveness of the MIAC scheme was validated through simulations in the Matlab-Simulink environment, showcasing its robustness against parametric uncertainties and measurement noise.

Aircraft roll control is critical for maneuverability and stability. However, roll dynamics can be challenging to control due to uncertainties in aerodynamic parameters that may vary with flight conditions. This lab focuses on applying the MIAC technique to an aircraft's roll dynamics, aiming to maintain precise control despite these uncertainties.

III. Problem Statement

The task is to design a MIAC system for an aircraft's roll dynamics, approximated by a first-order linear model:

$T_0 \dot{y} + y = k_0 u$, where $y \equiv \omega$, $u \equiv \delta_a$

Here, ω is the roll rate in rad/s, δ_a is the aileron deflection in rad, and T_0 , k_0 are unknown, possibly time-varying parameters.

IV. The control objectives

- R1: Track a bounded, time-varying reference trajectory y_r(t).
- R2: Achieve zero steady-state error without overshoot.
- R3: Attain a settling time T_s1% = α = 3.0 s.

V. Methodology:

✓ Plant Identification

- Used State Variable Filters (SVF) to prepare signals for linear regression.
- Applied Recursive Least Squares (RLS) for online parameter estimation.

✓ Controller Design

Structure: $u(t) = w_1 e(t) + w_2 y\_r(t) + w_3 \dot{y}\_r(t)$

- w_1 : Proportional gain for error
- w_2 , w_3 : Feedforward terms using reference and its derivative

✓ Synthesis

Derived equations relating controller parameters to plant parameters:

- $w_1 = (5T_0 - \alpha) / (k_0 \alpha)$
- $w_2 = 1 / k_0$
- $w_3 = T_0 / k_0$

VI. Implementation of our Model

1. Adaptive Law:

Applied Certainty Equivalence (CE) principle:

$w = w(\hat{T}_0, \hat{k}_0) = [(5\hat{T}_0 - \alpha)/(\hat{k}_0\alpha), 1/\hat{k}_0, \hat{T}_0/\hat{k}_0]$

Where $\hat{T}_0, \hat{k}_0$ are online estimates from RLS.

2. System Components:

- Plant: Continuous-time Transfer Function
- Identification: MATLAB Function for SVF-RLS
- Controller: MATLAB Function implementing adaptive law
- Reference Generator: Signal Generator for sinusoidal and rectangular inputs

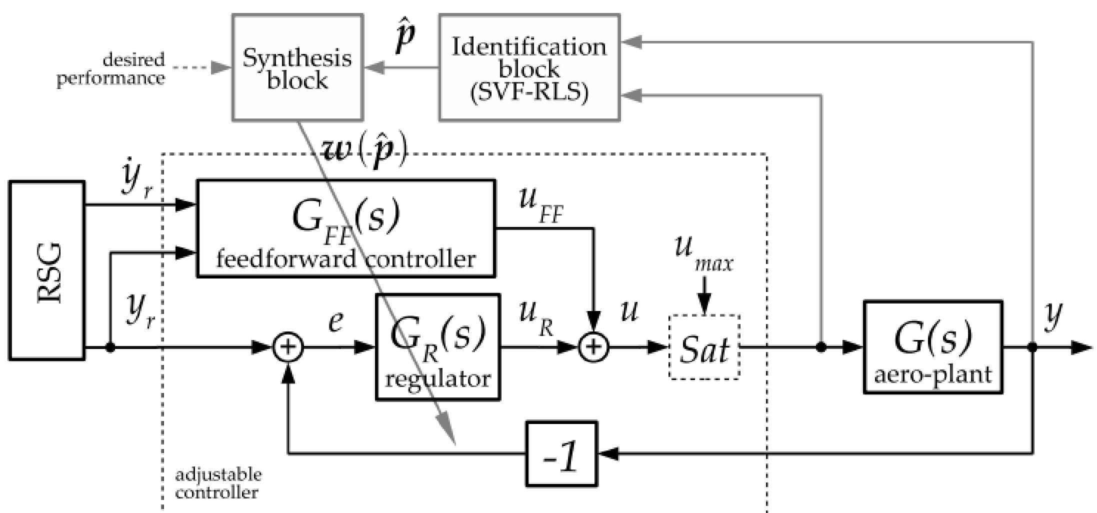


Figure1 : Block scheme of the MIAC system for the aero-plant

3. Key Parameters

- T_a = 0.05 s (adaptation loop sampling)
- T_c = 0.001 s (control loop sampling)
- T_F = 1.5T_a (SVF time constant)

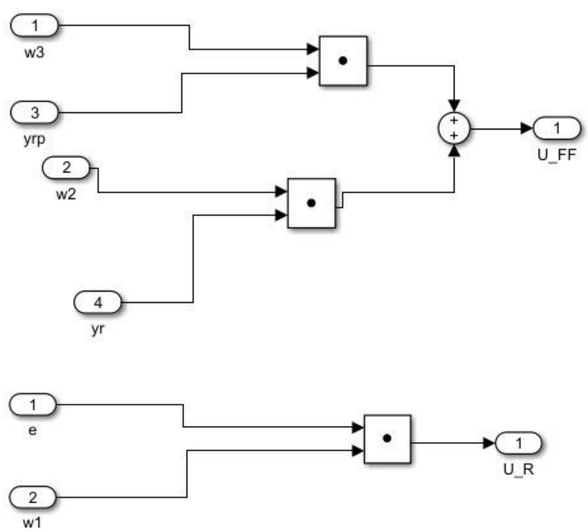
```
clear all
clc
```

```
%initialize global variables
    Ta=0.05;      %sampling time  of adaptation loop
    Tc=0.001;     %sampling interval of conventional control
    sigma2e=0.01; %variance of stochastic noise of disturbing plant1
                  % To be changed from 0,  0.01, 0.1 to simulate noisy
                  % conditions
    TF = 1.5*Ta;  %Time constant for SVF filters

%The identification block
    %initialization of RecursiveLeastSquare
    global P p_hat;
    P = eye(2);
    p_hat = [1 ; 1];
```

4. Adjustable Controller

We have to design of the **Regulator Gr(s) and the Feedforward controller Gff(s) :**



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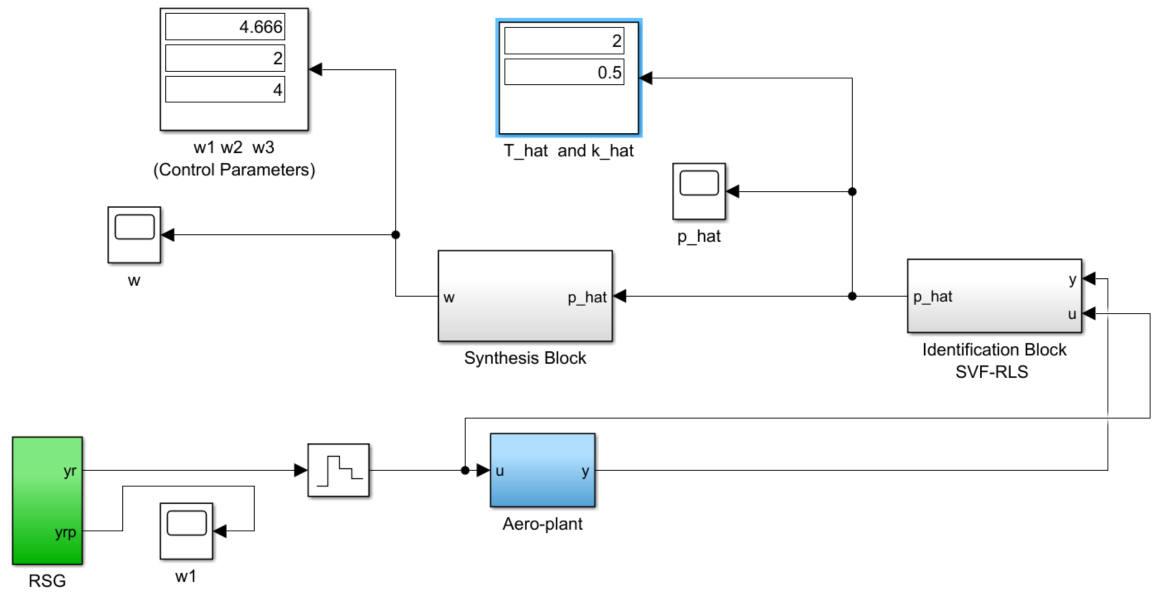
VII. Results and Discussion:

1. Open-Loop Identification:

- Input: y_r = 1.0 sin(0.5t)
- Obtained accurate estimates of T_0 , k_0 in noise-free conditions
- Performance degraded with increased noise ($\sigma^2_e \in \{0.01, 0.1, 1.0\}$)



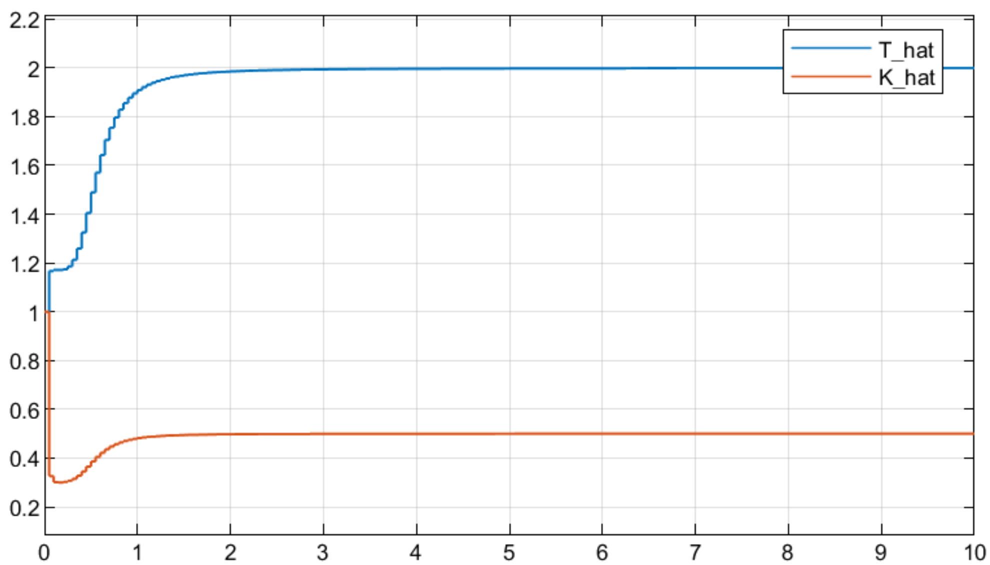


Figure: The parameters T and of our Plant

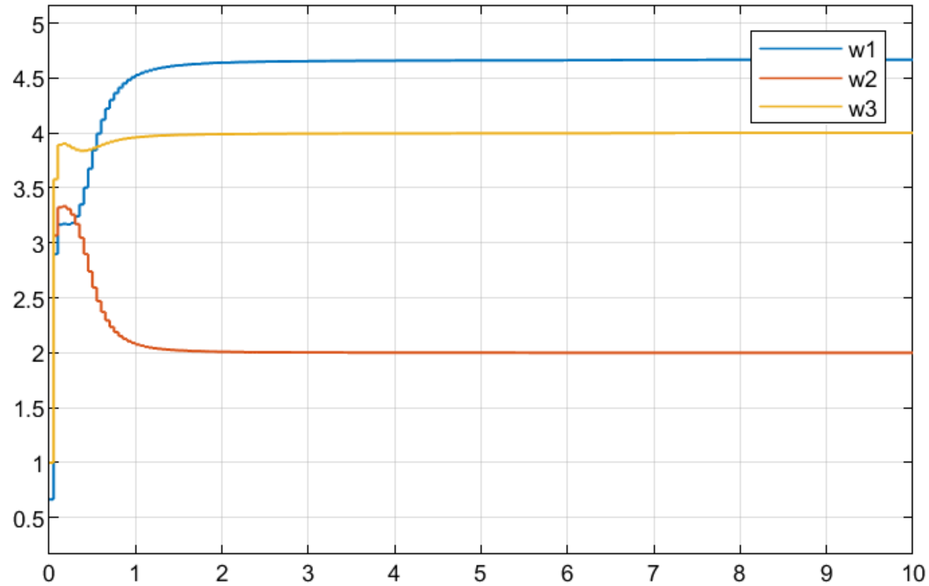
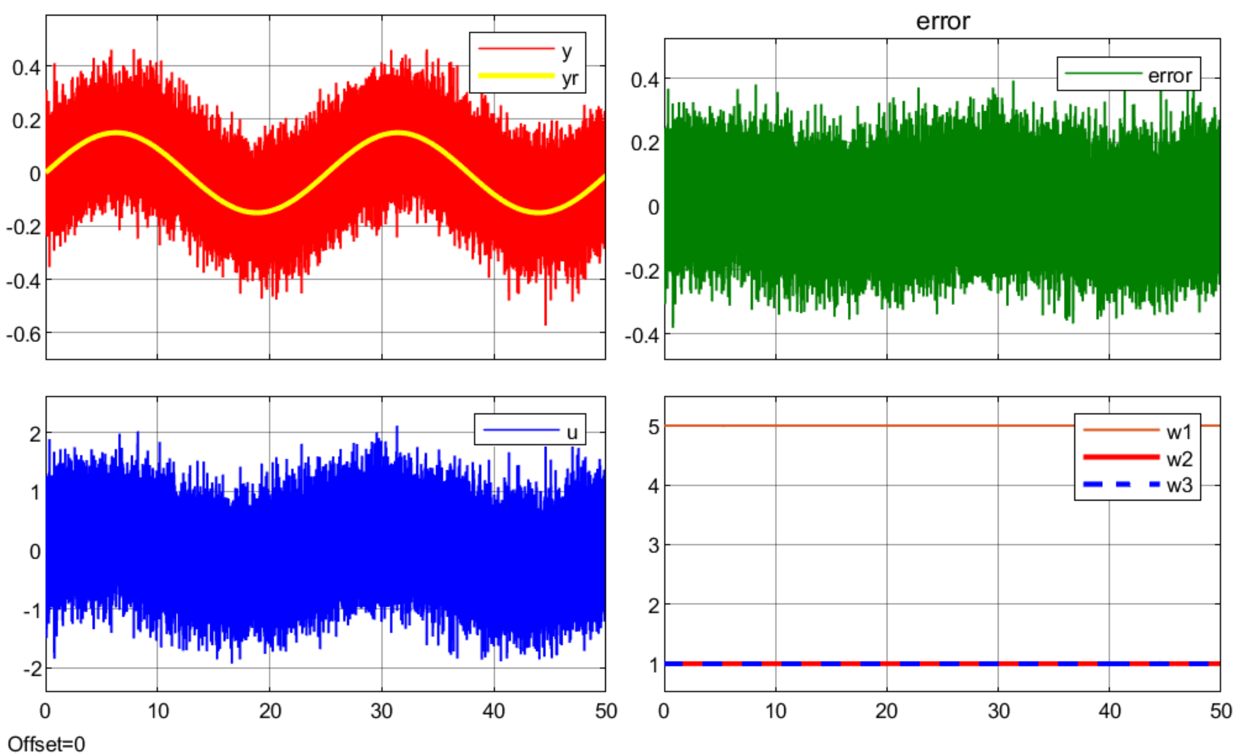


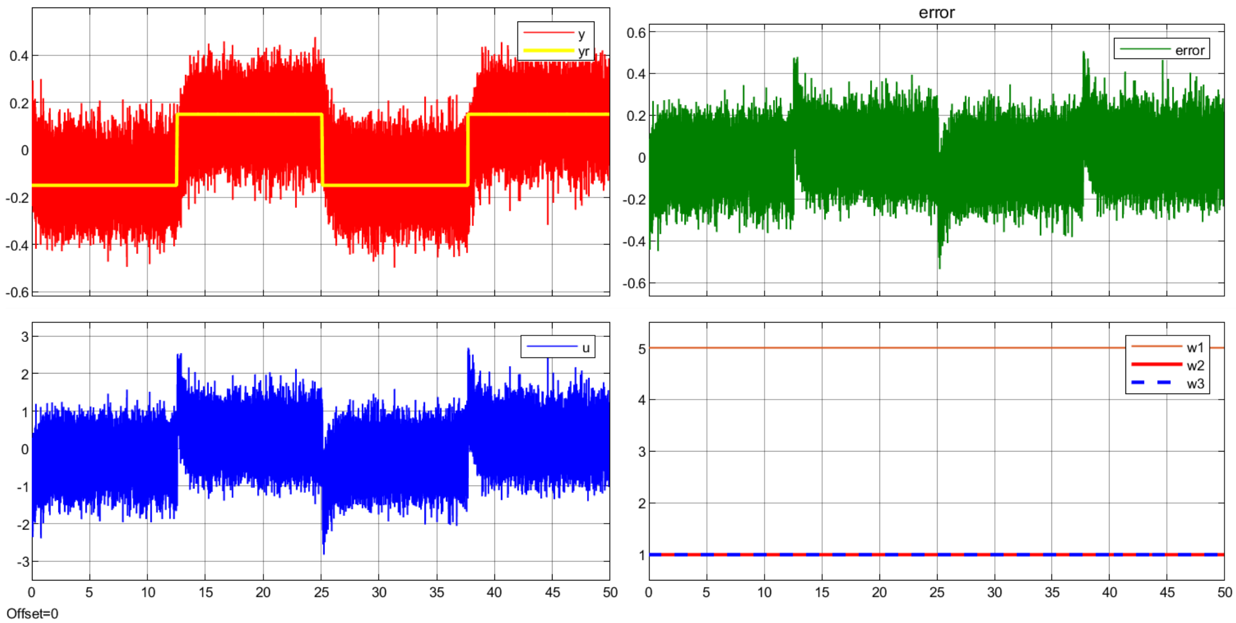
Figure: The parameters of our Controller

2. Closed-Loop, Non-Adaptive Control

- Fixed parameters: w = [5.0, 1.0, 1.0]
- Input: y_r = 0.15 sin(0.25t)
- Without filtering the noise

sigma2e = 0.01

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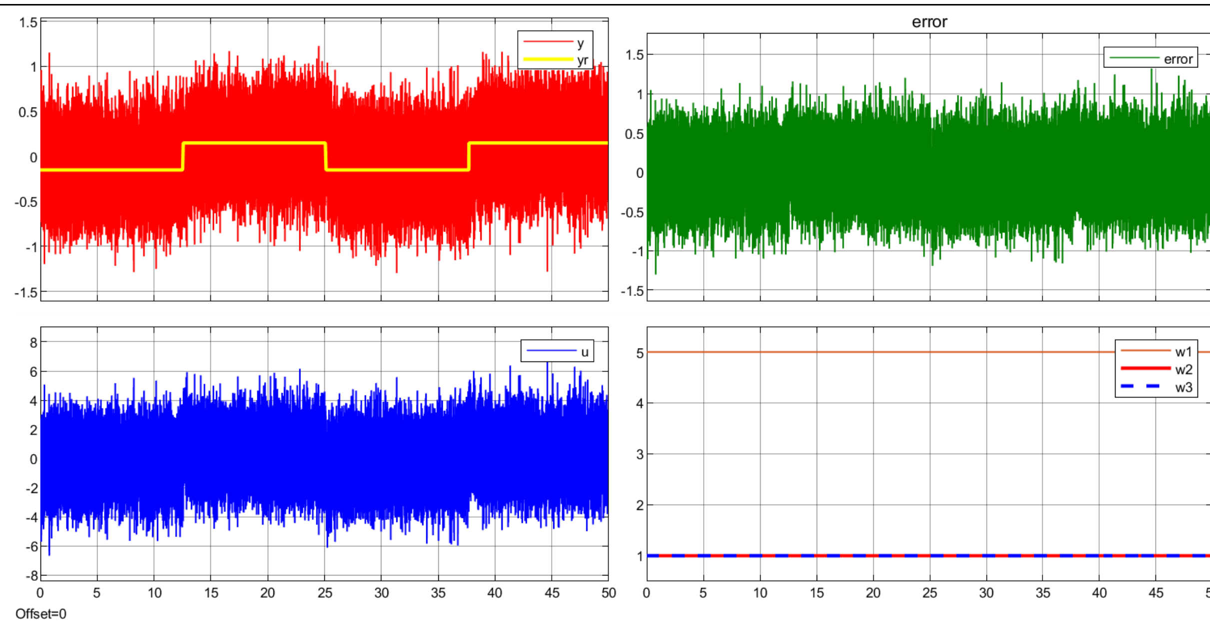
Sigma2e = 0.1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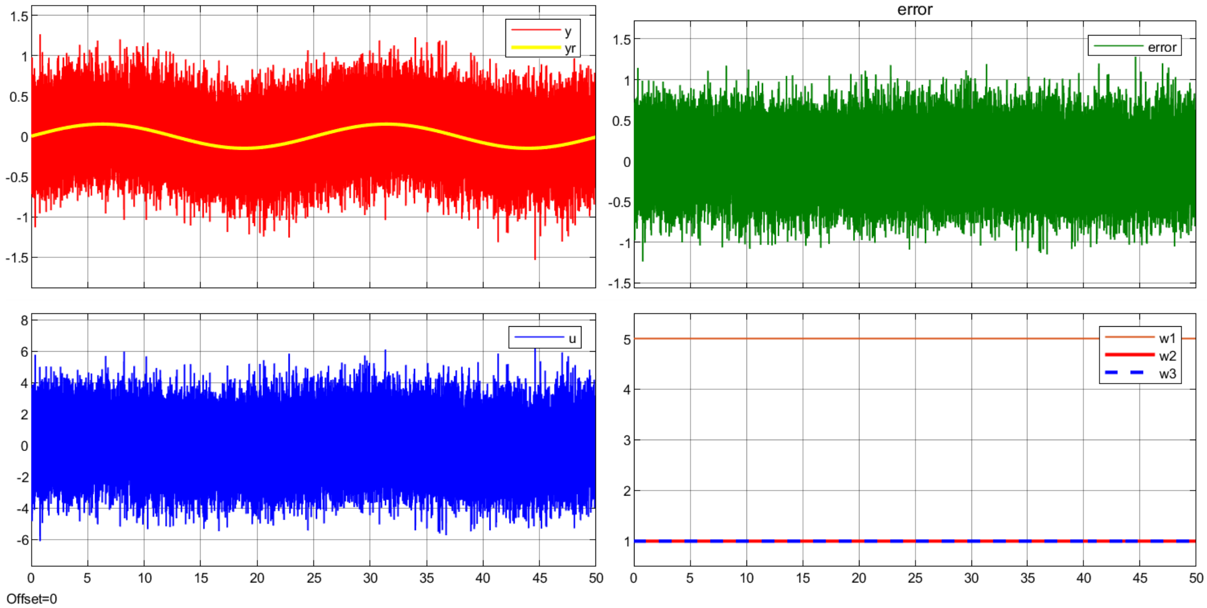
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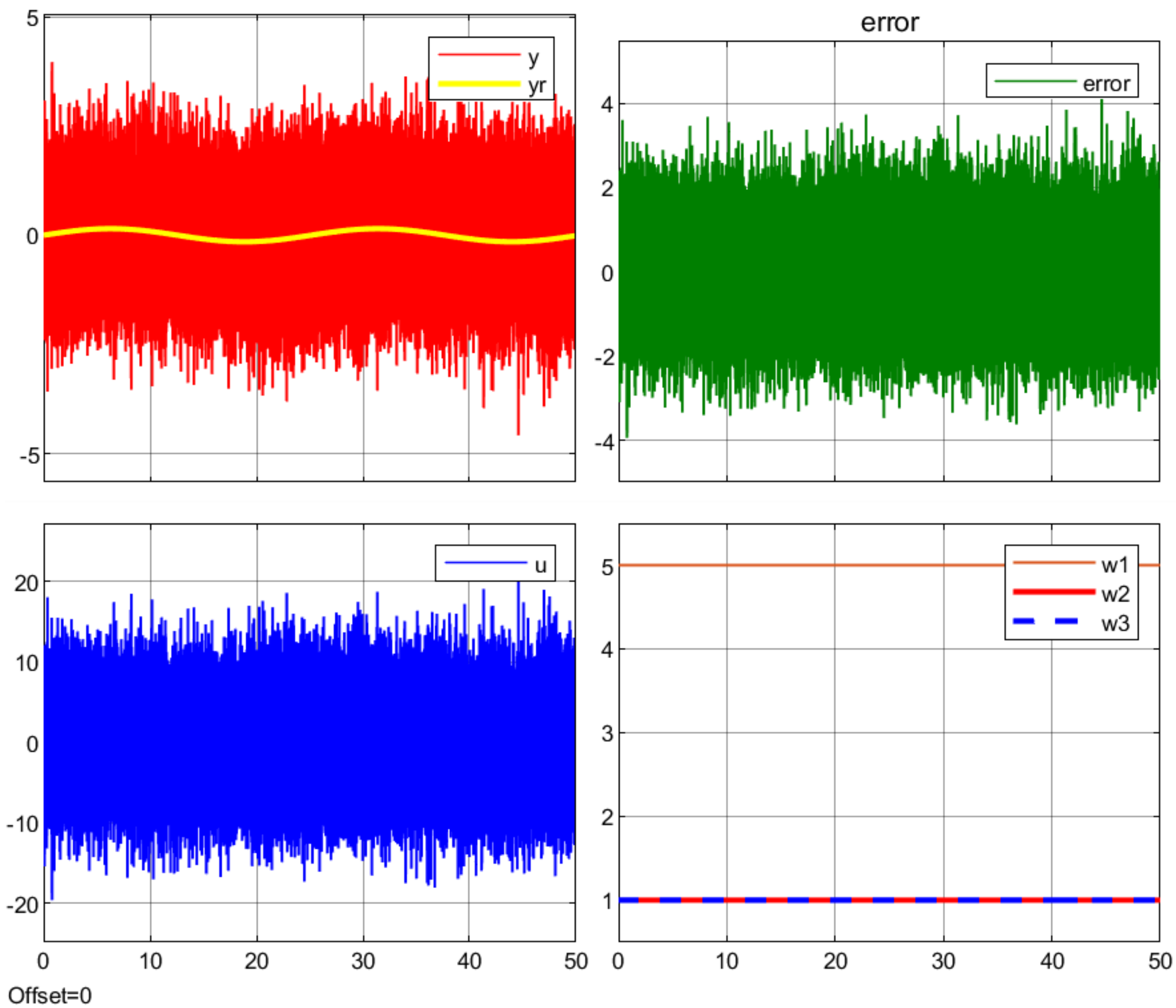
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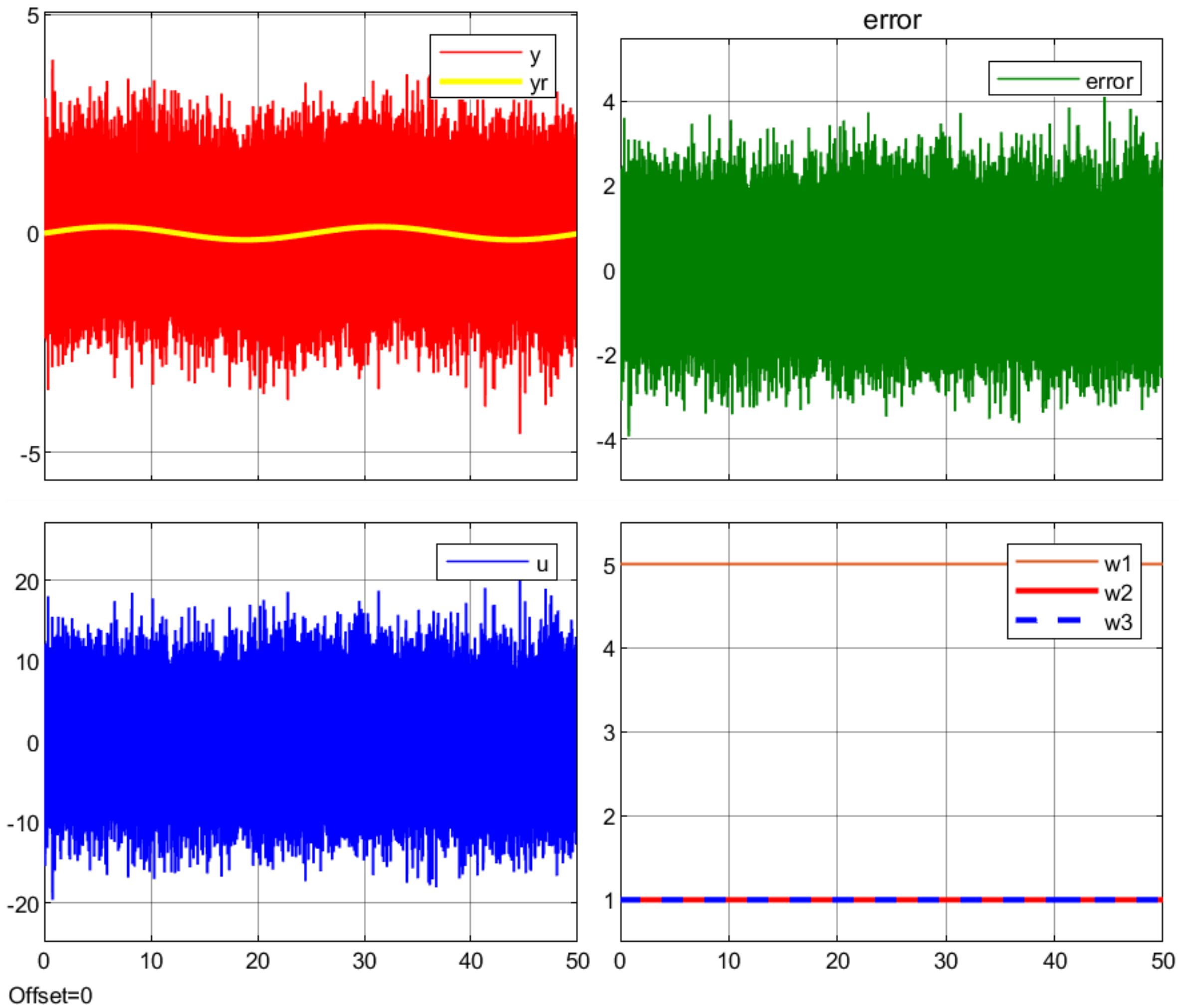


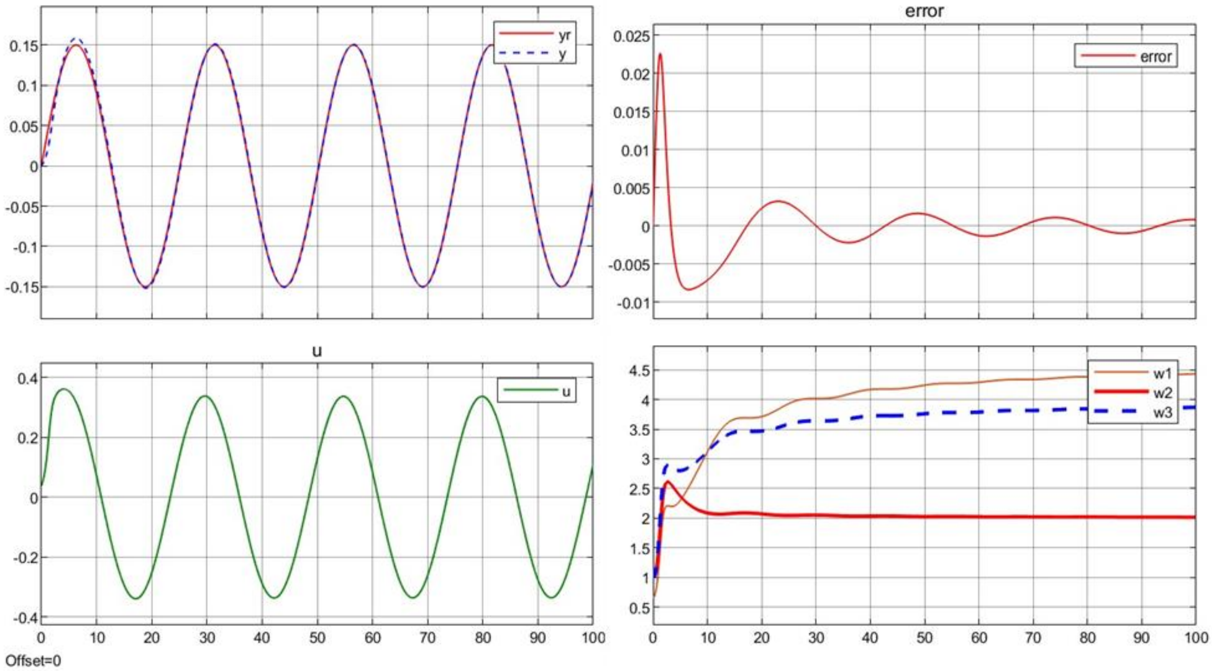
Results:

- **Poor tracking, requirements R2, R3 not met**
- **Manual tuning difficult due to unknown plant parameters**

3. Adaptive Control (MIAC)

- Input 1: y_r = 0.15 sin(0.25t)
- Input 2: y_r = 0.15 rect(0.25t)
- With filtering white noise

Sigma2e=0.0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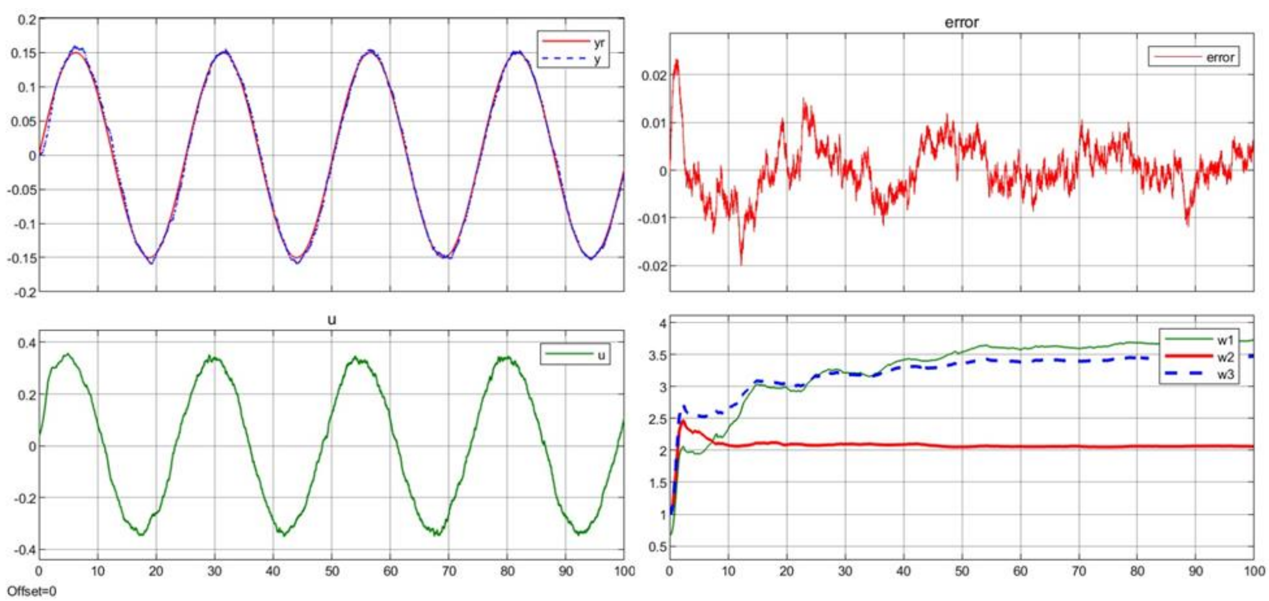
Sigma2e=0.01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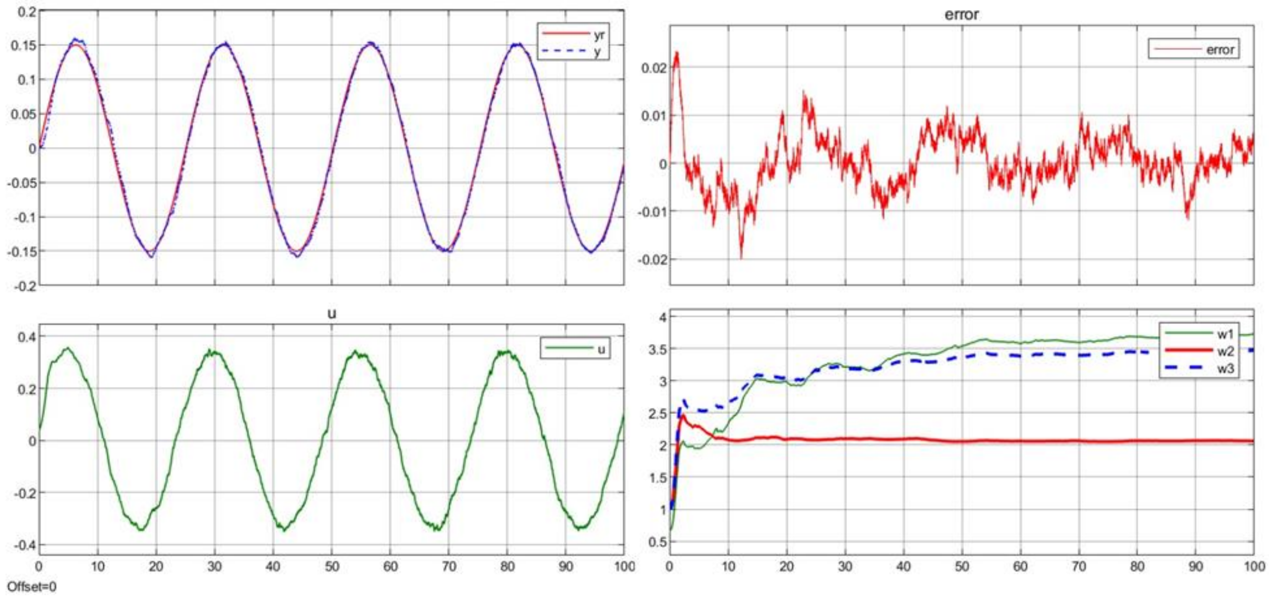

Results:

a) Noise-free (σ^2_e = 0): Excellent tracking, R2 and R3 satisfied
b) Low noise (σ^2_e = 0.01): Good performance, R2 and R3 satisfied

c) Higher noise (σ^2_e = 0.1): Degraded, but still stable

- Control signal u mostly within [−π, π], occasional saturation
- Safety nets (kÜ≥ 0.1) prevented instability

4. Additional Tests:

- **Control saturation:** Minor impact on performance
- **Sampling time T_a:** Faster adaptation with smaller T_a
- **Initial covariance P(0) = ρI:** Higher ρ led to faster adaptation but more sensitivity to noise

Conclusion

In this Laboratory we have successfully applied the Model-Identification Adaptive Control (MIAC) scheme to an aircraft's roll dynamics, demonstrating its effectiveness in handling parametric uncertainties. The MIAC system met all performance requirements, achieving zero steady-state error, prescribed settling time, and robust tracking under various conditions. It outperformed fixed-gain and gain-scheduled controllers, particularly when plant parameters varied.