Institutionen för systemteknik
Department of Electrical Engineering

Examensarbete

Road roughness estimation using available vehicle sensors

Examensarbete utfört i Fordonsystem
vid Tekniska högskolan i Linköping
av

Johan Lundström

LITH-ISY-EX--09/4227--SE

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Department of Electrical Engineering
Linköpings universitet
SE-581 83 Linköping, Sweden

Linköpings tekniska högskola
Linköpings universitet
581 83 Linköping

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Handledare: **Erik Hellström**
ISY, Linköpings universitet
Ines Kasumovic
Scania CV AB Södertälje

Examinator: **Jan Åslund**
ISY, Linköpings universitet

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Division of Automatic Control
Department of Electrical Engineering
Linköpings universitet
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Vägkvalitét skattning med befintliga sensorer

Road roughness estimation using available vehicle sensors

Författare
Author

Johan Lundström

Sammanfattning
Abstract

Road conditions affect fuel efficiency and vehicle fatigue when driving heavy trucks. Information about traveled road conditions enable optimization of chassis configuration when driving, and logging of vehicle stress. Previous work on this topic focus mainly on tuning of active suspension parameters in the car industry. One conceivable application for heavy trucks is implementation of active chassis level control based on road conditions, with possible improvements in driving economy as result. Another is logging of usage conditions which helps explain vehicle faults caused by abnormal wear. This work examines the possibilities to use already on vehicle sensors for road roughness estimation. It also investigates what requirements existing signals must fulfill to ensure reliable estimates. Two methods for road roughness estimation are proposed using rear axle level sensor and a simple linear suspension system model.

Nyckelord
Keywords

Road roughness, Road estimation, Air suspension, Heavy truck, ISO 8608

Abstract

Road conditions affect fuel efficiency and vehicle fatigue when driving heavy trucks. Information about traveled road conditions enable optimization of chassis configuration when driving, and logging of vehicle stress. Previous work on this topic focus mainly on tuning of active suspension parameters in the car industry. One conceivable application for heavy trucks is implementation of active chassis level control based on road conditions, with possible improvements in driving economy as result. Another is logging of usage conditions which helps explain vehicle faults caused by abnormal wear. This work examines the possibilities to use already on vehicle sensors for road roughness estimation. It also investigates what requirements existing signals must fulfill to ensure reliable estimates. Two methods for road roughness estimation are proposed using rear axle level sensor and a simple linear suspension system model.

Sammanfattning

Underlagets beskaffenhet vid körning med tunga fordon påverkar körekonomi och slitaget på fordonets komponenter. Mer information om vägkvalitén medger större möjligheter att, optimera chassiinställningen för rådande föhållanden, samt insamla kördata. I personbilindustrin har en mängd olika metoder provats för att värdera underlaget under färd. Då främst i samband med optimering av parametrar i aktiv fjädring. En tänkbar tillämpning för tung trafik är att låta ett system ställa in chassihöjden under färd baserat på information om underlaget. På så vis kan man eventuellt minska förluster av luftmotstånd och turbulens kring fordonet då vägförhållandena är gynsamma. Detta kan vara till nytta för brukaren om bränslekostnaderna minskar. Ett annat område är belastningsberäkningar. Om serviceverkstaden i efterhand kan påvisa att bilen gått onormalt mycket på dålig väg kan man förklara felutfall eller ökade reparationskostnader. Detta arbete undersöker möjligheterna att använda befintliga sensorer för vägkvalitétskattning samt vilka krav dessa måste uppfylla för att garantera pålitliga resultat. Två metoder för vägkvalitétskattning föreslås där en nivåsensor vid bakaxeln samt en enkel fjädringsmodell används.

Acknowledgments

I would like to thank everyone at REVB, REVC and RTCS groups Scania Södertälje for taking good care of me while working on the thesis. Ines Kasumovic at Scania, Erik Hellström at LIU, Göran Andersson and Lennart Andersson for all help, Klas Bogsjö for road profiles and invaluable advise, Anders Björkman for testdriving and Conny Fransson for support and fika.

Contents

Chapter 1

Introduction

1.1 Motivation

The ability to provide powerful yet highly fuel efficient vehicles is crucial in heavy truck industry. Customers and legislators put constraints on the design of new trucks. Engine and drive line development aside, one way to lower fuel consumption is to minimize the vehicle´s air resistance by automatic optimization of the chassis level when driving. This requires some information about road conditions or ride roughness to ensure safe maneuvering of the chassis level and enough room for the suspension to travel. One positive side effect is the possibility to log and analyze using conditions. The motivation for this work is to find methods to gather road information using in vehicle available signals.

What is new in this work is the use of a suspension model that facilitates the adaption of parameters to current vehicle configuration. The ISO 8608 standard is also adopted for the definition of different road classes, which generalizes the concept road quality and facilitates the interpretation of results for the benefit of research in other fields.

1.2 Goal

Investigate the following.

1. What internal signals are available from the air suspension system in a Scania heavy truck and useful for road roughness estimation.

2. What requirements must these signals fulfill to ensure reliable estimates.

3. Describe a method to estimate road roughness.

1.3 Delimitations

A Scania 4x2 tractor with 2-bellow air suspension on drive axle is used for road measurements and model parameter verification. Only signals available on the vehicle CAN-bus are considered. Vehicle yaw state is assumed known. This means measurements and road estimations are only made during longitudinal operation of the truck with no lateral forces acting on the chassis. Although measurements are intended to resemble real driving conditions, the effects from vehicle roll into data is not desired. Therefor care is taken when selecting road test sections where fairly straight roads are preferred. Vehicle speed is also adapted to the conditions to minimize roll. This means moderate speed is preferred. For the coming computations it is important that constant speed is maintained during measurements.

The said test vehicle is designed to haul a heavy trailer. For convenience, no trailer was connected during this study. Instead extra weight in form of metal bars was attached to the vehicle body above the drive axle to increase axle load. The resulting rear axle load was approximately 5100 Kg. It is of interest to know if a real trailer interacts with tractor much differently. That is however left as future improvement.

1.4 Abbreviations and keywords

ISO 8608	An international standard on road classification
PSD	Power Spectral Density. A mathematical concept that describes how a signal´s energy is distributed over all frequency bands.
ELC	Electric Leveling Control. A Scania specific name on their air suspension control system.
ECU	Electronic control unit.
RMS	Root Mean Square. The quadratic mean of a sequence of numbers.
Ipetronik DMS	A device from a commercial supplier of measuring equipment.
Vector CANcard	Another commercial measuring device.

1.5 Related work

Prior work methods to estimate road roughness using chassis level data involve frequency analysis (FFT) [1] and RMS calculations [9]. Patent [1] describes an algorithm that classifies ride quality with application in active damping control. Patent [9] describes a method of road roughness estimation using calculated RMS values on a band-pass filtered signal where cut-off frequencies are cunningly chosen. Vehicle speed and load is compensated for roughly, to provide an estimate of actual road conditions. Both methods above require some test driving for the tuning of parameters and thresholds.

Papers covering road roughness standardization and metering are: [15], [12], [17], [13], [7], [4] and [11]. A paper including a suspension model is [16].

Worth mentioning is that several other methods of road roughness estimation are to be found in literature, of which some use accelerometers, some use tire pressure and some even use the fuel tank level signal to calculate estimates. The dominant application is together with active or semi-active suspension where estimates are used in damping control.

1.6 Road quality

How do one define road quality? Many factors affect our sense of road quality such as evenness, visibility, friction and lane width. What is interesting from a vehicle point of view and in the scope of this paper is some measure on surface roughness. Road roughness is the main source of vehicle vibration and material fatigue in haul trucks. Others are vibration caused by engine, drive line and unbalanced tires. Several different measures have been used and proposed over the years for the indexing or classification of road surface and ride roughness.

For this work ISO standard 8608 is adopted as road quality measure. It classifies a given road section based on the frequency content in a number of measured surface profiles.

1.7 ISO 8608

Fundamental concepts in ISO 8608 are *spatial frequency*, *road profile* and *PSD*. *Spatial frequency* is contrary to the ordinary unit Hertz [cycles/second] defined as [cycles/meter]. Otherwise it is analogous to the unit Hertz and the calculations are the same. *Road profile* is the measured variations in height of the road surface measured along one track on, and parallel with, the road. *PSD* is short for *Power Spectral Density* and is a mathematical concept described in e.g [14].

The use of ISO 8608 is based on the assumption that a given road have equal statistical properties everywhere along a section that is to be classified. That is: the road surface is a combination of a large number of longer and shorter periodic bumps with different amplitudes. The combination is the same wherever one looks along the road section. More precisely, the road can be described as a Weak-Sense Stationary process (WSS). However, this is clearly not true for all roads, but in a majority of cases it is a good approximation and therefore a reasonable assumption. This means that a classification made over a road section that is not homogeneous may be misleading. See [2] for further details.

Chapter 2

Experimental setup

Figure 2.1. Test vehicle Scania R420 tractor 4x2.

An experiment is carried out where the vehicle is driven along a Swedish paved country road. The road profile in left wheel track is known beforehand. The profile is measured, by third party, with very good precision using an assigned measuring vehicle equipped with a laser distance sensor rig. Profile measurements are performed according to current standards. The procedure is described in [10].

One pressure sensor is mounted on right air suspension bellow. One distance sensor is mounted on vehicle frame measuring vertical distance to rear axle on left side. In addition the vehicle CAN-bus is monitored whereas the following signals are logged:

- Vehicle speed
- ELC chassis level
- ELC bellow pressure
- ELC control state

- Weight on rear axle

Figure 2.2. Mounted distance sensor.

2.1 Measurement equipment

2.1.1 Sensors

1. One analog distance sensor using a spring loaded thread roll connected to a potentiometer.
2. One analog pressure sensor.

2.1.2 Logger equipment

Sensors are connected to an Ipetronik DMS module that in turn is connected to a PC via a Vector CANcard. The CANcard has two channels. Channel 1 is connected to the Ipetronik DMS module. Channel 2 is connected to vehicle CAN-bus. CANalyzer software is used with the PC for the monitoring and saving of data. Analog sensors are sampled with 500 Hz. Messages on CAN-bus are received periodically. ELC level and pressure where for a start not available on CAN-bus by default. These messages where received by polling the ELC ECU using a simple *Capl*-script. See Appendix A. The resulting sample rate is 20 Hz.

Figure 2.3. Mounted pressure sensor.

Later, through ELC software upgrades, these signals became available. Now with the default period 100 ms or 10 Hz sample rate.

2.2 Signal preprocessing

The Ipetronik apparatus provides a built in hardware filter with cut-off frequency 30 or 300 Hz. The 300 Hz filter is applied before sampling the analog signals to avoid aliasing. A 300 Hz cut-off frequency is not ideal. With 500 Hz sampling a 250 Hz cut-off frequency is preferred. But this is not an option using the said equipment. However, 500 Hz sampling is fairly fast and all system dynamics should be captured. As a comparison vehicle suspension eigen-frequencies are typically ≈ 1 Hz and ≈ 10 Hz.

2.3 Concerning the pressure signal

It is early realized that the level and pressure signals contain more or less same information concerning vertical vehicle motion. But the level signal is a more direct measure of such motions. To convert the pressure signal into vertical deviation, some kind of model of the suspension bellow and its mechanical components is required. Neither is the pressure signal of better quality than the level signal in the said test vehicle. They have same specified resolution and update frequency on CAN. Therefor the pressure signal is not discussed further but passed on to possible future work.

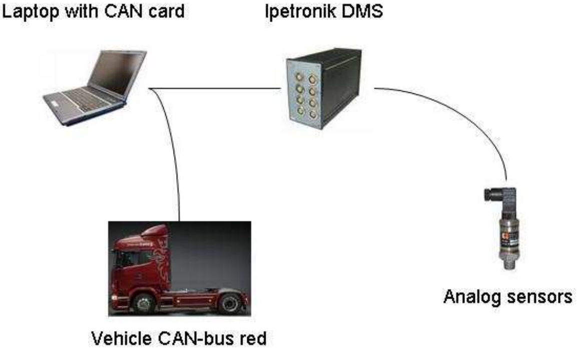

Figure 2.4. Measurement setup.

Chapter 3

Road roughness estimation

This chapter describes two methods of road roughness estimation. Which one to choose is very much dependent on how the problem is described and on the purpose with the implementation. Each method is thoroughly discussed and advantages and shortages with each method are listed.

One important decision that has to be made when considering road estimates is whether some road geometric property or simply vehicle stress is to be estimated. Say that actual road roughness needs to be estimated. Then vehicle traveling speed and mass is important to the measurements. A small bump traveled in high speed causes more suspension travel than the same bump traveled over slowly. Likewise a big bump traveled over slowly does not necessarily cause more suspension travel than a small bump traveled over fast.

But say that rough road conditions is to be detected. Or that vehicle stress is to be estimated. Or simply that suspension travel is to be measured. Then vehicle speed and mass is of minor interest. Only road induced vehicle motions are of interest without respect to traveling speed.

This is one of the aspects that governs the choice of method. Others are computational resources and simplicity.

3.1 Method 1 - Estimate the road PSD using a linear vehicle suspension model

This section describes a method to estimate the road PSD as defined in the ISO 8608 standard. A linear vehicle suspension model is used to calculate the frequency response from road input to suspension travel. This method is more precisely the way to estimate road geometrical properties or actual road roughness with respect to vehicle speed and mass as described in Chapter 3 introduction.

In the preparatory work much effort was laid on an attempt to formulate the problem in terms of linear observer theory, e.g Kalman. But the nature of road surface irregularities being not a system property but an unknown input to the system make such solutions very difficult. Even though road profile can be satisfactory modeled as a transfer function driven by white noise and incorporated in the system description. The problem left is to estimate the white noise variance which again is not the benefit with e.g Kalman theory. Here system noise is a parameter rather than a observable internal state.

But if the requirements on the estimate are eased a little, demanding not momentary road amplitude estimates, but estimates of a more statistical nature, calculations become easy and straight forward in the frequency domain. Results apply well to the definitions in ISO 8608.

3.1.1 Suspension model

To understand how road input affect suspension travel a model of the suspension is needed. A linear model is preferred. Such a model is the so called quarter-car model widely used in literature.

Studying the air suspension on the test vehicle it is found that the damper characteristics are not linear. Damping depends on the direction of operation. One magnitude of damping when compressing and another when extracting. This implies a problem when seeking a good model description of the system. Despite this shortage a linear model is chosen for the benefit of easy calculations. Results show that a linear approximation may be sufficient.

Quarter-car model

The widely used quarter-car model (see Figure 3.1), consist of a sprung mass connected to a unsprung mass via a spring and damper. Road input affects the unsprung mass via another spring modeling the tire. Damping between road and unsprung mass is neglected. Further description of the model is found in [18]. Design parameters are (see Table 3.1): Spring and damper characteristics are

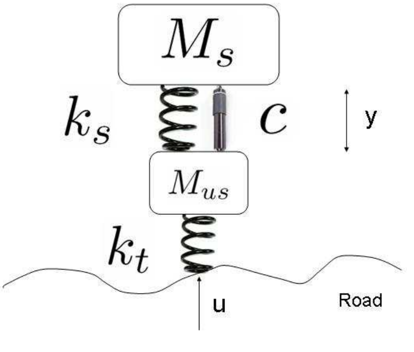

Figure 3.1. Quarter-car model.

M_{us}	Unsprung mass	600 [kg]
M_s	Sprung mass	2591 [kg]
k_s	Spring stiffness	297.49 [N/mm]
k_t	Tire stiffness	1700 [N/mm]
c	Damping constant	31835 [Ns/m]

Table 3.1. Design parameters.

linearized in equilibrium. Scania drawings referred to are [8], [3], [6] and [5]. Unsprung mass is the sum of mass of rear axle and tires divided by two which gives the proper quarter car parameter value. Sprung mass is available on vehicle CAN-bus in the form of rear axle load. This load is also divided by two. Chosen parameter values are found in Table 3.1.

Writing the model on state-space form (Equations 3.1 and 3.2) gives the matrices in Equations 3.3 to 3.5.

$$\dot{x} = Ax + Bu \tag{3.1}$$

$$y = Cx \tag{3.2}$$

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{k_s}{M_s} & -\frac{c}{M_s} & \frac{k_s}{M_s} & \frac{c}{M_s} \\ 0 & 0 & 0 & 1 \\ \frac{k_s}{M_{us}} & \frac{c}{M_{us}} & -\frac{(k_s+k_t)}{M_{us}} & -\frac{c}{M_{us}} \end{bmatrix} \tag{3.3}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{k_t}{M_{us}} \end{bmatrix} \tag{3.4}$$

$$C = \begin{bmatrix} -1 & 0 & 1 & 0 \end{bmatrix} \tag{3.5}$$

States are (Equation 3.6):

$$x = \begin{bmatrix} x_s \\ \dot{x}_s \\ x_{us} \\ \dot{x}_{us} \end{bmatrix} \tag{3.6}$$

Where x_s and x_{us} are positions of sprung mass and unsprung mass respectively. Damped natural frequencies for the suspension system model are 1.52 Hz and 7.12 Hz.

3.1.2 Calculate road PSD estimate

This method uses level signal y as output from suspension system. Road irregularities u is input. Given the above model $G(s)$ and using the signal Fourier transforms this can be written:

$$Y(s) = G(s)\,U(s) \tag{3.7}$$

The PSD relation then becomes:

$$\Phi_Y(f) = |G(i2\pi f)|^2 \Phi_U(f) \tag{3.8}$$

Substitution of variables in road PSD gives:

$$\Phi_U(f) = \frac{\Phi_U(n)}{v} \tag{3.9}$$

Equation 3.8 and 3.9 combined leads to the road PSD estimate:

$$\hat{\Phi}_U(n) = \frac{v}{|G(i2\pi f)|^2}\Phi_Y(f) \tag{3.10}$$

The vehicle speed v is assumed constant. $\hat{\Phi}_U(n)$, $|G(i2\pi f)|^2$ and $\Phi_Y(f)$ are vectors. Operations are performed element wise.

The received PSD estimate is smoothed using the method described in reference [2].

3.1.3 Classification using line fit

Given the estimated and smoothed road PSD presented in a figure with log-log scale. A linear line fit is performed on the PSD between spatial frequencies $2^{-6.5}$ and $2^{1.5}$ as described in [2]. This line can be written as the line Equation 3.11.

$$y = G(n_0)\left(\frac{n}{n_0}\right)^{-w} \tag{3.11}$$

This line roughly characterize the frequency content in the road surface. That is its composition of short and long wave periodical bumps. To obtain a unambiguous road classification based on the information in the fitted line, n_0 is defined as in Equation 3.12.

$$n_0 = 0.1\,[cycles/meter] \tag{3.12}$$

and the value of $G(n_0)$ and w completely describes the road quality estimate. the line slope w is assumed having a value near -2 as a typical real road and consequently the ISO class limits slope. A comparison of $G(n_0)$ with the limits defined in ISO 8608 render a road class estimate. A letter from A to H where A corresponds to very good road quality and H is very poor.

A majority of road PSDs tend to have a slightly bent knee near spatial frequency $n = \frac{1}{2\pi}$, why for example reference [18] introduce a minor modification to the above procedure in that the ISO class limits are bent accordingly with the slope $\omega = -2$ to the left of $n = \frac{1}{2\pi}$ and for lower frequencies and slope $\omega = -1.5$

to the right for higher frequencies. This implies that the described PSD line fit should be made either in frequency band:

$$2^{-6.5} \leq n \leq \frac{1}{2\,\pi}\,[cycles/meter] \tag{3.13}$$

or

$$\frac{1}{2\,\pi} \leq n \leq 2^{1.5}\,[cycles/meter] \tag{3.14}$$

or both.

3.1.4 Classification using calculated RMS values in frequency domain

As an additional alternative, a RMS value in one or several ISO 8608 predefined frequency bands can be calculated using the easy operation in Equation 3.16.

$$RMS = \sqrt{\hat{\Phi}_U(n)\,B} \tag{3.15}$$

Where B is frequency separation between PSD elements. Such RMS value limits are also defined in the ISO standard and a comparison enables classification in a similar way as above with letters A to H.

The two methods, line fit, and RMS in frequency domain should result in similar estimates. The choice should only be a matter of preferences.

3.1.5 Comments on method 1

This method estimates a geometrical property of the road surface according to a well established standard namely ISO 8606. The suspension model used in calculations can easily be adapted to new loads on line via design parameter sprung mass $M_s$that may be updated from vehicle CAN-bus. The method is ready to use. Once it is verified no test driving is required. That is since no empirical thresholds are used. Nothing is said about vehicle stress. Implementation complexity may overshadow its advantages.

3.2 Method 2 - Compute RMS on level signal after bandpass filtering

This section describes a method suitable when focus is on actual suspension travel and resulting vehicle stress. The estimate is of the nature *"vehicle experiences rough road conditions of a certain magnitude"*.

3.2.1 Calculate RMS on level signal

The level signal is measured and saved over a preselected period of n samples. The quadratic mean of the same signal is calculated as:

$$RMS(y) = \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i^2} \tag{3.16}$$

The received scalar value works as an index in it self indicating the roughness of the ride. If required one or several thresholds can be introduced classifying ride roughness. Using this technique large amplitude low frequency variations will dominate the resulting RMS value. Such variations occur for example when traveling over sudden irregularities like pot holes. Such irregularities may not be representative for the rest of the road surface. To avoid this problem a standard band pass filter is applied to the level signal damping out its low and high frequency characteristics. See patent [1].

3.2.2 Comments on method 2

The method is easily implemented with little demands on computational power. Interpretation of resulting index is not straight forward. The setting of relevant thresholds requires good understanding in vehicle dynamics and perhaps extensive test driving.

Chapter 4

Experimental results

4.1 Data

Measurements are performed as described in Chapter 2 with said test vehicle along the following roads near Södertälje, Sweden. Road profiles from roads 1 and 2 in

Measurement	**Road number or name**	**Road type**	**Start**	**Stop**	**Distance km**
1	E20	motorway	Södertälje	Läggesta	24.5
2	990	country road	Läggesta	Snebro	11.4
3	Tvetavägen	country road	Södertälje	Jumsta	5.4
4	Tvetavägen	country road	Jumsta	Södertälje	3.7
5	-	country road	Jumsta	Almnäs	1.8
6	-	dirt road	Almnäs	Jumsta	2.3

Table 4.1. Test roads.

Table 4.1 are kindly provided by the author of [11]. Profile data consist of 17 parallel profiles. One profile that lie in left wheel track is used for analysis. In this case the 3:rd from left. Profile data consist of equidistant samples every 0.05 meter. Profile data is used for verification of the suspension model and estimates. Measurements from roads 3 to 6 in Table 4.1 are intended to prove that different road qualities, at least, can be detected, without necessarily estimating correct ISO-class at all times.

On road measurements from roads 1 and 2 produce 5 data sets corresponding to the road sections in Table 4.2. Profile data is divided into 5 sets accordingly. Transients are carefully removed from measurements leaving only sets where vehicle speed is held reasonably constant and no gear shifting occurs.

Measurements from roads 5 and 6 in Table 4.1 produce several sets of data accordingly. Due to the nature of the roads and the need for preprocessing as in removing transients, some data sets are rather short from a statistical point of view. Short in the sense that measurements are made over a few hundred meters only. Whenever, in the following, results are derived from such a road section, it is shown. On less maintained roads the assumption that the road is homogeneous

Set	Road	Start	Stop
1.1	E20	Södertälje	Nykvarn exit
1.2	E20	Nykvarn exit	Märkartorp
1.3	E20	Märkartorp	Läggesta
2.1	990	Läggesta	Taxinge
2.2	990	Taxinge	Snebro

Table 4.2. Road sections.

becomes weaker. This may corrupt estimates.

4.2 Suspension model verification

The test vehicle is driven with constant speed with left wheel pair over a hole with sharp edges in an otherwise smooth road. Suspension travel is measured as in Chapter 2. The suspension model proposed in Section 3.1 is simulated with input corresponding to the road irregularity on test course. Results are presented in Figure 4.1. Results show that a linear model does not predict suspension travel

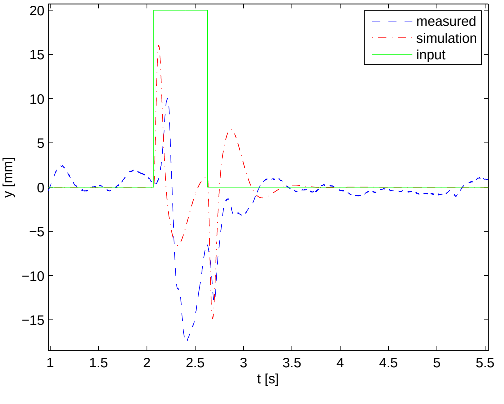

Figure 4.1. Model verification.

correctly. This is because damper characteristics are not linear but depend on the direction of operation as described in Section 3.1. An assumption is made. That is: the model frequency response is good enough in some frequency range enabling PSD estimate as in Section 3.1.

4.3 ELC signal

When performing on road measurements, the ELC level signal was monitored at all times. To indicate how the level signal behave qualitatively, Figure 4.2 is presented. Figure 4.2 show that ELC suspension system produce a well scaled but

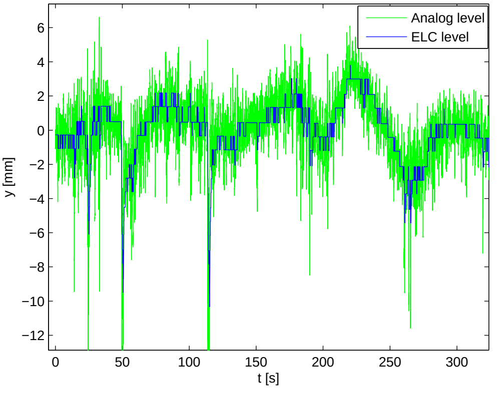

Figure 4.2. Analog and 20 Hz ELC level signal comparison.

badly resolved signal.

4.4 Road PSD and PSD estimate

Road profile PSD and road PSD estimate are computed, from each data set in Table 4.2 where available, as described in Section 3.1. Welch method was used. Results from data set 1 are shown in Figure 4.3 together with bent ISO 8608 class limits using log-log scale. Figure 4.3 show that estimated road PSD agree with real road PSD roughly from 0.02 to 1 [cycles/meter] spatial frequency. Outside this frequency band estimate deviates from the real value. This is a result of one or several of the following:

- Suspension model frequency response is inaccurate in these bands.
- Vehicle is subject to undesired roll or pitch motions during measurements.
- Level signal is noisy.
- Measured distance is to short.

Comments on the above:

Model errors are not to be compensated for in the scope of this work. A conceivable area of further development is the suspension model.

Though measures were taken to avoid pitch and roll movements into measurements, some may have occurred. In an attempt to compensate for the errors in

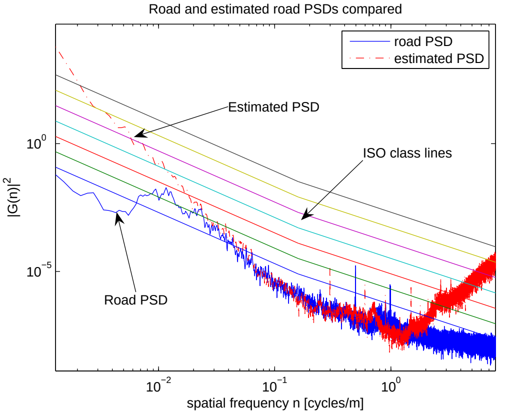

Figure 4.3. Data set 1 road PSD and estimated road PSD compared.

high frequency domain, a butterworth low pass filter with cut-off frequency 25 Hz was introduced and applied to the signal in time domain. But as long as only information in lower frequency bands are used for estimates this procedure is unnecessary.

Since some data sets originates from 5000 meters of measurements or more and no significant difference is found when comparing with the shorter data sets, the problem with possibly deficient measuring distances is assumed being of less importance. As a conclusion: derive results based on information in frequency band 0.02 to 1 [cycles/meter] only.

Estimated and smoothed road PSD from measurement 5 is presented in Figure 4.4. The Figure represents how the typical PSD looks from measurements 3, 4, 5 and 6 where road profiles are unavailable.

4.5 Classification of road

When it comes to classification of road based on its frequency information several different approaches are possible. Main issue is to achieve unambiguity. Decisions to make are whether to compute the RMS value in selected frequency bands or to calculate the offset of a linear approximation to the road PSD. However these two approaches are closely related and should give same results. Details are found in Section 3.1. The ambiguity issue is more complex. Ideally a road would produce the same class estimates in all frequency bands which none of the presented measurements have shown. Using the approach of linearizing PSD and calculate off-set as in method 1 Section 3.1, the line slope is expected to be around -2 which is rarely fulfilled. Based on the signs of model errors outside frequency band 0.02 to 1 [cycles/meter] a class estimate has to be derived from information in this band. The majority of road PSD estimates tend to have a knee around spatial

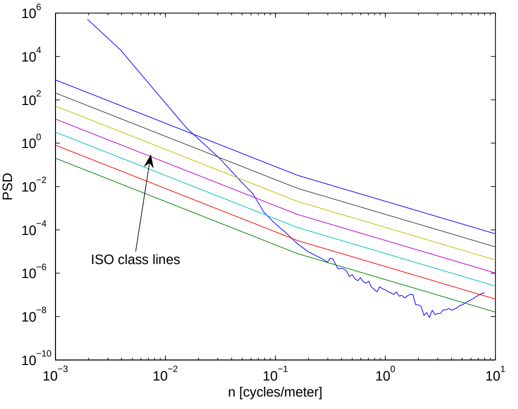

Figure 4.4. Measurment 5 estimated and smoothed road PSD.

frequency $n = \frac{1}{2\pi}$ why ISO class lines alternatively may be bent here with a slope of -2 to the left and a slope of -1.5 to the right as described in reference [18]. With reference to this the selected frequency band for class estimate becomes

$$0.02 \leq n \leq \frac{1}{2\pi} \, [cycles/meter] \tag{4.1}$$

As a further motivation the dominant system resonance frequency around $1-2$ Hz is here by captured as

$$v = \frac{f}{n} \tag{4.2}$$

$$2\pi \leq v \leq \frac{1}{0.02} \, [m/s] \tag{4.3}$$

$$or$$

$$6.3 \leq v \leq 50 \, [m/s] \tag{4.4}$$

$$\tag{4.5}$$

which include all typical traveling speeds. Using this approach the class estimates becomes as presented in Table 4.3.

Set	Road	Road type	Start	Stop	Distance km	Class estimates	
						Line fit	RMS
1.1	E20	motorway	Södertälje	Nykvarn exit	7.4	A	A
1.2	E20	motorway	Nykvarn exit	Märkartorp	7.3	A	A
1.3	E20	motorway	Märkartorp	Läggesta	6.7	A	A
2.1	990	country road	Läggesta	Taxinge	6.8	A	A
2.2	990	country road	Taxinge	Snebro	4.3	A	A
3.1	Tvetavägen	country road	Södertälje	Jumsta	1.6	B	A
3.2	-				1.7	A	A
4.1	Tvetavägen	country road	Jumsta	Södertälje	2.0	A	A
5.1	-	less maintained country road	Jumsta	Almnäs	1.1	C	C
5.2	-				0.5	C	C
6.1	-	dirt road	Almnäs	Jumsta	0.5	D	D
6.2	-				0.1	F	F
6.3	-				0.2	G	G
6.4	-				0.2	G	G

Table 4.3. Road class estimates.

There is a good reason to believe that sets 1 and 2 really are class A quality since they are well maintained motorways. This is also verified by the real road profile PSD presented in Figure 4.3. Road profile PSD, smoothed PSD estimate and fitted line from data set 1.3 are shown in Figure 4.5. Class estimates on

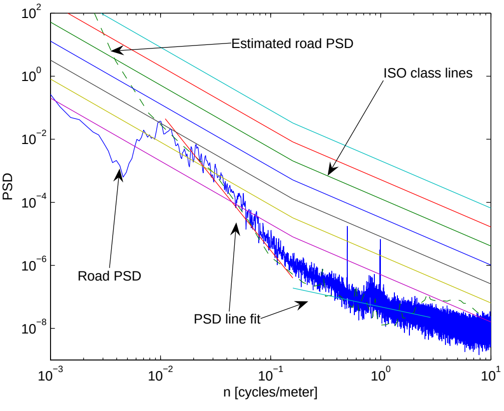

Figure 4.5. Road profile PSD, estimated PSD and fitted line from data set 1.3.

data set 5 show that slightly worse roads actually can be detected and separated from very good roads. Unfortunately road profiles for this road was not available. Estimates on set 6 are to be regarded as uncertain since road conditions made vehicle speed vary considerably and measured distances where generally rather short. However, this section is, according to estimates, undoubtedly worse than 5 which is a result in itself.

As a comparison RMS class estimates, according to ISO 8608, and as described in Section 3.1.4 in frequency band

$$2^{-3.5} \leq n \leq 2^{-2.5} \tag{4.6}$$

are presented in Table 4.3.

4.6 Requirements on measured distance

To study how estimates change when measured distance is shortened, measurement 1 is chosen. Data set 1.1 is divided into a number N equal length subsets numbered (1, 2 ... N), whereas class estimates are computed on each. Result for one of all subsets (1 to N) for different values on N are shown in Figure 4.6. Result for a different choice of subset with varying N is shown in Figure 4.7. Each measurement subset correspond to a unique part of the measured road section. The position of the fitted line appear to depend more on local conditions on the road than measured distance which of course is reassuring. No direct conclusion can be drawn based on the above comparison. Undertaking a more general reasoning,

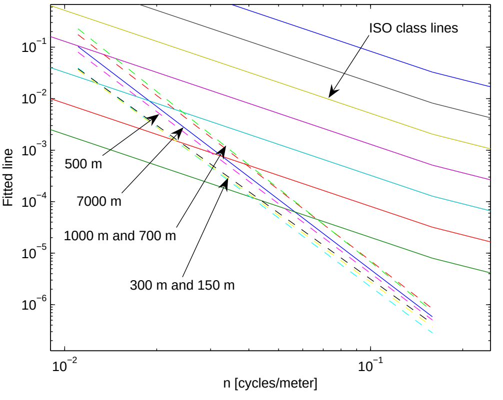

Figure 4.6. Linear fit with different measured distance.

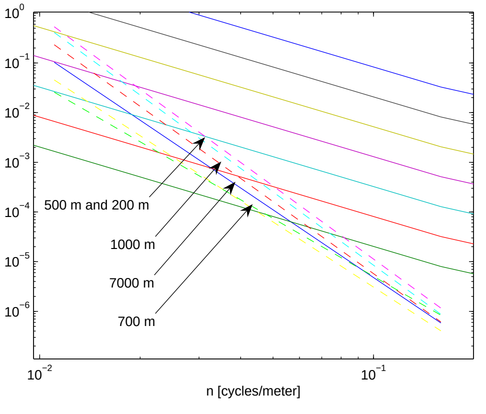

Figure 4.7. Linear fit with different measured distance.

it is noticed that the lower limit for line fitting using method 1 in Section 3.1 is $n = 2^{-6.5} = 0.011[cycles/meter]$ which corresponds roughly to 100 meter wave lengths. To not distort the signal to much when detrending it, at least a few cycles of this length should pass before estimating road quality. Say 500 meters is the shortest appropriate measurement distance when aiming for a overall road quality estimate.

For further comparisons the following Table 4.4 is presented showing class estimates from measurement 5.1 as data is divided into shorter sets. Distance starts at 1000 meters why the number of estimates are rather small limiting the statistical precision. Measurements 1 and 2 that indeed are much longer in distance are not used because these are all class A roads and estimates tend to go towards higher classes as measured distance is shortened. No higher class than A exists why no changes in class estimates occur. However, Table 4.4 show that estimates vary when sets are shorter and the number of subsets larger. Maybe in this case because of local variations in road quality. The intention was to indicate a lower limit for measured distance, but results only show that no predictions can be made for a long road section based on estimates from very short sections. When the over all road quality degrades, it is less probable that the homogeneity assumption holds. An alternative approach could be to compute several estimates from short consecutive road segments and weigh them together cleverly.

N	**Distance**	**Estimates**							
		Line fit				RMS			
		A	B	C	D	A	B	C	D
1	1000			1				1	
1	700			1			1		
2	500			2			2		
3	300		2	1			3		
10	100	1	3	2	4	3	3	3	1

Table 4.4. Road class estimates compared.

4.7 Road classifications using the ELC signal

To test the validity of estimates derived from the ELC signal, road PSD estimates where calculated based on the ELC level signal from measurements 1. Results are shown in Figure 4.8. Estimated PSD seem to agree with road profile PSD only for spatial frequencies near 0.02 [cycles/meter] which also happens to be the lower limit for where method 1 applies. Robustness is questionable.

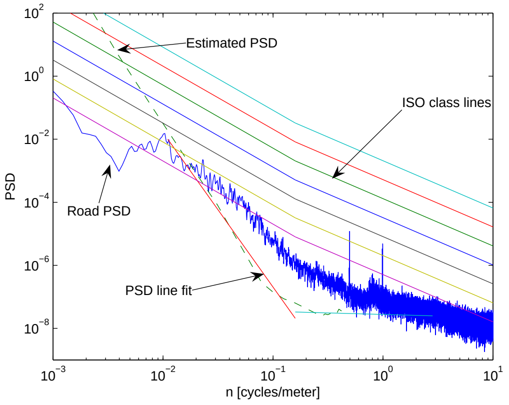

Figure 4.8. Road PSD estimates using ELC signal.

4.8 Bandpass filtering and RMS calculation in time domain

To verify the value with method 2 a 4th order butterworth bandpass filter is designed, with cut-off frequencies:

$$\omega_1 = \frac{0.5}{\frac{fs}{2}} \tag{4.7}$$

$$\omega_2 = \frac{5}{\frac{fs}{2}} \tag{4.8}$$

$$\tag{4.9}$$

The filter is applied using Matlab `filtfilt` to the analog level signal from data sets listed in Table 4.3. The resulting signal y RMS value is calculated as follows:

```
RMS(y) = sqrt(y*y'/length(y));
```

Results are shown below in Table 4.5. It is immediately clear that good driving conditions are separable from moderate and bad. Notice that this method does not compensate for different loads and variations in speed. The butterworth filter used was chosen with respect to the suspension eigen-frequencies and with intention to suppress low frequency high amplitude variations, as well as high frequency noise, that would completely dominate the RMS value calculated and degrade its significance.

Notice that the suspension system RMS values differ a lot from the analog signal RMS. This is because the ELC system signal in the given test vehicle apparently was scaled in an unspecified way. This strange behavior is outside the scope of this work and is therefor not investigated further. Noticeable is that the trend is the same as for the analog signal RMS, namely that bad roads cause

Data set	RMS	
	Analog signal	Suspension signal
1.1	1.29	-
1.2	1.09	-
1.3	1.11	-
3.2	1.67	0.065
5.1	1.87	0.067
5.2	1.79	0.067
6.1	4.13	0.145
6.2	5.50	0.218

Table 4.5. Calculated RMS values in time domain.

greater RMS values than good roads. Hence is the given ELC system signal, with sample rate 10 Hz and 0.1 mm resolution, suitable for driving condition estimates using method 2.

4.9 Discussion

Reaching an unambiguous class estimate using method 1 is clearly a problem. Once the preferred approach, and frequency band upon which to base ones estimate is selected, a class estimation is possible. Different road qualities are thereby measurable and good roads can be separated from worse. If tuning the suspension model parameters well and cleverly select estimation frequency band, it is likely that class estimates agree with class definitions according to ISO 8608.

Method 2 is straight forward and easily applied even on signals with moderate quality. Method 2 does not compensate for different loads and variations in speed.

Care has to be taken when selecting measuring distance. Using road sections longer than 500 meters is advised.

Chapter 5

Signal requirements

This chapter is of trial and error nature. When it comes to the problem of modifying signal resolution, a not so theoretical but rather practical attitude is kept.

5.1 Decimation of level data

To test performance when signals are sampled at a lower rate, the level data signal is decimated using Matlab decimate and its default anti alias filter with cut-off frequency $0.8\frac{fs}{2}$. If implemented, 500 Hz sampling is not realistic. As a comparison the CAN update frequency is 10 Hz for the relevant signals as ELC messages arrive every 100 ms. For this study a Capl-script (See Appendix A) was used requesting ELC data with a sample rate at 20 Hz. Say one wants to detect road irregularities up to $n_{max}[cycles/meter]$ at the speed of v. Then minimum sample rate is:

$$f_{min} = 2\,v\,n_{max} \tag{5.1}$$

If $n_{max} = 2^{1.5}$ is chosen as used in the smoothing algorithm described in [2] and v is a typical vehicle speed say 25 [m/s], f_{min} becomes 142 Hz. If lower sample rates are used the idea to smooth the estimated PSD and perform a line fit becomes unsuitable since not all frequency information is available. However, if the frequency band used for line fit is modified as in Section 3.1, n_{max} becomes $n_{max} = \frac{1}{2\pi}$. Then f_{min} becomes approximately 10 Hz which is rather moderate and a typical CAN update frequency.

5.2 Modifying signal resolution

When the system level signal is examined and compared with the corresponding analog signal, it is found that it´s actual resolution is somewhat worse than the Scania CAN-specification. It is of great interest to, given a road estimation method, find a limit for the required signal resolution.

To modify the analog signal resolution, each sample in the original signal x is rounded to nearest discrete level decided by a predefined resolution r. Namely

$$y = round\left(\frac{x}{r}\right) r \tag{5.2}$$

This is assumed to well imitate a badly resolved signal. Figure 5.1 shows how a modified resolution affects the analog signal PSD. Sample rate is 500 Hz. Apparently

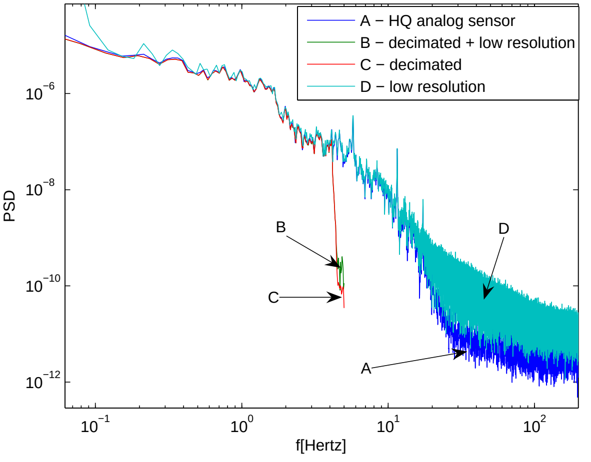

Figure 5.1. Analog and with modified resolution signal PSDs.

bad resolution causes high frequency errors in the estimated PSD which is also realized on intuition. A reasonable assumption is that the cut-off frequency for the occurrence of PSD errors depend on not only r, but also the sample frequency fs. Figure 5.1 also show estimated PSDs for a decimated, and with modified resolution, analog signal. The resulting sample rate and resolution is 10 Hz and 0.1 mm. This allows for the detection of frequencies up to 5 Hz. In this case the standard anti alias filter used with Matlab `decimate` has the cut-off frequency $0.8\frac{f_s}{2} = 4[Hz]$. The modified resolution seems not to affect the PSD negatively below this limit. So far the test indicates that 10 Hz sample rate and 0.1 mm is sufficient for use with road estimation method 1. However, there is reason to believe that the available system signal is low pass filtered additionally in an unspecified way. Figure 5.2 show how well the ELC system signal PSD agree with the high sampled and well resolved analog signal PSD in one of the measurements on road E20. Sample rate is 20 Hz for the ELC system signal. Clearly, despite indications from the experiment above, the given signal characteristics are insufficient for the use with method 1 due to inexact frequency detection above approximately 0.2 Hz. If a 0.1 mm resolution would do better is left unanswered until a real vehicle mounted system with said characteristics is available for test. To sum up, any configuration that detects frequencies correctly up to $f_{max} = n_{max} v_{max} = \frac{25}{2\pi} \approx 4[Hz]$ is sufficient.

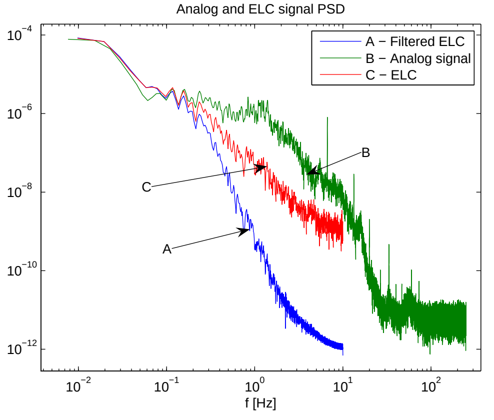

Figure 5.2. System and analog signal PSDs compared.

5.3 Road class estimates using decimated and low resolution level signal

These are the class estimates using the 50 times decimated and 0.1 mm resolution analog level signal. Estimation method is identical with the one used in Section 4.5. Table 5.1 is to be compared with Table 4.3 where high quality signal was used. Here the road names are omitted for readability.

5.4 Processing of ELC level signal

The ELC level signal obtained from the vehicle CAN-bus provides an on board source of suspension information. However, the quality of the signal is rather low. In this study a maximum sample rate of 20 Hz is achieved. signal bit resolution is specified in the CAN document. Measurements show that actual amplitude resolution is lower. This is according to the system supplier mainly because the inductive angle sensor used has in itself a limited resolution and the mechanical linkage connecting this one to the drive axle amplifies this effect due to its relatively long stroke.

The ELC signal presented in Figure 5.3 gives a rather jagged impression. It is desirable to smooth this signal considerably to enable meaningful frequency analysis. An attempt is made using a simple signal model and assuming Gaussian measurement error. A Kalman filter is designed followed by the application of the Rausch-Tung-Striebel algorithm described in e.g [14]. Little is known about the signal. The motivation to the choice of signal model is its simplicity. It based on the assumption that the signal first derivative is constant but noisy.

Set	Road	Distance km	Class estimates	
			Line fit	RMS
1.1	E20	7.4	A	A
1.2	E20	7.3	A	A
1.3	E20	6.7	A	A
2.1	990	6.8	A	A
2.2	990	4.3	A	A
3.1	Tvetavägen	1.6	B	A
3.2	-	1.7	A	A
4.1	Tvetavägen	2	A	A
5.1	-	1.1	C	B
5.2	-	0.5	C	C
6.1	-	0.5	D	D
6.2	-	0.1	G	F
6.3	-	0.2	H	G
6.4	-	0.2	G	G

Table 5.1. Road class estimates using decimated low resolution level signal.

5.4.1 Signal model

$$x(t+1) = x(t) + dt\frac{x(t) - x(t-1)}{dt} \tag{5.3}$$

Where dt is sample period $\frac{1}{fs}$. Rewriting this in state-space form gives:

$$\mathbf{x}(t+1) = \begin{bmatrix} 2 & -1 \\ 1 & 0 \end{bmatrix} \mathbf{x}(t) + w \tag{5.4}$$

$$\mathbf{y} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \mathbf{x}(t) + v \tag{5.5}$$

Where w and v are model noise and measurement noise respectively. Measurement noise is assumed having larger influence on filter estimate error. The noise covariance matrices R and Q are selected empirically based on the assumption that measurement noise is more influential than signal model error. R and Q are found in Equations 5.7 and 5.6.

$$Q = 1 \tag{5.6}$$

$$R = \begin{bmatrix} 150 & 0 \\ 0 & 150 \end{bmatrix} \tag{5.7}$$

5.4.2 Smoothing

An entire dataset is filtered using the Rausch-Tung-Striebel algorithm. The signal appears smoother and more true. Though the following computation of PSD show

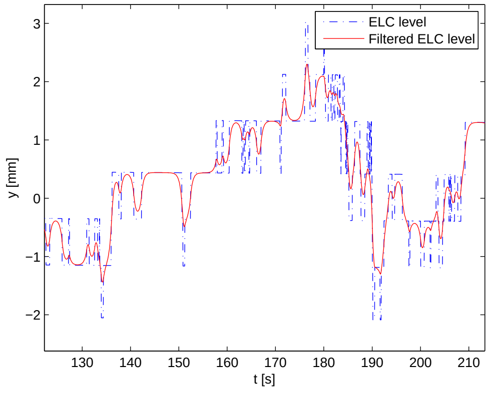

Figure 5.3. Filtered ELC level signal.

that to much information is lost. The PSD is compared with the corresponding PSD computed from the analog level sensor. See Figure 5.2. They are equal up to about 0.1 Hz frequency where they diverge. This is not good enough for method 1. A reproduction of frequencies up to 0.1 Hz maximum gives a maximum spatial frequency reproduction of $\frac{f}{v} = 0.004$ [cycles/meter] for $v = 25$ [m/s]. This is a region where road PSD estimate according to method 1 as in Section 3.1 is uncertain. Comparisons show that the unfiltered suspension system signal PSD better agree with the manual sensor PSD, why the described filtering process is not recommended. An ordinary standard low-pass filter applied in the forward and backward direction give similar results.

5.5 Discussion

Level signal must have at least 10 Hz update frequency. Signal resolution must be sufficient. The ELC system level signal quality turned out to be to poor due to insufficient resolution or more likely system low-pass filtering. The combined effects of sample time, resolution and filters must not distort the level signal in frequencies below 4 Hz. The attempt to smooth the ELC system signal turns out to be useless. The influence from the systems low-pass filtering is much stronger in distorting the signal.

Chapter 6

Sensitivity analysis

To demonstrate how parameter faults affect the over-all performance of the described method 1 to estimate road PSD the estimate is reviewed.

$$\hat{\Phi}_U(n) = \frac{v}{|G(i2\pi f)|^2}\,\Phi_Y(f) \tag{6.1}$$

For convenience the estimate formula is rewritten as:

$$\hat{\Phi}_U(n) = v\,g(f)\,\Phi_Y(f) \tag{6.2}$$

with $g(f) = |G(i2\pi f)|^{-2}$.

Clearly a scaling error on v passes on to the estimated PSD linearly. The inverse of the suspension model frequency response expression is differentiated partially with respect to each model parameter. Expressions are rather complicated why parameter values are inserted to enable the calculation of numerical values of the derivatives for a series of angular frequencies.

Given the state-space representation as in Section 3.1 with system matrices A,B,C and D a transfer function is computed according to [14] as:

$$G(s) = C(sI - A)^{-1}B + D \tag{6.3}$$

G(s) is presented in Equation 6.4.

$$G(s) = \frac{s^2 M_s\, k_t}{s^4 M_s\, M_{us} + s^3 c(M_s + M_{us}) + s^2 (M_s\, k_s\, M_{us} + M_s\, k_t + k_s\, M_{us}) + sc(k_s\, M_{us} + k_t - k_s) + {k_s}^2 M_{us} + k_s\, k_t - {k_s}^2} \tag{6.4}$$

The inverse frequency response function $g(f) = |G(i2\pi f)|^{-2}$ is partially differentiated with respect to each model parameter. Matlab symbolic toolbox was very helpful here. Expressions tend to become rather complex why g is not presented here. The following partial derivatives where computed:

$$\frac{\partial g}{\partial M_s},\ \frac{\partial g}{\partial M_{us}},\ \frac{\partial g}{\partial c},\ \frac{\partial g}{\partial k_t},\ \frac{\partial g}{\partial k_s} \tag{6.5}$$

Estimate errors and error quotients can be expressed as in Equations 6.7 and 6.8.

$$\hat{\Phi}_U + \Delta\hat{\Phi}_U = (v\, g(f) + \Delta_{vg})\Phi_Y \tag{6.6}$$

$$\frac{\Delta\hat{\Phi}_U}{\hat{\Phi}_U} = \left.\frac{\Delta g}{g}\right|_{\Delta v=0} \approx \frac{\Delta p_i \frac{\partial g}{\partial p_i}}{g} \tag{6.7}$$

for each parameter p. For $\Delta g = 0$:

$$\frac{\Delta\hat{\Phi}_U}{\hat{\Phi}_U} = \left.\frac{\Delta v}{v}\right|_{\Delta g=0} \tag{6.8}$$

To improve readability the chosen parameters with values as in Section 3.1 are inserted and the error quotients are presented as a function of angular frequency in Figure 6.1. Apparently an incorrect suspension stiffness k_s causes an estimate

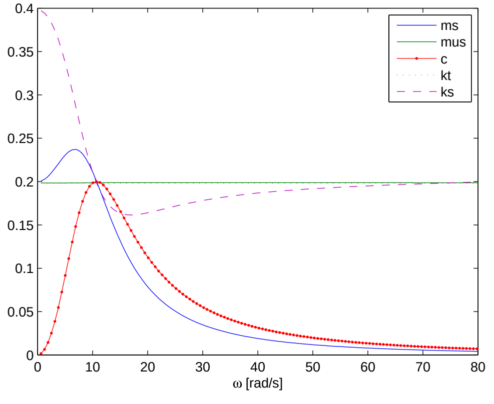

Figure 6.1. $\frac{\Delta\hat{\Phi}_U}{\hat{\Phi}_U}$ as function of ω with 10% parameter errors.

error around 40% for low frequencies. Around 10 [rad/s] which correspond to approximately 1.6 Hertz a 10% parameter error causes an estimate error on approximately 20%. This is near the suspension´s first resonance frequency. The influence from M_{us} and c then quickly decreases while remaining parameter´s error influences stay near 20% for higher frequencies. It should be observed that this applies for 10% parameter errors only.

Chapter 7

Further work

With more road profiles available, tuning of method 1 is possible. Such data enables verification of road class estimates according to ISO 8608.

Method 2 may possibly be modified to compensate for vehicle speed v and mass m in the following way.

$$y = G(s)u \Leftrightarrow Tu = TG(s)^{-1}y \tag{7.1}$$

y is level signal. u is input to suspension system $G(s)$, or in other words road profile. Introduce a bandpass filter T where cut-off frequencies are chosen as a function of vehicle speed v. T is also designed to ensure that the combination $TG(s)^{-1}$ is realizable. This could possibly provide an adaptive filter design that, through $G(s)$ compensates for m, and through T compensates for v when applied to the suspension level signal. Finally the RMS value of the received signal indicates how rough the traveled road is independent of v and m. This method is very similar to method 1 in that it includes the inverse suspension system dynamics. The difference is that calculations are performed in time domain. The method is yet to be evaluated.

The suspension model $G(s)$ could possibly be improved including unlinearities. The major downside is that the transformation of suspension PSD into estimated road PSD becomes more complex.

Method 1 uses a large number N in the calculation of signal N-point FFT which the PSD calculation is based upon. Further the suspension system frequency response $|G(i2\pi f)|^2$ is also calculated in a large number of points to provide a wide band road PSD estimate. But the road classification is based on the value in one point only, after all the smoothing and line fitting of course. This procedure could possibly be simplified. Ideally with the suspension signal PSD and suspension system frequency response calculated in only one point respectively. That is one frequency. Say for example 0.1 [cycles/meter] or $f = 0.1\,v$ Hz enabling road classification according to ISO 8608. The benefit would be fewer math operations. A downside is that even more assumptions may have to be made concerning road characteristics in remaining frequency bands.

The hardware filter used with the measurement equipment should have been applied with the other possible cut-off frequency 30 Hz to effectively avoid aliasing. It was not clear at the time for measurements that the upper limit for frequencies used in road roughness estimates would be around 4 Hz.

Chapter 8

Conclusions

Road quality or ride roughness estimates can be made using a suspension level signal. Depending on application one of two methods, described in this paper, may be chosen.

Method 1 uses a suspension system model to calculate a road profile PSD estimate upon which a road classification according to ISO 8608 is based. It is shown that good roads can thereby be separated from bad ones. It is merely shown that, road classification according to ISO, probably is of value. Quality requirements on the used level signal include true frequency detection up to at least 4 Hz. An experiment with manually modified signal resolution and sample rate indicate that 10 Hz and 0.1 mm resolution should be sufficient. However, a real system signal with same characteristics fails in detecting frequencies above approximately 0.2 Hz properly due to the system´s unknown built in low pass filtering of the signal. This makes conclusions in this field uncertain.

Method 2 use a standard IIR bandpass filter on the suspension level signal, followed by a RMS calculation in the time domain. The received scalar value can be used as a ride roughness index and provide means to analyze road conditions. Signal quality requirements are lower than for method 1. Basically, since the exact connection between road roughness, load and speed is not considered, the signal does not have to reproduce suspension travel exactly as long as its RMS value can be assumed to be, if not proportional, at least a monotonically increasing function of ride roughness. The given test vehicle´s, in system available, ELC level signal proves to be sufficient.

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Appendix A

Capl-script

```
/*@@var:*/
variables
{
    //sent messages
    pg 0xDA00   requestLevel = {SA = 0xFA, DA = 0x2F, DLC = 8, PRIO = 6};
    pg 0xDA00   reqpressure = {SA = 0xFA, DA = 0x2F, DLC = 8, PRIO = 6};
    pg 0xDA00   reqnomval = {SA = 0xFA, DA = 0x2F, DLC = 8, PRIO = 6};
    //pg 0xDA00   reqrot = {SA = 0xFA, DA = 0x2F, DLC = 8, PRIO = 6};
    //received messages
    pg 0xDA00 data;

    msTimer lptimer;
    msTimer lptimer2;

    int flag = 1;

}
/*@@end*/

/*@@timer:lptimer:*/
on timer lptimer
{
    //output(requestLevel);
    //output(reqpressure);
    //output(reqrot);
    setTimer(lptimer,100);
}
/*@@end*/

/*@@startStart:Start:*/
on start
```

```
{
    //write(flag=2);
    //setTimer(lptimer, 50);
    //setTimer(lptimer2,100);
    //requestLevel
    requestLevel.BYTE(0) = ????; //numbers are here replaced by question marks
    requestLevel.BYTE(1) = ????;    //service request
    requestLevel.BYTE(2) = ????;    //lid actual value level rear axle left.
    requestLevel.BYTE(3) = ????;
    requestLevel.CAN = 2;

    reqpressure.BYTE(0) = ????;
    reqpressure.BYTE(1) = ????;
    reqpressure.BYTE(2) = ????; //pressure RL
    reqpressure.BYTE(3) = ????;
    reqpressure.CAN = 2;

    reqnomval.BYTE(0)=????;
    reqnomval.BYTE(1)=????;
    reqnomval.BYTE(2)=????;
    reqnomval.BYTE(3)=????;
    reqnomval.CAN = 2;

    output(requestLevel);
    /*
    reqrot.BYTE(0) = ????;
    reqrot.BYTE(1) = ????;
    reqrot.BYTE(2) = ????;
    reqrot.BYTE(3) = ????;
    //output(requestLevel);
    */
}
/*@@end*/

/*@@timer:lptimer2:*/
on timer lptimer2
{
    //output(reqpressure);
    setTimer(lptimer2,100);
}
/*@@end*/

/*@@key:'m':*/
on key 'm'
{
    output(reqnomval);
```

```
}
/*@@end*/

/*@@msg:0x18DAFA2FX:*/
on message 0x18DAFA2Fx
{
    //output(requestLevel);

    if(flag == 1)
    {
    write("flag: %ld",flag);
    output(requestLevel);
    flag = 0;
    }
    else
    {
    write("flag: %ld",flag);
    output(reqpressure);
    flag = 1;
    }

}
/*@@end*/
```