gipsa-lab

GIPSA-Lab
Control System Department

Benchmark on Adaptive Regulation: Rejection of unknown/time-varying multiple narrow band disturbances

Prepared by:
I.D. Landau, T.B. Airimitoaie, A. Castellanos Silva,
J.J. Martinez, M. Alma, G. Buche (GIPSA-Lab)
A. Karimi (EPFL, Automatic Control Lab.)

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Contents:

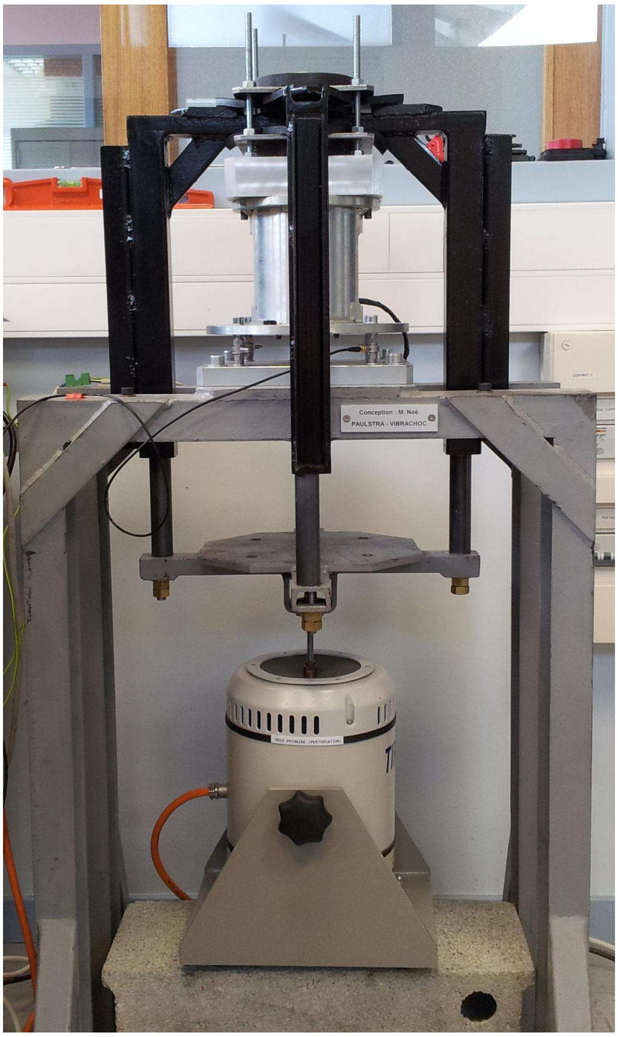
1. General Information

Results to be submitted to:

- ***European Control Conference, Zürich, Switzerland, July 17-19, 2013***
- ***Special issue of European Journal of Control***

The scientific objective of the benchmark is to evaluate current available procedures which may be applied in the fields of active vibration control and noise control. The benchmark specifically will focus in testing: 1) performances, 2) robustness and 3) complexity.

The test bed is an active suspension using an inertial actuator and equipped with a shaker and a measure of the residual force. It is located at GIPSA-Lab, Grenoble (France) which has already experience on organizing benchmarks on test beds (see European J. of Control, no.2, 1995 and no.1, 2003).



The disturbances are unknown/time-varying multiple narrow band disturbances located in a given frequency region. The plant model is (almost) constant. An identified model of the plant is provided. Further identification procedures can be carried on demand.

A discrete time Matlab Simulink simulator of the plant is provided. The participants should give a Simulink simulation including complete control scheme built around the given model. The “test” protocol is available to the participants. The simulation should be compatible with the Matlab xPC Target environment, which will be used for real-time implementation on the test bed of the proposed solutions. The real-time implementation and experiments will be carried on by the GIPSA-LAB staff. Final evaluation will be performed on the basis of real-time results.

Full information can be downloaded from the website: http://www.gipsa-lab.grenoble-inp.fr/~ioandore.landau/benchmark_adaptive_regulation/

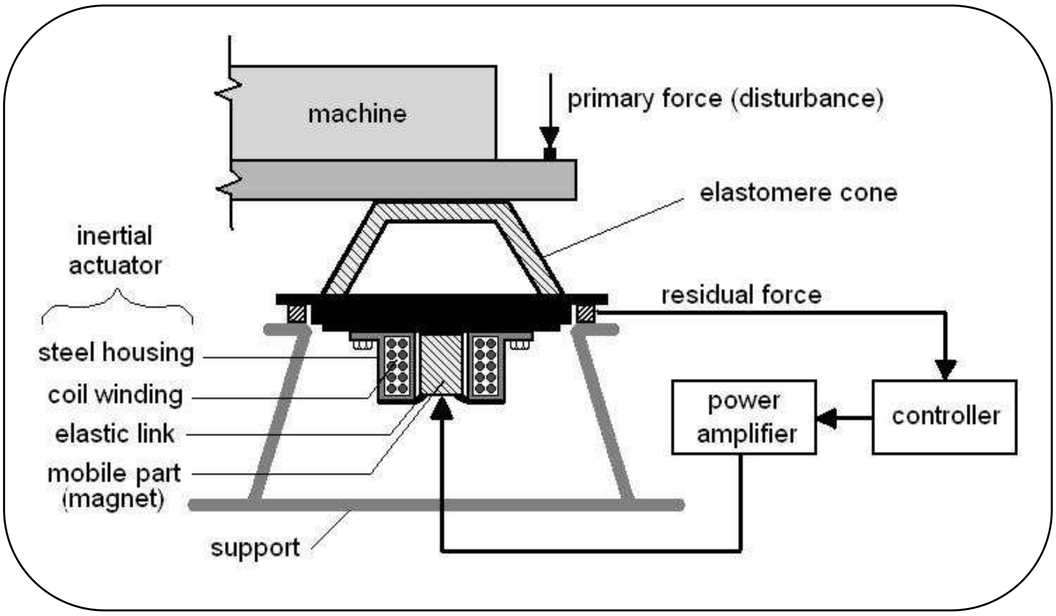
For the ECC 2013, the preliminary results should include simulation results and at least one real time real time results. The schedule is as follows:
October 1st, 2012: Papers with preliminary results
April 20th, 2013: Papers with final results (if accepted)

For the EJC special issue the deadline is February 1, 2013.
The papers will be subject to peer review and have to be simultaneously sent to the journal and to I.D. Landau.

Organizers: I.D. Landau, T.B. Airimitoaie, Abraham Castellanos-Silva, J. J. Martinez-Molina, M. Alma, G. Buche (GIPSA-Lab, Control Dept., Grenoble, France), A. Karimi, (Automatic Control Lab., EPFL, Lausanne, Switzerland).

E-mails:
ioan-dore (dot) landau (at) gipsa-lab (dot) inp-grenoble (dot) fr
Abraham (dot) castellanos-silva (at) gipsa-lab (dot) inp-grenoble (dot) fr
tudor-bogdan (dot) airimitoaie (at) gipsa-lab (dot) inp-grenoble (dot) fr

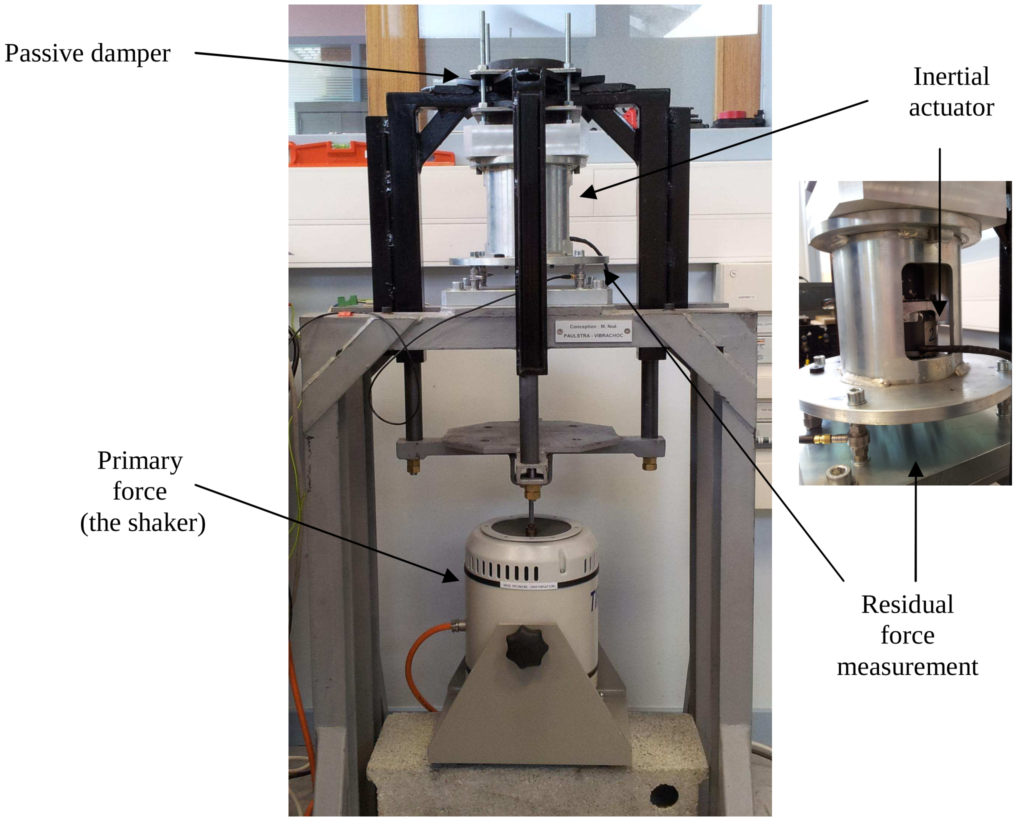
2. System Description



An active suspension system is used for attenuation of unknown/time varying narrow band disturbances. The figure above shows the scheme of the active suspension. The main parts of the active suspension are:

1 an elastomer cone (passive suspension)
2 an inertial actuator
3 a measure of the residual force
4 a power amplifier
5 a controller (computer generated control signal)
6 a shaker which generates the disturbances

A view of the active suspension is shown below.



The mechanical construction of the load is such that the vibrations produced by the shaker, fixed to the ground, are transmitted to the upper side of the active suspension.
The output of the system is the measured voltage corresponding to the residual force. The control input drives the inertial actuator through a power amplifier. The transfer function between the excitation of the shaker and the residual force is called the **primary path**. The **secondary path** is defined as the transfer function between the control input and the residual force.
Both the **primary path** and the **secondary path** are characterized by the presence of a double differentiator (since the input in the actuator is proportional to a position and the output is proportional with the acceleration).
These transfer functions have to be identified from input/output data provided (additional input/output data can be provided on demand). The sampling frequency is 800 Hz.
Under appropriate control the inertial actuator will provide the forces for the compensation of the mechanical disturbances, therefore leading to the absorption of the vibrations.
The control objective is to reject the effect of unknown narrow band disturbances on the output of the system (residual force), i.e. to attenuate the vibrations transmitted from the machine (the mechanical structure fixed on the active suspension and excited by the shaker) to the support via the active suspension.

A discrete time Matlab Simulink simulator of the plant can be downloaded (see section Simulator).

3. System Identification/Plant model

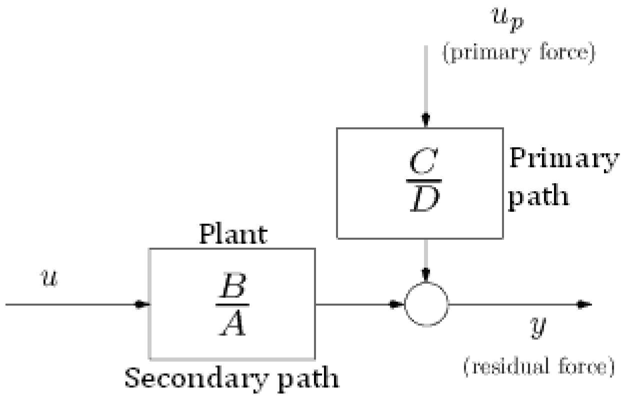


Figure 3.1

The block diagram of the active suspension system is presented in the above figure 3.1. Two models for the system can be identified, corresponding to the primary and secondary path. Here u_p denotes the input of the primary path (excitation of the shaker), u is the input of the secondary path (proportional to the inertial actuator input) and y is the system output (residual force). The sampling frequency for data acquisition is Fs = 800 Hz.

The best models have been obtained as follows:

- Primary path: open loop identification using ERLS
- Secondary path: identification in closed loop using an RS controller with the excitation added to the plant input (for more details see I.D. Landau, G. Zito, *Digital Control Systems*)

The models are available in the following files:

1. model_prim.mat
2. model_sec.mat
3. RS_contr_sec.mat (the controller used for the closed loop identification)

In Fig. 3.2, real time tests are shown in open and in closed loop for a controller designed to reject one sinusoidal disturbance. Fig. 3.3 shows the simulation results for the same configuration. A very good coherence can be observed between simulations and real time results.

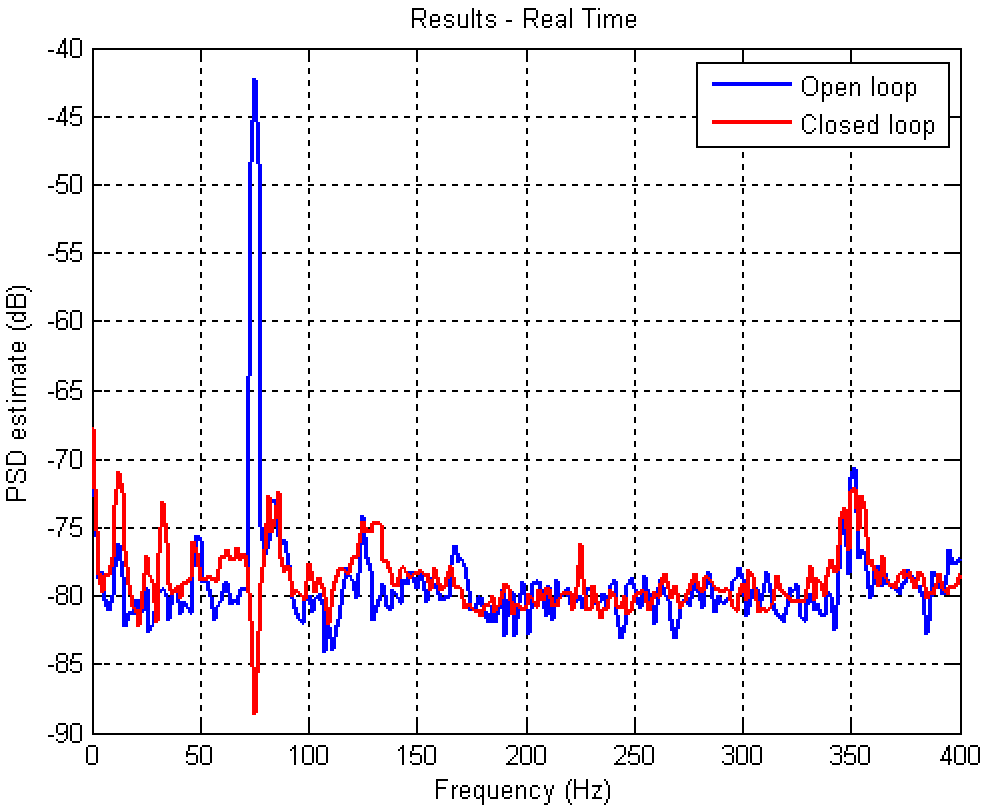


Figure 3.2 Real Time results.

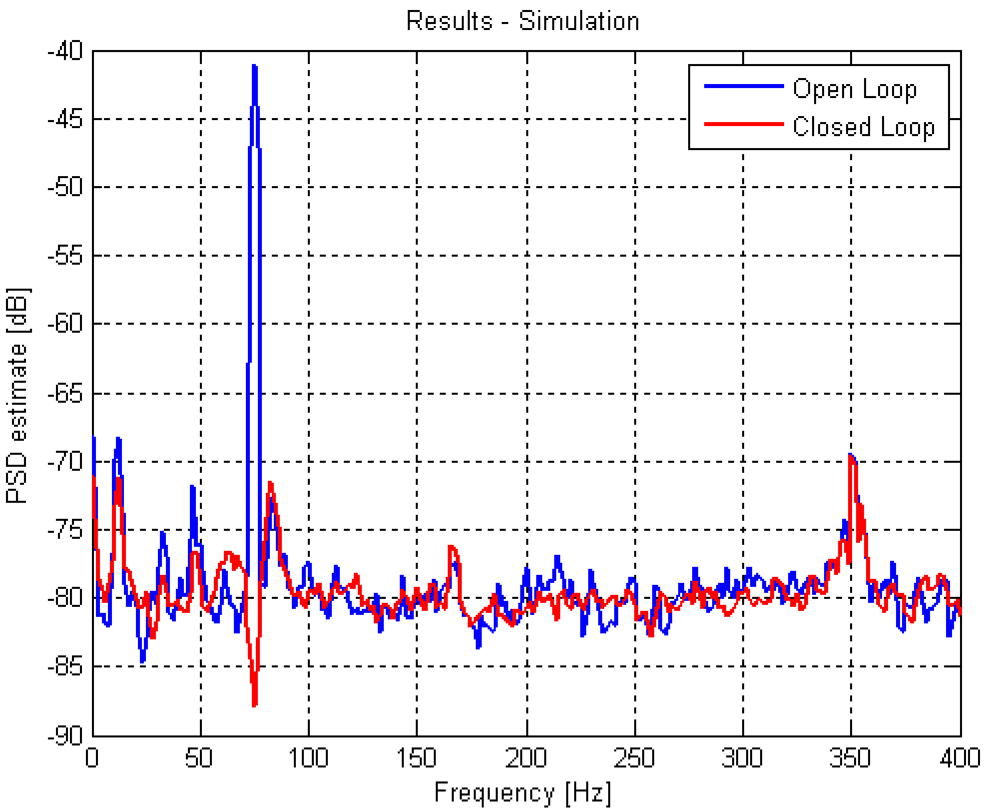


Figure 3.3 Simulation results.

A non parametric model of the primary path can be identified by the spectral analysis method. This analysis shows that the model contains several high-resonant modes.
The magnitude of the model frequency characteristic for the primary and the secondary paths are shown next in the figures 3.4 and 3.5, respectively. The frequency characteristics of the identified parametric models are also shown.

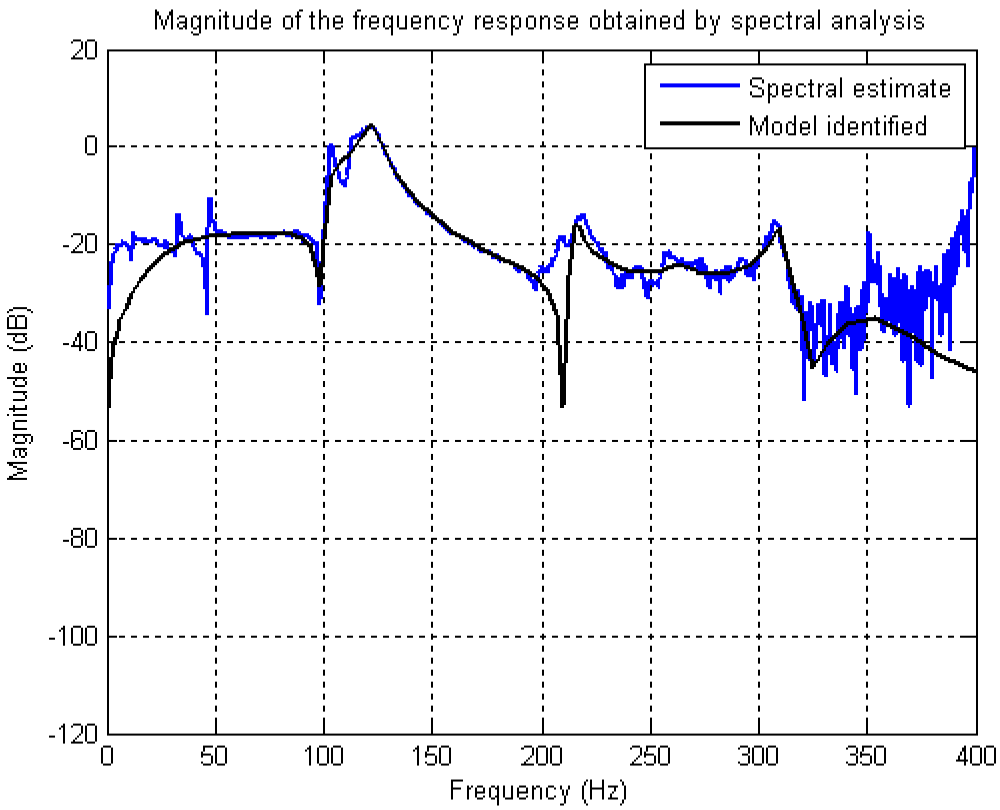


Figure 3.4 Primary Path

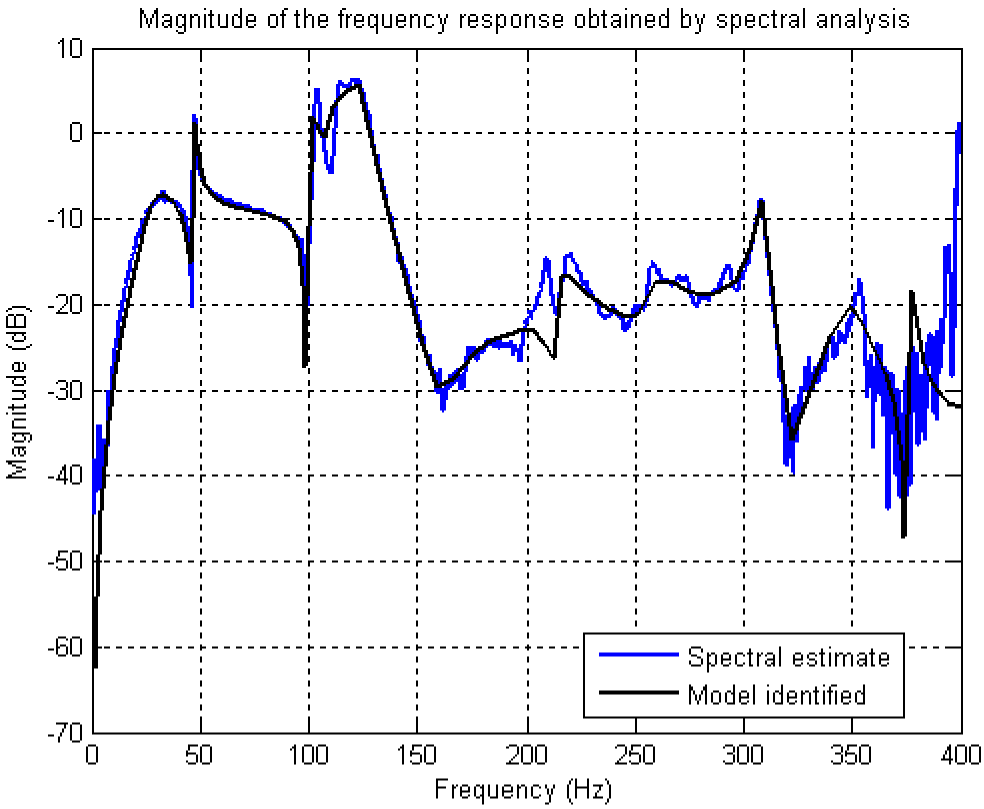


Figure 3.5 Secondary Path

Data used for system identification are described in section **Data acquisition**.

Continuous-time model

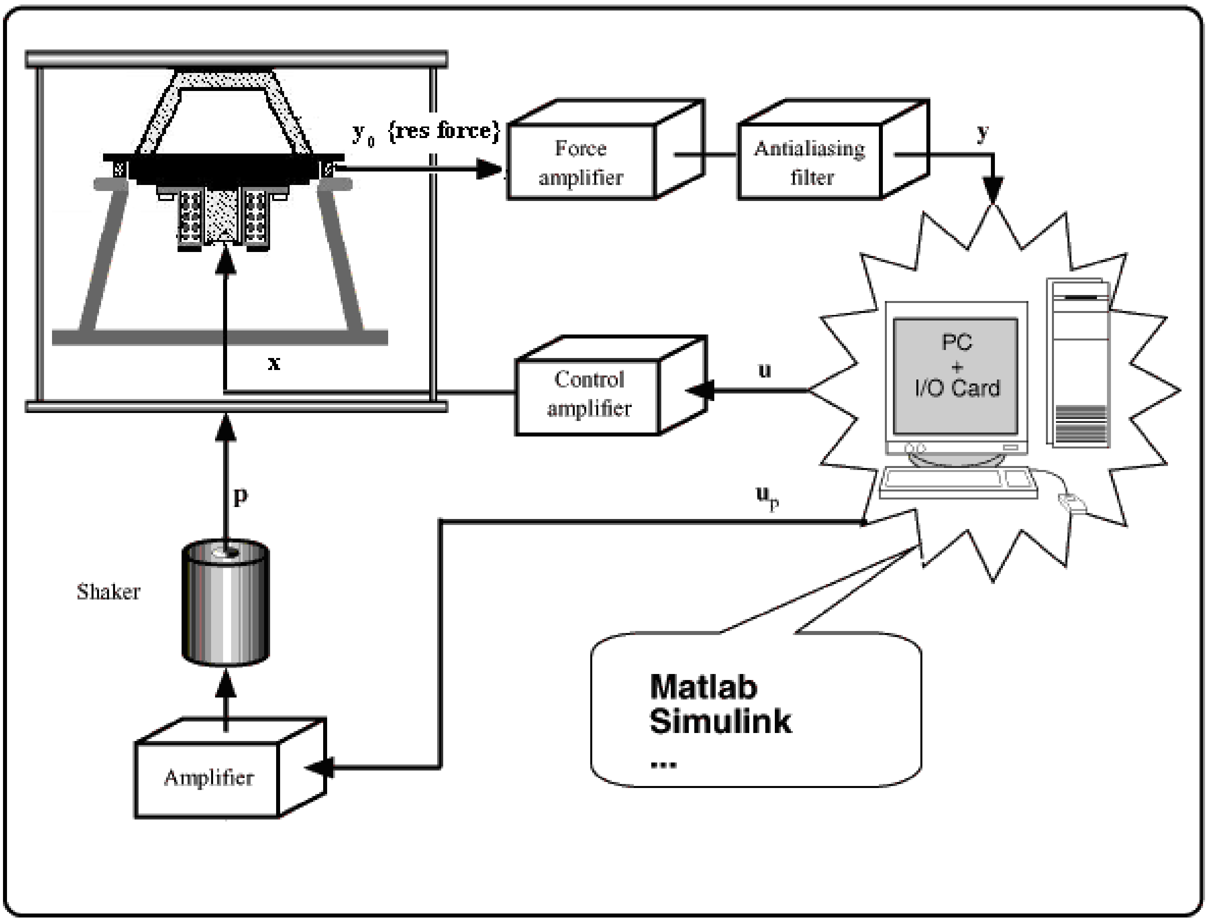
Approximate continuous-time models of the plant can be obtained by conversion of discrete-time identified models using the zero-order hold method or from the estimated frequency characteristics.

The real-time data acquired on the system are available in the data acquisition section.

Warning: The participants should be prepared to provide an experimental protocol for plant model identification in order to tune their control if necessary.

4. Data Acquisition

The block diagram of the data acquisition system is given in the figure bellow:



Open-loop operation
The real-time experiments have been performed with different PRBS signals, for the primary and secondary path. The sampling frequency was Fs = 800 Hz. The characteristics of the data obtained and the name of the files are given below:

Primary path

data_prim2.mat: PRBS input generated by a 10-bit shift register, with a clock frequency of Fs/2 input magnitude: 0.125V, data length: 8184

Secondary path

data_sec2.mat: data has been obtained in closed loop using a RST controller, the excitation signal has been added to the plant input (controller output), the excitation has been the same as for the primary path: PRBS input generated by a,10-bit shift register, with a clock frequency of Fs/2, input magnitude: 0.125V, data length: 8184

A compressed version of all files is available in the file**: data.zip.**
Other data can be acquired on demand.

5. Control Specifications

The identified models show that both the primary path and the secondary path models have several resonance modes (as well as resonant complex zeros). The most significant are those near 45 Hz (secondary path) and 100 Hz (primary and secondary paths).

The narrow band disturbances are located in the range 50 to 95 Hz.
It is important to take in account the fact that the secondary path (the actuator path) has no gain at very low frequencies and very low gain in high frequencies near 0.5 Fs. Therefore the control system has to be designed such that the gain of the controller be very low (or zero) in these regions (preferably 0 at 0.5Fs). Not taking in account these constraints can lead to undesirable stress of the actuator.

It is suggested that participants to the benchmark consider first a linear control design in order to assess the particularities of the secondary path. This design should consider the attenuation of one, two or three sinusoidal disturbances located between 50 and 95 Hz with the objective to introduce attenuation over 40 db at the disturbance frequencies and very little amplification at other frequencies.

Control objectives – Preliminaries

There are three levels of difficulty related to the number of sinusoidal disturbances (1, 2 or 3). The width of the frequency region where these disturbances occur is 50-*95 Hz*.

The easiest level is **level 1** (one sinusoidal time varying disturbance within 50-95 Hz) and the most difficult is **level 3** (three sinusoidal time varying disturbances within 50-95 Hz)
Level 1
Rejection of a **single** time varying sinusoidal disturbance within [50 95].
Level 2
Rejection of **two** time varying sinusoidal disturbances within [50 95Hz].
Level 3
Rejection of **three** time varying sinusoidal disturbances within [50 95Hz].

The magnitude of the disturbances is specified (see Evaluation of the Adaptive Controller)

Control objectives - Specifications

The control objectives for all the levels can be divided in three protocols plus some additional tests:

1. Step changes in frequencies. Time domain performances

An upper bound for the duration of the adaptation transient is imposed (2sec) since the time separation between the steps in frequencies will be 3sec. However, the transients will be further compared in terms of maximum value, duration and norm.

2. Evaluation in steady state operation at the frequencies considered above (after adaptation settles).

Test 1: The steady state performance in time domain will be evaluated by measuring the mean square value of the residual force which will be compared with the value of the residual force in open loop (providing a measure of the global attenuation). The minimum global attenuation imposed for the three levels is shown in Table 1.

Test 2: Power spectral density performances

For constant frequency disturbances, once the adaptation transient is over, the attenuation with respect to the open loop will be measured (using function: **spectre_psd_rms.m**)

The imposed performances in term of attenuation of the disturbance and tolerated amplification at other frequencies (with respect to the open loop) are presented in Table 1.

3. Chirp changes in frequency. Time domain evaluation

A linear time varying change between two situations with a corresponding speed (Hz/sec) given in Table 1, will be made. The maximum value of the residual force during the chirp will be measured and should be less than the specifications given in Table 1. The mean square value of the residual force will be also measured and compared.

The loop is closed before the disturbances are applied for all the above tests.

Supplementary tests (mandatory)

The operation of the system should remain stable for all the levels if one, two or three sinusoidal disturbances are applied simultaneously.

The operation of the loop should remain stable if the disturbance is applied simultaneously with the closing of the loop

The transients for the case when the disturbances vanish will be tested and measured for all the levels.

Testing protocols are provided (see **Evaluation of Adaptive Controller**).

For the final tests the values of the frequencies of the disturbances will be chosen randomly within the given range. (See evaluation section)

Participants can provide specific adaptive controller for each of the three levels.

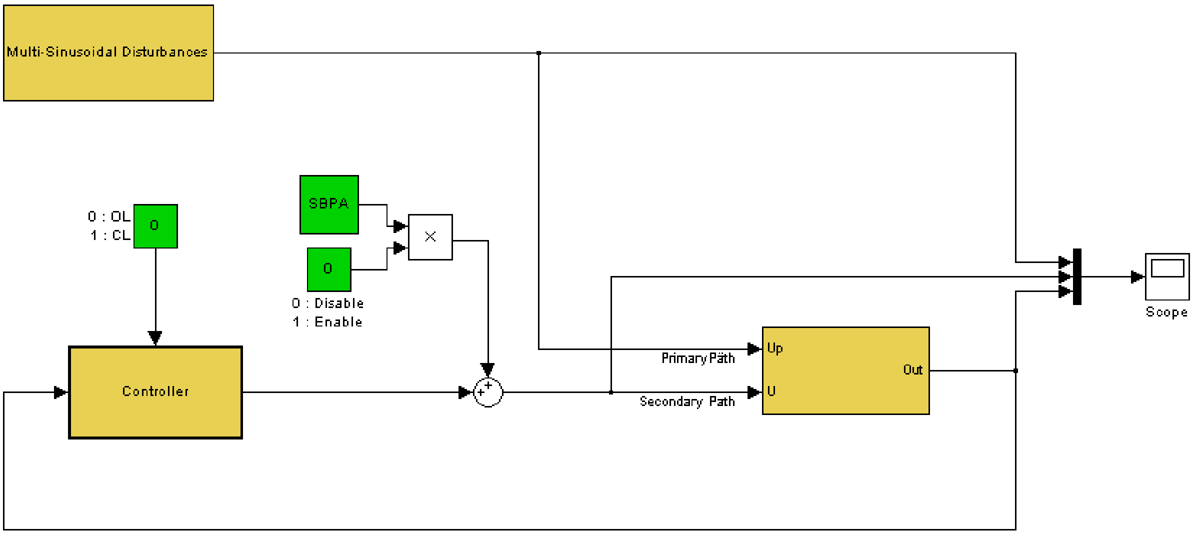
Control specifications	Level 1	Level 2	Level 3
Transient duration	≤ 2sec	≤ 2sec	≤ 2sec
Global attenuation	≥ 30 dB	≥ 30 dB	≥ 30 dB
Disturbance attenuation	≥ 40 dB	≥ 40 dB	≥ 40 dB
Maximum amplification	≤ 6 dB	≤ 7 dB	≤ 9 dB
Chirp speed	10 Hz/sec	5 Hz/sec	3 Hz/sec
Maximum value during chirp	≤ 0.1V	≤ 0.1V	≤ 0.1V

Table 1 Control specifications.

Input magnitude constraint: The magnitude of the plant control input should be below 0.65 V in all the situations.

6. Simulator

A discrete time simulator of the active suspension built on Matlab Simulink (Matlab 2007) can be downloaded: **bench_sim.zip**
The main simulation scheme is given below:



The zip file contains the folder: **bench_sim** which includes 3 files: init_simulator_bench.m, bruitbench.mat, and simulator_bench.mdl.
The sampling frequency is 800 Hz.

The primary path and the secondary path are indicated.
A generator for the PRBS is included in the scheme as well as the generator for the disturbances (up to three sinusoids).
A sample of the system noise in open loop is added to the simulation (a record of 80.000 samples).
The saturation of the actuator is included in the simulator. The corresponding input saturation level is 0.7 V (for both paths).
The control scheme (Controller) should be built around the given simulator using the actual model or another identified one. However, the organizers will test the scheme using the given model before its implementation on the real system.

To start the simulator one should run the **init_simulator_bench.m**.

7. Real Time Implementation

The real time implementation uses the Matlab xPC Target environment (2007). The PC for program development is a Dell Optiplex 760. The PC target (Dell) is equipped with I/O data acquisition, A/D and D/A converters.

The procedure will compile the algorithms directly from the Simulink scheme.

It is therefore strongly recommended that a test on a xPC target environment be done in order to be sure that compilation is complete.
One should check also the execution time which should be less than 1.25 ms.

For the real time experiments (data acquisition and controller evaluation) the participants should ask for a registration code.

The authors are advised to design and test their control scheme using the simulator because **the number of experiments on the real system** will be limited.

The real time experiments will be conducted by the GIPSA-Lab staff. Those who would like to participate to the experiments should contact the organizers.

8. Evaluation of the Adaptive Controller

The Simulink control scheme provided by the participants will be firstly evaluated on the simulator using the given sequences of disturbances.

The step changes in the frequencies of the disturbances can be generated with the block “multi sinusoidal disturbances” already included in the Simulink simulator. The description of these sequences can be found in the files **simple_step_tests.pdf** and **step_changes_tests.pdf**.

The chirp change in the frequencies of the disturbances can be generated with the Simulink block “**test_chirp**” given in the file **test_chirp.zip.** The description of the chirp tests are given in the file **chirp_test.pdf.**

Provided that the basic requirements are satisfied we will proceed to the next step i.e.: compilation using xPC Target. If compilation problems occur, these will be indicated to the contributors for making appropriate modifications.

Once the compilation is OK the scheme will be tested on the real system by the GIPSA-Lab staff..

The tests will be done with the sequences of disturbances described in the files **simple_step_tests.pdf**, **step_changes_tests.pdf** and **chirp_tests.pdf** as well. Once these tests are achieved, test on similar sequences of disturbance but with values of frequencies chosen randomly (within the given range) will be done.

For measurement of performances in the time domain, both transients and steady state will be evaluated.
The transients will be compared in terms of maximum value, norm and duration.
The steady state performance in time domain will be evaluated by measuring the mean square value of the residual force which will be compared with the value of the residual force in open loop (providing a measure of the global attenuation).

For chirp disturbances, the maximum value of the residual force during the chirp will be measured as well as the mean square value of the residual force (during the chirp).

Complexity of the control scheme will be evaluated in terms of execution time. (the organizers are aware that this is not a fully objective criterion – any suggestion is welcome).

For the calculation of the different required values, one can use the following Matlab functions, written especially for the Benchmark:

spectre_psd_rms.m: To compute power spectral density
global_attenuation.m: To compute the global attenuation
transient_duration.m: To compute the transient duration, maximum value and norm
transient_duration_step_changes.m: To compute the transient duration, maximum value and norm for step changes in frequencies.

8.1. Simple step application of the multi sinusoidal disturbances

The simple step of the multi sinusoidal disturbances can be implemented with the Simulink block "multi sinusoidal disturbances" available in the Simulink Simulator of the active suspension. One can specify 1, 2, or 3 sinusoids, their frequencies and magnitude values, the time of application.
Below the protocol for each multi-sinusoidal disturbance is given (the time schedule will be the same for 1 or for 3 sinusoids).

Simple step protocol:
Disturbance amplitude is **0.1V** for each sinusoid.

T=0 no disturbance, closing of the loop
T=5s application of the disturbance (1, 2 or 3 sinusoids)
T=20s suppression of the disturbances
T=30s end of the experiment

As indicated in the chapter "Evaluation of the Adaptive Controller" it is expected that the time sequence will remain the same for all the situations but the values of the frequencies may be changed.

Single sinusoidal disturbance (level 1):
For this level, all the frequencies in the range 50Hz→95Hz are tested (every 5Hz).

Two sinusoidal disturbances (level 2):
For this level, every couple of frequencies in the range: [50-70]Hz to [75-95]Hz are tested (every 5Hz for each sinusoid)
The tested frequencies are:
[50-70]Hz - [55-75]Hz - [60-80]Hz - [65-85]Hz - [70-90]Hz - [75-95]Hz.

Three sinusoidal disturbances (level 3):
For this level, every group of frequencies in the range: [50-65-80]Hz to [65-80-95]Hz are tested (every 5Hz for each sinusoid)
The tested frequencies are:
[50-65-80]Hz - [55-70-85]Hz - [60-75-90]Hz - [65-80-95]Hz.

8.2. Step changes in the frequencies of the multi sinusoidal disturbances

The step changes in the frequencies of the multi sinusoidal disturbances can be implemented with the Simulink block “multi sinusoidal disturbances” available in the Simulink Simulator of the active suspension. One can specify 1, 2, or 3 sinusoids, their frequencies and magnitude values, the time of application.
Below the protocol for each multi-sinusoidal disturbance is given (the time schedule will be the same for 1 or for 3 sinusoids.

Step changes protocol:
Disturbance amplitude is **0.1V** for each sinusoid.

T=0 no disturbance, closing of the loop
T=5s application of the first disturbance (1, 2 or 3 sinusoids)
T=8s application of the second disturbance (1, 2 or 3 sinusoids)
T=11s re-application of the first “central” disturbance (1, 2 or 3 sinusoids)
T=14s application of the third disturbance (1, 2 or 3 sinusoids)
T=17s re-application of the first “central” disturbance (1, 2 or 3 sinusoids)
T=32s suppression of the disturbances
T=40s end of the experiment

As indicated in the chapter “Evaluation of the Adaptive Controller” it is expected that the time sequence will remain the same for all the situations but the values of the frequencies may be changed.

Single sinusoidal disturbance (level 1):
The sequences considered for this level are:
60Hz → 70Hz → 60Hz → 50Hz → 60Hz
75Hz → 85Hz → 75Hz → 65Hz → 75Hz
85Hz → 95Hz → 85Hz → 75Hz → 85Hz

Two sinusoidal disturbances (level 2):
The sequences considered for this level are:
[55-75] Hz → [60-80] Hz → [55-75] Hz → [50-70] Hz → [55-75] Hz
[70-90] Hz → [75-95] Hz → [70-90] Hz → [65-85] Hz → [70-90] Hz

Three sinusoidal disturbances (level 3):
The sequences considered for this level are:
[55-70-85] Hz → [60-75-90] Hz → [55-70-85] Hz → [50-65-80] Hz → [55-70-85] Hz
[60-75-90] Hz → [65-80-95] Hz → [60-75-90] Hz → [55-70-85] Hz → [60-75-90] Hz

8.3. Chirp changes in the frequencies of the multi sinusoidal disturbances

The chirp change in the frequencies of the disturbances can be generated with the Simulink block "**test_chirp**" given in the file **test_chirp.zip.** One can specify 1, 2, or 3 sinusoids, their frequencies and magnitude values, the time of application, the duration of the chirp, the initial and final values of the frequencies of the disturbances.

The initial values of the frequencies are specified in the vector Fbeg, the final value of the frequencies are specified in the vector Ffin.
The loop is closed before T0.

T=0 no disturbance, closing of the loop
T=T0: The disturbances corresponding to Fbeg will be applied
T=T1: The chirp starts i.e. the values of the frequencies will vary linearly toward the values defined by Ffin
T=T1+Tb: The chirp stops at T1+Tb and the sinusoidal disturbances defined by Ffin are applied
T=T1+Tb+T2 A new chirp starts. The frequencies of the disturbances will vary linearly towards the values defined by Fbeg
T=T1+Tb+T2+Tb: The chirp stop and the frequencies defined by Fbeg are applied
T=T1+Tb+T2+Tb+T2 End of the experiment

The values of T0, T1 and T2 are the same for the three levels and are equal to:
T0 = 5sec, T1=10sec, T2=5sec.

Tb is the chirp duration, and it is used to define de chirp speed.

$$Tb = \frac{Ffin - Fbeg}{desired\_speed}$$

Protocol to be used:
For each test, the variation speed between two situations is maintained constant.
Disturbance amplitude is **0.1V** for each sinusoid.

Single sinusoidal disturbance (level 1):
Variation rate (speed) = 10 Hz/sec

The test to be done with the corresponding **Fbeg**, **Ffin** and **Tb** is described below:

Fbeg = 50Hz, Ffin = 95Hz.

$$Tb = \frac{Ffin - Fbeg}{desired\_speed} = \frac{95-50}{10} = 4.5\,\text{sec}$$

Two sinusoidal disturbances (level 2):
Variation rate (speed) = 5 Hz/sec

The test to be done with the corresponding **Fbeg**, **Ffin** and **Tb** is described below:

Fbeg = [50-70]Hz, Ffin = [75-95]Hz.

$$Tb = \frac{Ffin - Fbeg}{desired\_speed} = \frac{[75-95]-[50-70]}{5} = 4\sec$$

Three sinusoidal disturbances (level 3):
Variation rate (speed) = 3 Hz/sec

The test to be done with the corresponding **Fbeg**, **Ffin** and **Tb** is described below:
.
Fbeg = [50-65-80]Hz, Ffin = [65-85-95]Hz.

$$Tb = \frac{Ffin - Fbeg}{desired\_speed} = \frac{[65-85-95]-[50-65-80]}{3} = 5\sec$$

If the block “test_chirp” is used independently one has to specify the sampling frequency (800Hz).
As indicated in the chapter “evaluation of the adaptive controller” it is expected that the time sequence will remain the same for all the situations but the values of the frequencies may be changed (in the final test, these values will be selected randomly).