TITLE

Automatic Control
Electronic Engineering for Intelligent Vehicles
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Abstract

Here briefly detail the aims of the project.

Chapter 1

Introduction

1.1 Motivations

Explain why the selected application is important. Describe the application with informal words.

1.2 Contributions

Describe what this project deals with. What has been done to solve the problem presented in the motivations.

1.3 State of art and literature comparison

List the closest works that deal with the same problem and compare the achievement obtained and the strategies exploited in this paper. For the search of the literature use `https://ieeexplore.ieee.org/Xplore/home.jsp` and `https://www.sciencedirect.com/`.

1.4 Organisation of the manuscript

Describe what the reader finds in each of the Sections of this manuscript.

1.5 List of the symbols

Here list all the symbols used in the manuscript and add a description to each of them (Use the International System of Units `https://en.wikipedia.org/wiki/International_System_of_Units`).

Chapter 2

MAIN BODY

Change the title with the name of the selected application

2.1 Model and Problem Formulation

In this section, we formulate the control problem for the active suspension system of a half-car model. This system aims to regulate both the vertical position and the perceived pitch angle of the vehicle body, enhancing ride comfort and handling. The model is described by a nonlinear dynamic system influenced by road disturbances, actuator forces, and sensor measurements.

The general form of the system is expressed as:

$$\dot{x} = f(x, u, w) \tag{2.1}$$

$$y = h(x, u, w) \tag{2.2}$$

$$e = h_e(x, u, w) \tag{2.3}$$

Where:

- $x \in \mathbb{R}^n$ is the **state vector**,
- $u \in \mathbb{R}^p$ is the **control input vector**,
- $y \in \mathbb{R}^q$ is the **measured output vector**,
- $e \in \mathbb{R}^{l_m}$ is the **control error (goal)**,
- $d \in \mathbb{R}^{l_d}$ is the **disturbance vector**,
- $r \in \mathbb{R}^{l_r}$ is the **reference signal**,
- $\nu \in \mathbb{R}^q$ is the **sensor noise**,
- $w = \mathrm{col}(d, \nu, r)$ is the **exogenous input**.

$$\begin{aligned} \dot{x} &= f(x, u) \quad x(t_0) = x_0 \\ y &= h(x, u) \end{aligned} \tag{2.4}$$

Assumptions

To make the problem tractable and to ensure solvability of the control task, we impose the following assumptions:

1. The exogenous input w is not directly measurable.
2. Disturbances d are bounded.
3. Reference signal r and its first derivatives are known.
4. Bounded disturbances imply bounded internal states and outputs.
5. The system has at least as many control inputs as control goals, i.e., $p \geq l_m$.
6. The control error e can be reconstructed from the output y: $\exists E$ such that $e = E(y)$.

These assumptions lay the theoretical foundation required to design a control law capable of driving the error e to zero despite the presence of unknown disturbances and sensor noise.

2.2 Model Analysis

2.2.1 Dynamic Model

The half-car model captures the vertical and pitch dynamics of a vehicle subject to suspension forces and road disturbances. The state variables are:

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{bmatrix} = \begin{bmatrix} z - z_g \\ \dot{z} - \dot{z}_g \\ \phi \\ \dot{\phi} \\ \phi_g \\ \omega_g \end{bmatrix} \tag{2.5}$$

Control inputs are defined as:

$$u = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} f_{af} + f_{ar} \\ f_{af} d_f - f_{ar} d_r \end{bmatrix} \tag{2.6}$$

The system dynamics are expressed as:

$$\dot{x} = \begin{bmatrix} x_2 \\ f_2 - \ddot{z}_g \\ x_4 \\ f_4 \\ x_6 \\ \alpha_g \end{bmatrix} \tag{2.7}$$

Where:

$$f_2 = -g + \frac{1}{m}(f_{sf} + f_{sr}) + \frac{u_1}{m} \tag{2.8}$$

$$f_4 = \frac{1}{J}(f_{sf}d_f - f_{sr}d_r + u_2 + f_{wf}f + f_{wr}r) \tag{2.9}$$

The suspension deflections and velocities are:

$$s_1 = x_1 + d_f(\sin x_3 - \sin x_5), \quad s_3 = x_1 - d_r(\sin x_3 - \sin x_5) \tag{2.10}$$

$$s_2 = x_2 + d_f(x_4 \cos x_3 - x_6 \cos x_5), \quad s_4 = x_2 - d_r(x_4 \cos x_3 - x_6 \cos x_5) \tag{2.11}$$

Suspension forces are modeled as spring-damper systems:

$$f_s(p, v) = -kp - \beta v \tag{2.12}$$

2.2.2 Sensor Model

The measurement vector is given by:

$$y = \begin{bmatrix} y_y \\ y_z \\ y_g \\ y_l \\ y_r \end{bmatrix} = \begin{bmatrix} \sin x_3(f_2 + g) + \cos x_3 \frac{f_{wr}+f_{wf}}{m} \\ \cos x_3(f_2 + g) - \sin x_3 \frac{f_{wr}+f_{wf}}{m} \\ x_4 \\ s_1 \\ s_3 \end{bmatrix} + \nu \tag{2.13}$$

2.2.3 Control Objectives

We define the apparent pitch angle ϕ_a using accelerometer data:

$$\phi_a = \sin^{-1}\left(\frac{y_y}{\sqrt{y_y^2 + y_z^2}}\right) \tag{2.14}$$

The control error vector is defined as:

$$e = \begin{bmatrix} \frac{y_f d_r + y_r d_f}{d_r + d_f} - r_z \\ \phi_a - r_\phi \end{bmatrix} \tag{2.15}$$

This error describes deviations from the desired vertical height and perceived pitch. The control task is to design u to drive $e \to 0$ in the presence of disturbances and noise.

2.3 Proposed Solution

Here describe the proposed solution: Control system architecture (draw a block scheme!), mathematical description of the solution, listings of the MATLAB code implemented to obtain the solution

To include a picture use the environment *figure*. Use the environment *ref* to

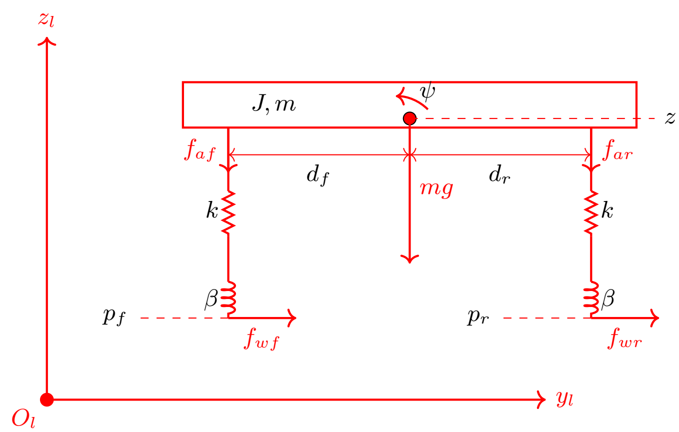
Figure 2.1: Add the caption to each figure! The caption should completely describe the figure so that the reader should be able to understand it without the need of reading the main text.

add a hyperlink to the figure. As example Figure 2.1.

Chapter 3

Application

3.1 Simulator description



Copy and past the Simulink block scheme and describe what each block does. Describe the set-up MATLAB file, where and how to change the parameters of the simulations. Remember to include also the sensor noises and realistic external disturbances.

3.2 Simulation results

Describe the simulation scenario: initial conditions, purpose of the simulation. Describe the results: are the results coherent with the expectation? If not why? Investigate the tuning: how the performance are affected by the selection of the parameters at disposal of the designer?

Chapter 4

Conclusions and further investigation

Recap the main results obtained in the project and highlight eventual further investigation directions alogn which the performance could be improved.

Bibliography

List the papers/books cited.

Appendix

Use appendices to add technical parts which are instrumental for the completeness of the manuscript but are too heavy to be included inside the main text. Basically, appendices are exploited to let the main text cleaner and smoother. As example, the complete MATLAB listings can be reported in appendix.

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