

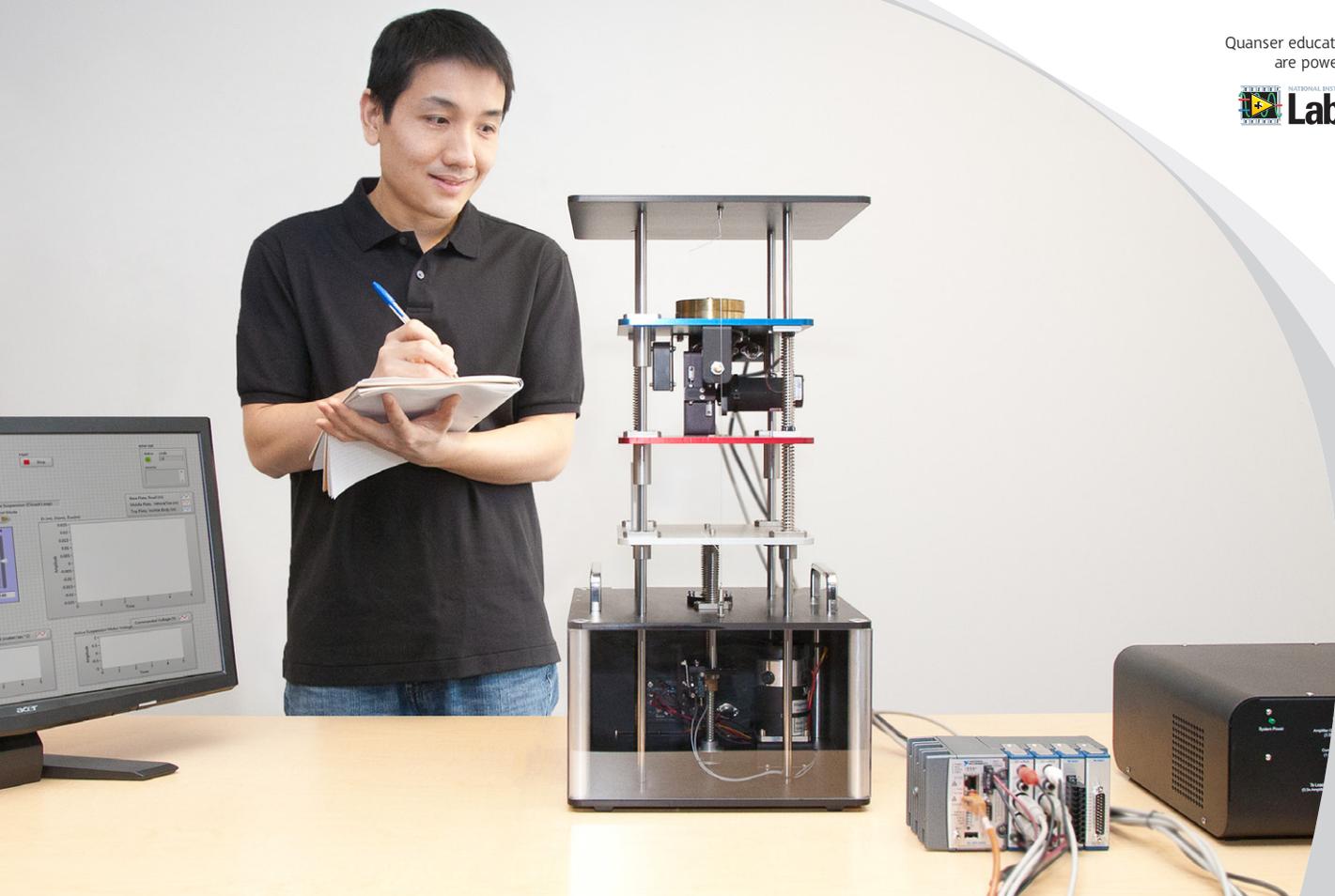


LABORATORY GUIDE

Active Suspension Experiment for LabVIEW™ Users

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CONTENTS

1	Introduction	4
1.1	Description	4
1.2	Topics Covered	4
2	Background	5
2.1	Modeling	5
2.2	Control	9
3	In-Lab Procedure	11
3.1	Simulation	11
3.2	Experiment	12
4	System Requirements	14
4.1	Overview of Files	15
4.2	Setup for Simulation	15
4.3	Setup for Experiment	17

1 INTRODUCTION

1.1 Description

The purpose of the Active Suspension is to design and implement a state-feedback controller for a quarter-car model. This system consists of two masses, each supported by a spring and a damper. The *sprung mass*, M_s , represents the mass of the vehicle body while the *unsprung mass*, M_{us} , represents the tire in the quarter-car model. This system is fourth order because there are four independent storage elements, the two masses and the two springs. The spring K_s and the damper B_s support the body weight over the tire. The spring K_{us} and the damper B_{us} model the stiffness of the tire in contact with the road. An LQR controller can be used to optimize a variety of performance parameters in the quarter-car model. In this approach, the performance criteria are formulated into a mathematical model. This mathematical representation is then optimized while considering the control actuator limitations. The performance measures that have to be minimized are listed below:

- *Ride Comfort* is related to vehicle body motion sensed by the passengers. A measure for the Ride Comfort is the acceleration of the sprung mass in the quarter car model.
- *Suspension Travel* refers to relative displacement between the vehicle body and the tire and is constrained within an allowable workspace. In the quarter car model, relative displacement between the sprung mass and the unsprung mass represents Suspension Travel.
- *Road Handling* is associated with the contact forces between the road surface and the vehicle tires. These forces provide the necessary friction between the road and the tires in a real car. The contact forces between the road and the tires depend on the *tire deflection*. In a quarter car model, relative displacement between the unsprung mass and the road represents the tire deflection.

1.2 Topics Covered

The following topics are covered in this manual:

- How to mathematically model the Active Suspension plant, using, for example, force analysis on free body diagrams.
- How to obtain a state-space representation of the open-loop system and to do open-loop analysis
- How to obtain different transfer functions for the Active Suspension Experiment as a MIMO system.
- How to use the obtained Active Suspension state-space representation to design a Linear Quadratic Regulator (LQR).
- To simulate the Linear Quadratic Regulator (LQR) controller using the developed model of the plant and to ensure the controller performance specifications are met without any actuator saturation.
- To implement an LQR-based state-feedback controller in real-time and evaluate its actual performance.
- To observe and investigate the disturbance response of the suspension system in response to chirp and pulse shape road disturbances.

2 BACKGROUND

2.1 Modeling

2.1.1 Dynamics

In this section, the general dynamic equations of the Active Suspension System will be derived. The Free Body Diagram method is used to obtain the dynamics of the system as a double mass-spring damper model. This diagram is illustrated in Figure 2.1. In this approach, the two inputs to the system are considered to be active suspension control command F_c and the road surface position z_r . Furthermore, it is reminded that the reference frames in Figure 2.1 are used to choose the generalized coordinates, i.e. x_1 and x_2 . The generalized coordinate x_1 represents the tire displacement (unsprung mass in quarter car model) and x_2 represents the vehicle body displacement (sprung mass in the quarter car model) all with respect to the ground. The positive directions are upwards.

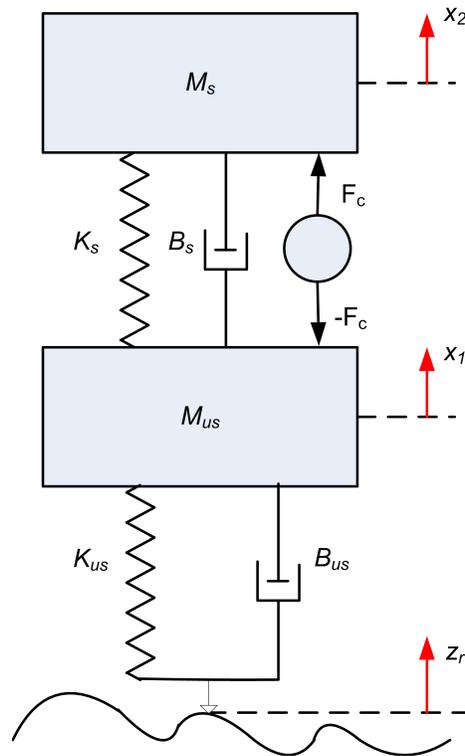


Figure 2.1: Double Mass-Spring-Damper used to model Active Suspension

To find out equations of motion (EOM) for this system, The free body diagram for each mass should be determined. There are two masses in the system and the forces applied to each mass should be drawn on the diagrams. There will be two equations of motion. All the initial conditions are assumed to be zero. The free body diagram for M_s looks like Figure 2.2. The forces applied to the M_s are due to the spring force, damping force, active suspension force, and gravity.

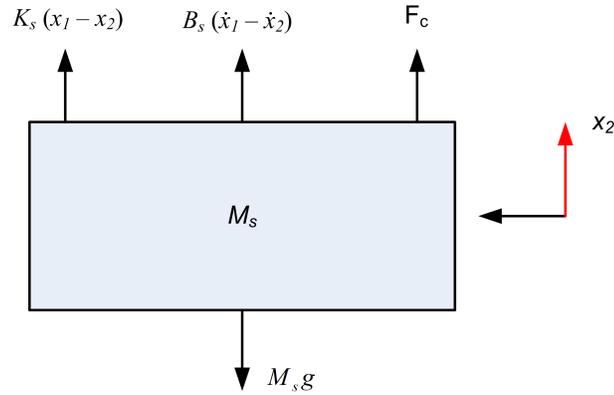


Figure 2.2: The free body diagram for M_s

The EOM for M_s will be as follows

$$\ddot{x}_2 = -g + \frac{F_c}{M_s} + \frac{B_s \dot{x}_1}{M_s} - \frac{B_s \dot{x}_2}{M_s} + \frac{K_s x_1}{M_s} - \frac{K_s x_2}{M_s} \quad (2.1)$$

The free body diagram for M_{us} looks like Figure 2.3. The forces applied to the M_{us} are the springs forces, damping forces, active suspension force, and gravity.

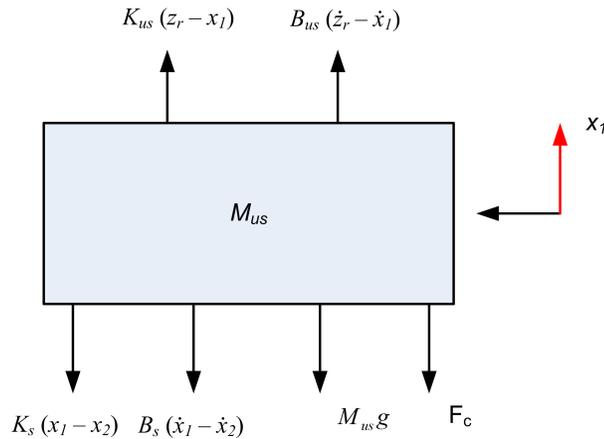


Figure 2.3: The free body diagram for M_{us}

The EOM for M_{us} can be derived as follows

$$\begin{aligned} \ddot{x}_1 = & -g - \frac{F_c}{M_{us}} - \frac{(B_s + B_{us}) \dot{x}_1}{M_{us}} + \frac{B_s \dot{x}_2}{M_{us}} + \frac{B_{us} \dot{z}_r}{M_{us}} \\ & - \frac{(K_{us} + K_s) x_1}{M_{us}} + \frac{K_s x_2}{M_{us}} + \frac{z_r K_{us}}{M_{us}} \end{aligned} \quad (2.2)$$

2.1.2 Eliminating Gravity Force from EOM

The objective of this section is to prove mathematically that the gravity force only changes the equilibrium points in the Active Suspension EOM and it does not affect the dynamics of the system. At the static equilibrium point,

i.e. $x_1 = x_{eq1}, x_2 = x_{eq2}$, all the derivatives of x_1 and x_2 of any order are zero. Also, the road surface z_r and all its derivatives and the control force F_c are zero. Substituting these changes in equations 2.1 and 2.2 will give the following results

$$\begin{aligned} K_s x_{eq1} - K_s x_{eq2} + M_{us} g + x_{eq1} K_{us} &= 0 \\ M_s g + K_s x_{eq2} - K_s x_{eq1} &= 0 \end{aligned} \quad (2.3)$$

As a result, the equilibrium points due to gravity will be

$$x_{eq1} = -\frac{g(M_s + M_{us})}{K_{us}} \quad (2.4)$$

$$x_{eq2} = -\frac{g(M_s K_{us} + K_s M_s + K_s M_{us})}{K_{us} K_s} \quad (2.5)$$

In order to remove gravity forces from the equations of motion we apply the following change of variables to the equations of motion:

$$\begin{aligned} x_1 &= z_{us} - \frac{g(M_s + M_{us})}{K_{us}}, & x_2 &= z_s - \frac{M_s g}{K_s} - \frac{g(M_s + M_{us})}{K_{us}} \\ \dot{x}_1 &= \dot{z}_u, & \dot{x}_2 &= \dot{z}_s \\ \ddot{x}_1 &= \ddot{z}_{us}, & \ddot{x}_2 &= \ddot{z}_s \end{aligned} \quad (2.6)$$

By substituting the variable changes in 2.6 into Active Suspension EOM we get the following equations where the effect of gravity has been eliminated from the equations. In other words, the relaxed position of the springs, i.e. $z_{us} = 0, z_s = 0$, will be the equilibrium point of the system.

$$M_{us} \ddot{z}_{us} = -B_s \dot{z}_{us} - B_{us} \dot{z}_{us} - F_c + B_s \dot{z}_s + B_{us} \dot{z}_r - (z_{us} - z_s) K_s - (z_{us} - z_r) K_{us} \quad (2.7)$$

$$M_s \ddot{z}_s = B_s \dot{z}_{us} + F_c - B_s \dot{z}_s - (z_s - z_{us}) K_s \quad (2.8)$$

The only inputs to this system are the control force and the road surface.

2.1.3 State Space Representation

In order to design and implement a state-feedback controller for a system a state-space representation of that system needs to be derived. In this Section, a state space representation for the Active Suspension will be derived. It is reminded that state-space matrices, by definition, represent a set of linear differential equations that describe the system's dynamics. Since the two EOM of the Active Suspension system should already be linear and time-invariant, they can be written under the state-space representation as follows

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \quad (2.9)$$

The state space approach is a convenient way to model the quarter-car model with multiple inputs and outputs. The states can be defined such that they reflect the system performance parameters that have to be optimized. Moreover, this state space can be later used for state-feedback controller and observer design. Due to the existence

of four energy storage elements in the quarter car model one should define four state for the system. The four state variables, the two inputs to the system, and the two outputs can be defined as follows:

$$x = \begin{bmatrix} z_s - z_{us} \\ \dot{z}_s \\ z_{us} - z_r \\ \dot{z}_{us} \end{bmatrix}, u = \begin{bmatrix} \dot{z}_r \\ F_c \end{bmatrix}, y = \begin{bmatrix} z_s - z_{us} \\ \ddot{z}_s \end{bmatrix} \quad (2.10)$$

Where the first state represents suspension deflection/travel. The second state is the vehicle body vertical velocity. The third state is the tire deflection which is a measure of road handling. The fourth state is the tire vertical velocity. The first input to the system is the road surface velocity. The second input is the control action that will be later designed. The first measured output of the system is the suspension travel. Assuming that the vehicle body is equipped with an accelerometer, the second measured output of the system will be the body acceleration. Using the equations of motions defined in one can calculate the matrices A , B , C , and D as follows:

$$A = \begin{bmatrix} 0 & 1 & 0 & -1 \\ -\frac{K_s}{M_s} & -\frac{B_s}{M_s} & 0 & \frac{B_s}{M_s} \\ 0 & 0 & 0 & 1 \\ \frac{K_s}{M_{us}} & \frac{B_s}{M_{us}} & -\frac{K_{us}}{M_{us}} & -\frac{B_s+B_{us}}{M_{us}} \end{bmatrix}, B = \begin{bmatrix} 0 & 0 \\ 0 & \frac{1}{M_s} \\ -1 & 0 \\ \frac{B_{us}}{M_{us}} & -\frac{1}{M_{us}} \end{bmatrix} \\ C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ -\frac{K_s}{M_s} & -\frac{B_s}{M_s} & 0 & \frac{B_s}{M_s} \end{bmatrix}, D = \begin{bmatrix} 0 & 0 \\ 0 & \frac{1}{M_s} \end{bmatrix} \quad (2.11)$$

2.1.4 System Transfer Functions

The state space representation that was derived in last section is an example of a multi-input and multi-output system (MIMO) with two inputs, i.e., road surface velocity and controller force F_c , and two outputs, i.e., suspension travel and body acceleration. The characteristic equation of the open-loop system can be expressed as shown below:

$$\det(sI - A) = 0 \quad (2.12)$$

where $\det()$ is the determinant function, s is the Laplace operator, and I is the identity matrix. Therefore, the system's open-loop poles can be seen as the eigenvalues of the state-space matrix A . The characteristic equation of the Active Suspension is as follows:

$$\det(sI - A) = \frac{1}{M_s M_{us}} (s^4 M_s M_{us} + s^3 M_s B_s + s^3 M_s B_{us} + s^2 M_s K_{us} + B_s s^3 M_{us} + B_s s^2 B_{us} + s B_s K_{us} + K_s s^2 M_{us} + K_s s B_{us} + K_s K_{us} + K_s s^2 M_s) \quad (2.13)$$

The transfer functions for a MIMO system can be calculated as follows based on the system state space representation:

$$C(sI - A)^{-1}B + D \quad (2.14)$$

Below, the transfer functions for all the combinations of the two inputs and two outputs of Active Suspension are derived. The operator \mathcal{L} is the Laplace operator.

$$\mathcal{L}\left(\frac{z_s - z_{us}}{\dot{z}_r}\right) = -sM_s(K_{us} + sB_{us}) / (s^4M_sM_{us} + (M_sB_{us} + B_sM_{us} + M_sB_s)s^3 + (M_sK_{us} + B_sB_{us} + K_sM_s + K_sM_{us})s^2 + (K_sB_{us} + B_sK_{us})s + K_sK_{us}) \quad (2.15)$$

$$\mathcal{L}\left(\frac{z_s - z_{us}}{F_c}\right) = ((M_{us} + M_s)s^2 + sB_{us} + K_{us}) / (s^4M_sM_{us} + (M_sB_{us} + B_sM_{us} + M_sB_s)s^3 + (M_sK_{us} + B_sB_{us} + K_sM_s + K_sM_{us})s^2 + (K_sB_{us} + B_sK_{us})s + K_sK_{us}) \quad (2.16)$$

$$\mathcal{L}\left(\frac{\ddot{z}_s}{\dot{z}_r}\right) = s(B_s s^2 B_{us} + (K_s B_{us} + B_s K_{us})s + K_s K_{us}) / (s^4 M_s M_{us} + (M_s B_{us} + B_s M_{us} + M_s B_s)s^3 + (M_s K_{us} + B_s B_{us} + K_s M_s + K_s M_{us})s^2 + (K_s B_{us} + B_s K_{us})s + K_s K_{us}) \quad (2.17)$$

$$\mathcal{L}\left(\frac{\ddot{z}_s}{F_c}\right) = s^2(s^2 M_{us} + sB_{us} + K_{us}) / (s^4 M_s M_{us} + (M_s B_{us} + B_s M_{us} + M_s B_s)s^3 + (M_s K_{us} + B_s B_{us} + K_s M_s + K_s M_{us})s^2 + (K_s B_{us} + B_s K_{us})s + K_s K_{us}) \quad (2.18)$$

2.2 Control

There is a high demand for better ride comfort and handling of road vehicles. No suspension system can fully minimize all the performance measures introduced in Section 1 simultaneously. However, in comparison to passive suspension system, an actively controlled suspension, i.e., Active Suspension, can be exploited to come up with a better possible trade-off between the performance measures. In this Section, you will investigate the effects of Linear Quadratic Regulator (LQR) control. In this systematic approach, performance parameters as well as actuator limitations will be quantified in a quadratic measure which is later optimized. The optimal gain can then be used in a state feedback controller where it is assumed that the states are measurable.

In Section 2.1.3, we found a linear state-state space model that represents the Active Suspension system. This model is used to investigate the stability properties of the system in Section 2.2.1. The controllability notion of the system is presented in Section 2.2.2, Finally, in Section 2.2.3 the LQR controller is presented which will be later used to design a state-feedback gain to stabilize the system.

2.2.1 Stability

The stability of a system can be determined from its poles ([3]):

- Stable systems have poles only in the left-hand plane.
- Unstable systems have at least one pole in the right-hand plane and/or poles of multiplicity greater than 1 on the imaginary axis.
- Marginally stable systems have one pole on the imaginary axis and the other poles in the left-hand plane.

The poles are the roots of the system's characteristic equation. From the state-space, the characteristic equation of the system can be found using

$$\det(sI - A) = 0 \quad (2.19)$$

where $\det()$ is the determinant function, s is the Laplace operator, and I the identity matrix. These are the *eigenvalues* of the state-space matrix A .

2.2.2 Controllability

If the control input, u , of a system can take each state variable, x_i where $i = 1 \dots n$, from an initial state to a final state then the system is controllable, otherwise it is uncontrollable ([3]).

Rank Test The system is controllable if the rank of its controllability matrix

$$T = [B \ AB \ A^2B \ \dots \ A^nB] \quad (2.20)$$

equals the number of states in the system,

$$\text{rank}(T) = n. \quad (2.21)$$

2.2.3 Linear Quadratic Regulator (LQR)

If (A,B) are controllable, then the Linear Quadratic Regulator optimization method can be used to find a feedback control gain. Given the plant model in Equation 2.23, find a control input F_c that minimizes the cost function

$$J = \int_0^{\infty} x(t)'Qx(t) + RF_c(t)^2 dt, \quad (2.22)$$

Where $x(t)$ contains the actual states of the system defined in Equation 2.10. The performance index J penalizes the states of the system, i.e., suspension travel and tire deflection as the two performance measures, as well as the body velocity and tire velocity through the weighting matrix Q . It also reflects the control limitations by penalizing the control input through the weighting gain R . The weighting matrices affect how LQR minimizes the function and are, essentially, tuning variables.

In Active Suspension, the control action is F_c . Thus, the corresponding A matrix and B vector that correspond to this control action are as follows:

$$A = \begin{bmatrix} 0 & 1 & 0 & -1 \\ -\frac{K_s}{M_s} & -\frac{B_s}{M_s} & 0 & \frac{B_s}{M_s} \\ 0 & 0 & 0 & 1 \\ \frac{K_s}{M_{us}} & \frac{B_s}{M_{us}} & -\frac{K_{us}}{M_{us}} & -\frac{B_s+B_{us}}{M_{us}} \end{bmatrix}, B = \begin{bmatrix} 0 \\ \frac{1}{M_s} \\ 0 \\ -\frac{1}{M_{us}} \end{bmatrix} \quad (2.23)$$

This model was used to access the controllability of the system, and to derive appropriate feedback control gains.

The solution to the optimization problem in Equation 2.22 is $F_c = -Kx$. Given this control law, the state-space in Equation 2.23 becomes

$$\begin{aligned} \dot{x} &= Ax + B(-Kx) \\ &= (A - BK)x \end{aligned} \quad (2.24)$$

3 IN-LAB PROCEDURE

IMPORTANT: Before you can conduct these simulations and experiments, you need to make sure that the lab files are configured according to your setup. If they have not been configured already, then you need to go to Section 4 to configure the lab files first.

3.1 Simulation

The state space representation of Active Suspension was derived in Equation 2.11. In this section, you will generate those equations and design a controller.

The parameter values are outlined in the table below. These values have been derived using system identification techniques and they might not exactly match the nominal values presented in the Active Suspension User Manual.

Parameter Symbol	Parameter Name	Parameter Value
M_s	Sprung Mass	2.45 kg
M_{us}	Unsprung Mass	1 kg
K_s	Suspension Stiffness	900 N/m
K_{us}	Tire Stiffness	1250 N/m
B_s	Suspension Inherent Damping coefficient	7.5 Nsec/m
B_{us}	Tire Inherent Damping coefficient	5 Nsec/m

Table 3.1: Active Suspension Parameter Nomenclature

3.1.1 Procedure

Follow these steps to simulate the system:

1. Open the *ASE Simulation Control.vi* VI, shown in Figure 4.3. Make sure you choose your model file using the *File Path* control.
2. Run the VI. The state space representation of ASE will be loaded and demonstrated in the white window. The second column in the B matrix corresponds to the control action F_c .
3. The road input is a square shape signal with an amplitude of $0.01m$ and frequency of $.3Hz$
4. You can use any of the three different control strategies to design a closed loop controller for the active suspension system, i.e. ,
 - Manual Gain Tuning
 - Pole Placement Design
 - LQR Control Design

For instance, in LQR Design tab, tune the elements inside Q and R matrices and the resulting feedback gain will be automatically updated. Any of these methods can be chosen by clicking on their respective tab. The control gain will be automatically updated on the fly and the closed loop performance of the system can be observed. The closed loop gain is shown inside the Controller Feedback Gain (K). The default value of this gain is set to keep the system stable. In addition, the closed loop poles of the system are shown in the *Closed Loop Poles Map*.

5. Z_r represents the bottom plate position which refers to the road. Z_{us} represents the middle plate position which refers to vehicle tire. Z_s represents the top plate position which refers to vehicle body.
6. After the desired control performance is achieved in simulation, write down the Feedback Gain to use it in the experiment.

7. Stop the VI by pressing the Stop button.

3.1.2 Analysis

In the closed loop system the vehicle body and tire exhibit smaller oscillations in response to the road disturbances. The acceleration signal amplitude is also smaller in closed loop which indicates a better comfort measure in the quarter-car system. The tire oscillations are also dampened which indicates a better road handling measure.

3.2 Experiment

3.2.1 Closed-Loop Control

1. Open the *ASE Experiment Control.vi* VI, shown in Figure 4.3.
2. The road input is a square shape signal with an amplitude of $0.01m$ and frequency of $0.3Hz$
3. Run this VI.
4. Z_r represents the bottom plate position which refers to the road. Z_{us} represents the middle plate position which refers to vehicle tire. Z_s represents the top plate position which refers to vehicle body. The open loop response of the system should look like the picture below

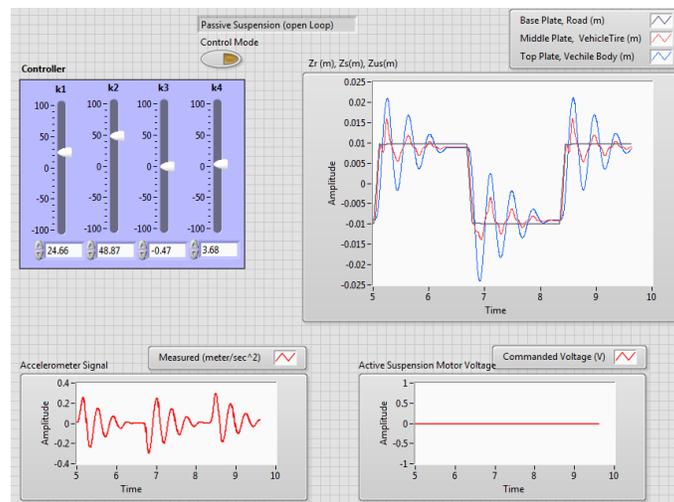


Figure 3.1: Active Suspension Control Experiment VI, Open Loop Response.

5. Switch between the open loop (passive suspension) and closed loop (active suspension) control using the *Control Mode* button. A sample stable set of control gains are set by default. The closed loop response of the system with the default gains looks like the figure below

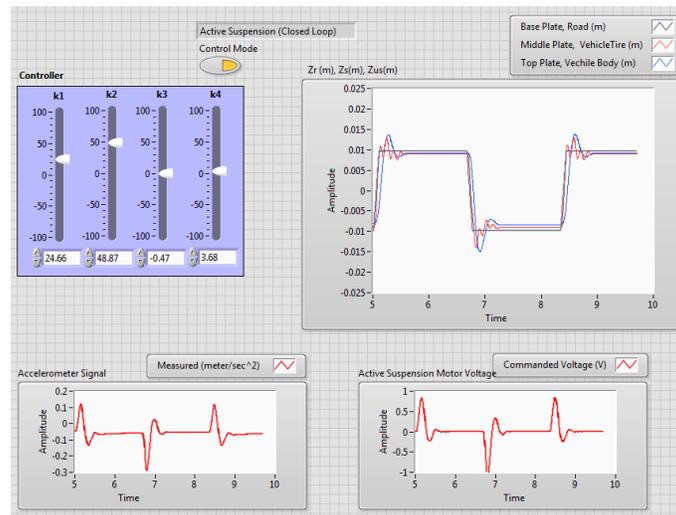


Figure 3.2: Active Suspension Control Experiment VI, Closed Loop Response.

6. Manually tune the control gains based on the results. You can either use the sliders or type in the gain values.
7. Stop the VI by pressing the Stop button.

3.2.2 Open-Loop Analysis

1. Open the *ASE Open Loop.vi* VI, shown in Figure 3.3.
2. Make sure the data acquisition (DAQ) device is configured as instructed in Section 4.3.
3. The road input is a chirp signal. It starts at a frequency of 1Hz and an amplitude of 0.002m. It reaches a frequency of 9Hz and an amplitude of 0.001m at 25th second.
4. Run this VI.
5. Z_r represents the bottom plate position which refers to the road. Z_{us} represents the middle plate position which refers to vehicle tire. Z_s represents the top plate position which refers to vehicle body. The open loop response of the system should look like the picture below

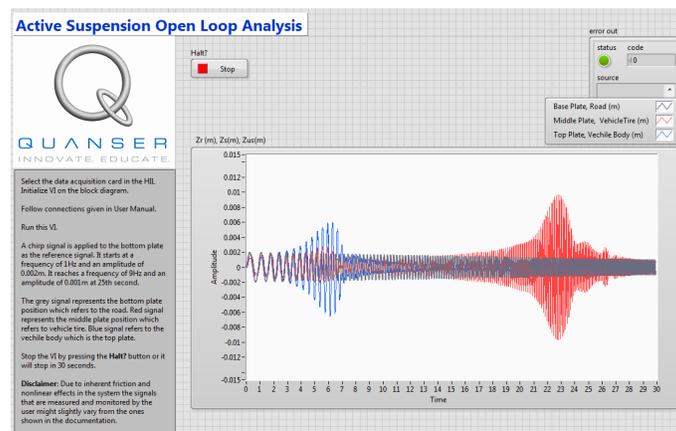


Figure 3.3: Active Suspension Open Loop Response.

6. Stop the VI by pressing the *Halt?* button or it will stop in 30 seconds.

4 SYSTEM REQUIREMENTS

Required Software

Make sure **LabVIEW™** is installed with the following required add-ons:

1. **LabVIEW™**
2. NI-DAQmx
3. NI **LabVIEW™** Control Design and Simulation Module
4. NI **LabVIEW™** MathScript RT Module
5. **Quanser Rapid Control Prototyping Toolkit®**

Note: Make sure the Quanser Rapid Control Prototyping (RCP) Toolkit is installed after LabVIEW. See the RCP Toolkit Quick Start Guide for more information.

Required Hardware

- Data acquisition (DAQ) device **with 3x encoder inputs** and that is compatible with **Quanser Rapid Control Prototyping Toolkit®**.
- Quanser Active Suspension.
- Quanser AMPAQ-L2 power amplifier [2], or equivalent.

Before Starting Lab

Before you begin this laboratory make sure:

- **LabVIEW™** is installed on your PC.
- DAQ device has been successfully tested (e.g., using the test software in the Quick Start Guide or the *Analog Loopback Demo*).
- Active Suspension Plant and amplifier are connected to your DAQ board as described its User Manual [1].

4.1 Overview of Files

File Name	Description
Active Suspension User Manual.pdf	This manual describes the hardware of the Active Suspension system and explains how to setup and wire the system for the experiments.
Active Suspension Laboratory Guide.pdf	This document demonstrates how to obtain the linear state-space model of the system, simulate the closed-loop system, and implement controllers on the Active Suspension plant using LabVIEW™ .
Active Suspension Experiment.lvproj	LabVIEW project that contains all the VIs required for the lab.
ASE Linear Model.vi	VI used to generate the linear state-space model of the Active Suspension system.
ASE Simulation Control.vi	VI used to design the feedback control gain based on LQR state-feedback, pole placement, or manual design and to simulate the Active Suspension system.
ASE Experiment Control.vi	VI that implements the state-feedback control on the Active Suspension system.
Active Suspension.mws	Maple worksheet used to develop the model for the Active Suspension experiment. Waterloo Maple 9, or a later release, is required to open, modify, and execute this file.
Active Suspension.html	HTML presentation of the Maple Worksheet. It allows users to view the content of the Maple file without having Maple 9 installed. No modifications to the equations can be performed when in this format.

Table 4.1: Files supplied with the Active Suspension

4.2 Setup for Simulation

Before beginning the in-lab simulation procedure outlined in Section 3.1, the modeling and control design VIs must be configured.

Follow these steps:

1. Load **LabVIEW™**.
2. Open the *Active Suspension Experiment.lvproj* LabVIEW project, shown in Figure 4.1.

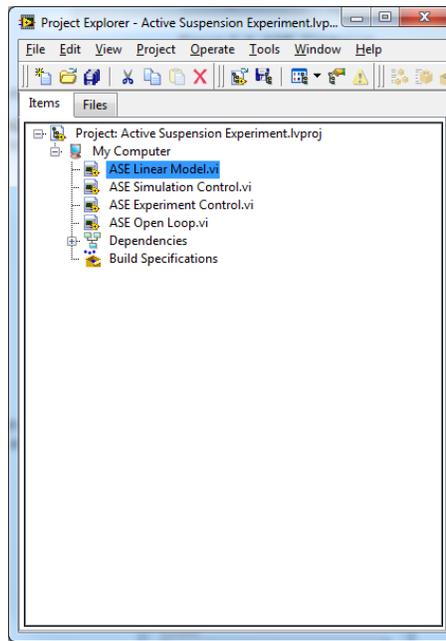


Figure 4.1: LabVIEW Active Suspension Project

3. From this project, open the *ASE Linear Model.vi* shown in Figure 4.2.

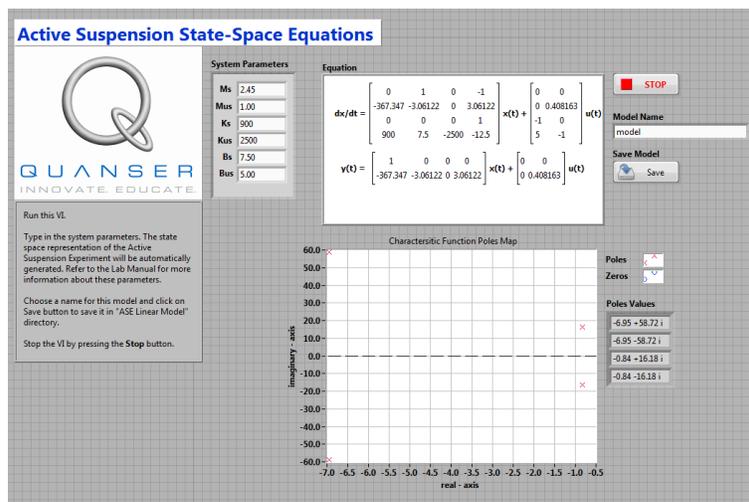


Figure 4.2: Active Suspension Modeling VI

4. The parameter values are already set, by default. Run the VI to generate the linear state-space model.
5. In *Model Name*, enter the name of the model and click on OK. This will save the state-space model under the folder *ASE Linear Model*. You can close this VI now.
6. From this project, open the *ASE Simulation Control.vi* VI, shown in Figure 4.3.

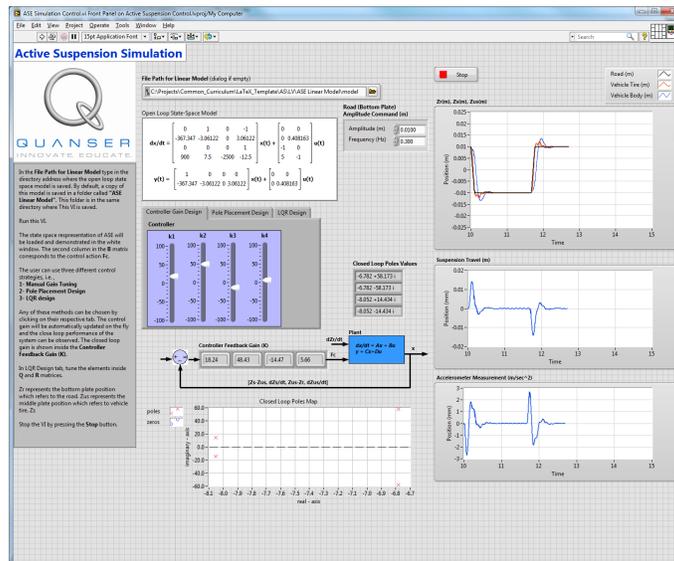


Figure 4.3: Active Suspension Control Simulation VI

7. Using the *File Path* control, select the model file and its directory. By default, a sample model is already saved in the folder *ASE Linear Model* inside the same directory where the LabVIEW project is saved.
8. Run the VI. The state-space model should load. You are now ready to design your LQR control and simulate the closed-loop response.

4.3 Setup for Experiment

Before performing the experiments in Section 3.2.1, the Active Suspension system and the *ASE Experiment Control.vi* must be configured properly.

Follow these steps to get the system ready for this lab:

1. Setup the Active Suspension as detailed in the Active Suspension User Manual [1].
2. Load **LabVIEW™**.
3. Open the *Active Suspension Experiment.lvproj* LabVIEW project, shown in Figure 4.1.
4. From this project, open the *ASE Experiment Control.vi*, shown in Figure 4.4.

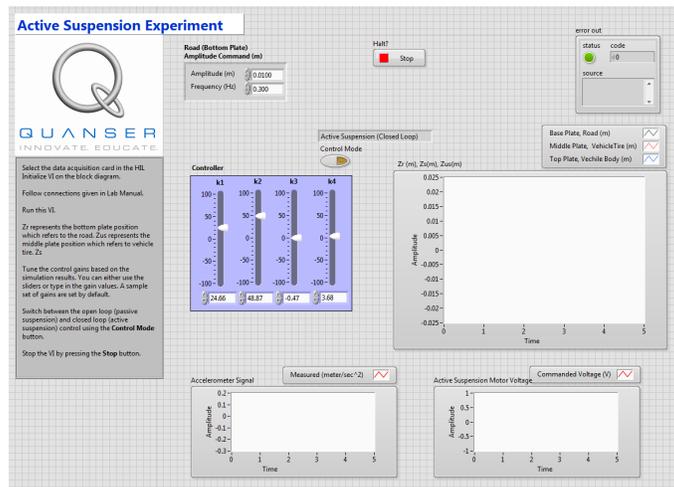


Figure 4.4: Active Suspension Control VI

- Set the gain K control in the VI to the value found in Section 4.2 (or another gain you want to test on the system).
- Configure DAQ:** Ensure the HIL Initialize block is configured for the DAQ device that is installed in your system. To do this, go to the block diagram (CTRL-E) and double click on the **HIL Initialize Express VI** shown in Figure 4.5.



Figure 4.5: HIL Initialize Express VI

- Under the Main tab, select the data acquisition device that is installed on your system in the *Board type* section. For example, in Figure 4.6 the Q8-USB is chosen.

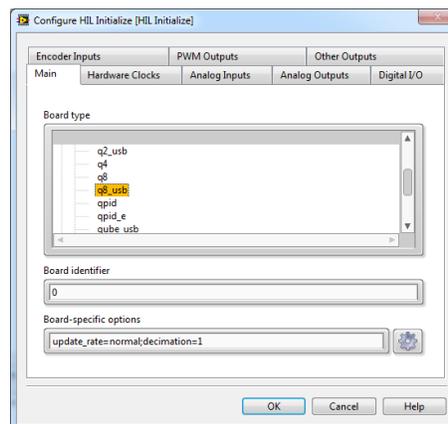


Figure 4.6: Select the data acquisition (DAQ) device that will be used to control the system

REFERENCES

- [1] Quanser Inc. *Active Suspension Experiment User Manual*, 2009.
- [2] Quanser Inc. *AMPAQ User Guide*, 2010.
- [3] Norman S. Nise. *Control Systems Engineering*. John Wiley & Sons, Inc., 2008.

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