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(54) Title: A METHOD AND SYSTEM FOR ESTIMATING PARAMETERS OF A VEHICLE

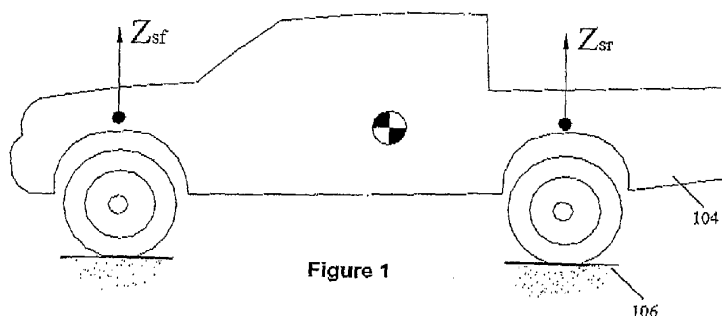


Figure 1

(57) Abstract: In one embodiment, a method of estimating parameters of a vehicle is disclosed. The method includes the steps of subjecting the vehicle to mechanical excitation, measuring movements of the vehicle during the excitation, determining the decay response of the vehicle from the measured movements and estimating at least one parameter of the vehicle based on the decay response.

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A METHOD AND SYSTEM FOR ESTIMATING PARAMETERS OF A VEHICLE

Technical Field

5 This invention relates to a method and system for estimating parameters of a vehicle including inertial parameters, damping and stiffness coefficients.

Background to the Invention

10 Changes in inertial parameters of vehicles such as sprung mass, centre of mass (vertical, lateral and longitudinal), principal mass moments of inertia (roll, pitch and yaw) and the products of these inertias affect the handling, comfort and performance characteristics of the vehicle. The changes may be caused, for example, by changes to the payloads of vehicles such as loading or unloading cargo or passengers, fuel changes, or by changes to the distribution of the payload on a vehicle. Changes in handling
15 characteristics can be particularly dangerous as they affect the safety of the vehicles. Changes to handling characteristics may lead to a situation where the operator of the vehicle loses control of the vehicle, such as in an oversteer situation, which may lead to crashes resulting in personal injury and damage. Changes to the inertial parameters may also affect the vehicles fuel consumption and engine emissions, and can also affect the
20 vehicles ride quality, performance and safety.

The effects of changes to inertial parameters are visible in most vehicles, however they are likely to be most pronounced in vehicles where the percentage change in passenger and cargo loading may vary significantly over time, such as in four
25 wheel drive vehicles (4wd's), commercial vehicles, buses, military vehicles, aircraft whilst taxiing, utility vehicles and small and light passenger cars. The subsystems that control the vehicles performance and safety features rely on fixed values for the inertial parameters, leading to a non-optimal control situation. These subsystems can include suspension systems, electronic stability control systems, vehicle automation, braking
30 control, traction control, engine management systems, cruise control, intelligent cruise control, power management and automatic gearbox control plus others.

Knowledge of damping and stiffness coefficients of a vehicle suspension system

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is important to the design of the system for achieving ride comfort and desirable vehicle road handling. Suspension damping is provided mainly through completely passive shock absorbers, or semi-active shock absorbers, or complete active actuators. The damping parameters may vary over the lifetime of the passive or semi-active shock absorbers due to heat and degradation.

Summary of the Invention

In a first aspect the present invention provides a method of estimating parameters of a vehicle, the method comprising the steps of:

- subjecting the vehicle to mechanical excitation; measuring movements of the vehicle during the excitation;
 - determining the decay response of the vehicle from the measured movements; and
 - estimating at least one parameter of the vehicle based on the decay response.
- The parameters may include inertial parameters.
- The parameters may include damping coefficients.
- The parameters may include stiffness coefficients.
- The step of subjecting the vehicle to mechanical excitation may be carried out by way of the vehicle travelling over an uneven surface.
- The uneven surface may be uneven and/or include a hump or step.
- The step of measuring the movements may include measuring either translational or angular displacement, velocity or acceleration at a location on the vehicle.
- The step of measuring the movements may be carried out at at least two locations on the vehicle.
- The step of determining the decay response may include the step of applying an autocorrelation function. Alternatively, methods such as the random decrement technique can be used to estimate the decay response.
- The step of estimating at least one parameter may include the step of applying a state variable method to the determined decay response to identify modal parameters of the vehicle. Alternatively, methods such as the Ibrahim time delay can be used to extract the modal parameters.
- The step of estimating at least one parameter may further include the step of establishing a vehicle characteristic matrix based on the modal parameters.

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The step of estimating at least one parameter may further include the step of performing a least squares analysis on the vehicle characteristic matrix.

The step of performing a least squares analysis may include the use of a vehicle model.

5 The step of performing a least squares analysis may include the use of vehicle stiffness, inertial or damping parameters.

The step of measuring movements may include the step of measuring movements using on vehicle and/or off vehicle sensors.

10 In a second aspect the present invention provides a system for estimating parameters of a vehicle, the system comprising:
a sensor or instrument for measuring movements of the vehicle;
a decay response determiner for determining the decay response of the vehicle from the measured movements; and
a parameter estimator for estimating at least one parameter of the vehicle based
15 on the decay response.

In a third aspect the present invention provides a vehicle fitted with a system according to the second aspect of the invention.

In a fourth aspect the present invention provides a method of changing a vehicle parameter, the method comprising the steps of:
20 subjecting the vehicle to mechanical excitation;
measuring movements of the vehicle during the excitation;
determining the decay response of the vehicle from the measured movements;
estimating the parameter based on the decay response; and
adjusting the vehicle parameter using the estimated parameter.

25 In a fifth aspect the present invention provides a system for changing a vehicle parameter, the system comprising:
a sensor or instrument for measuring movements of the vehicle;
a decay response determiner for determining the decay response of the vehicle
30 from the measured movements;
a parameter estimator for estimating the parameter based on the decay response;
and
a vehicle parameter adjustor for adjusting the vehicle parameter using the estimated parameter.

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In accordance with a sixth aspect, the present invention provides a computer program comprising instructions for controlling a computer to implement a method in accordance with either one of the first or fourth aspects of the invention.

- 5 In accordance with a seventh aspect, the present invention provides a computer readable medium providing a computer program in accordance with the sixth aspect of the invention.

Brief Description of the Drawings

- 10 Embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

FIG 1 shows a possible sensor layout using two accelerometers to measure the sprung mass response to mechanical excitation;

- 15 FIG 2 shows a possible sensor layout using one accelerometer and one gyroscope to measure the sprung mass response to mechanical excitation;

FIG 3 shows a possible sensor layout using four accelerometers to measure the sprung and unsprung mass response to mechanical excitation;

FIG 4 shows a possible arrangement for using one or more optical sensors to measure the sprung mass response to mechanical excitation;

- 20 FIG 5 shows a possible arrangement using three accelerometers to measure the sprung mass response to mechanical excitation;

FIG 6 shows a possible arrangement using one accelerometer and two gyroscopes to measure the sprung mass response to mechanical excitation;

- 25 FIG 7 shows a 7 degree of freedom simulation model using a vertical and two angular generalized coordinates;

FIG 8 shows the accelerometer and gyroscope response for the sprung mass subject to unknown impulsive input;

- 30 FIG 9 shows extracted auto and cross free decay response for a vehicle model subject to unknown impulsive input with accelerometer and gyroscope pitch and roll sensors;

FIG 10 shows a 3 degree of freedom estimation model using one accelerometer and two gyroscopes;

FIG 11 shows the estimated inertial parameters of sprung mass, pitch and roll mass moments of inertia and lateral and longitudinal centre of gravity locations;

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FIG 12 shows the accelerometer and pitch and roll gyroscope response for the sprung mass subject to unknown random road excitation;

FIG 13 shows extracted auto and cross free decay response using the autocorrelation function for the vehicle model subject to unknown random road excitation with accelerometer and gyroscope pitch and roll sensors;

FIG 14 shows the estimated inertial parameters of sprung mass, pitch and roll mass moments of inertia and lateral and longitudinal centre of gravity locations;

FIG 15 shows the estimated inertial parameters of sprung mass, pitch and roll mass moments of inertia and lateral and longitudinal centre of gravity locations using a Ibrahim time domain method;

FIG 16 shows extracted auto and cross free decay response using the random decrement function for the vehicle model subject to unknown random road profile input with accelerometer and gyroscope pitch and roll sensors;

FIG 17 shows the estimated inertial parameters of sprung mass, pitch and roll mass moments of inertia and lateral and longitudinal centre of gravity locations using the SVM;

FIG 18 shows the estimated inertial parameters of sprung mass, pitch and roll mass moments of inertia and lateral and longitudinal centre of gravity locations using the SVM with alternate equivalent stiffness equation;

FIG 19 shows a 7 degree of freedom simulation model with generalized coordinates at 3 vertical locations on the sprung mass;

FIG 20 shows the three accelerometer responses for the sprung mass subject to random road excitation;

FIG 21 shows extracted auto and cross free decay response for the vehicle model;

FIG 22 shows a 3 degree of freedom estimation model using three accelerometer sensors;

FIG 23 shows the estimated inertial parameters of sprung mass, pitch and roll mass moments of inertia and lateral and longitudinal centre of gravity locations; and

FIG 24 shows a block diagram of a system for changing a parameter of a vehicle.

Detailed Description of the Preferred Embodiments

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Figure 24 shows one embodiment of a system for changing a parameter of a vehicle, such as 104 in figure 1, the system generally being indicated by the numeral 100. The system 100 comprises one or more sensors or instruments 102 for measuring movements of the vehicle 104. The movements are typically generated or excited by the vehicle travelling over, for example, an uneven surface 106 and may constitute a mechanical excitation such as a vibration of the vehicle 104. The system also comprises a decay response determiner 108 for determining the decay response of the vehicle 104 from the movements detected by the sensors 102 and processed by the decay response determiner 108. The system also comprises a parameter estimator 110 for estimating the parameter based on the decay response. Some embodiments of the system 100 also include a vehicle parameter adjustor 112 for adjusting the vehicle parameter using the estimated parameter. The adjusted parameter may be, for example, damping and/or stiffness parameters of a vehicle component such as a suspension system of the vehicle 104.

Some embodiment require the response of the sprung mass of the vehicle 104, subject to a mechanical excitation, be recorded by sensors 102 mounted on the sprung mass of the vehicle 104 or remote sensors that observe the sprung mass motion from a position not attached to the vehicle body 104. The sensors 102 are typically mounted on the chassis of the vehicle 104. In alternative embodiments the responses of the unsprung wheel masses are measured. In one embodiment sensors 102 such as accelerometers, gyroscopes, GPS or similar are mounted onboard the sprung mass of the vehicle 104. In another embodiment, remote sensors 102 comprising, for example, cameras or lasers are mounted off board the vehicle 104 while still tracking the motions of the sprung chassis 104 and unsprung wheel mass. For onboard measurement the sensors 102 can be located at any position on the sprung mass 104 to fit in with specific manufacturer design requirements. For off board sensors any point on the vehicle 104 may be used for tracking of the vehicle's motions. The only requirement for all cases is the relative measurement position of the onboard or offboard measurement sensors 102 to a point on the vehicle in the lateral, longitudinal and vertical directions is known. The number of sensors 102 required is dependant on what inertial parameters the user wishes to measure and what type of sensors are used.

FIG 1 shows an embodiment for a system where the user wishes to measure the sprung mass, longitudinal centre of gravity location and pitching mass moment of inertia using vertical accelerometers located at the front and rear of the vehicle. The accelerometers measure the translational acceleration at these points and are a

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combination of the bounce and pitching modes of the vehicle. FIG 2 shows an embodiment to also estimate the sprung mass, longitudinal centre of gravity and pitching mass moment of inertia using a vertical accelerometer mounted at the rear of the vehicle and an angular gyroscope. The accelerometer measures the linear

5 acceleration at the rear of the vehicle and the gyroscope measures the absolute angular rate of the sprung mass regardless of position. In this embodiment either the accelerometer is integrated or the gyroscope differentiated so that both sensors are measuring in the same rate of change units. This preserves mode shape and scale factor information. FIG 3 shows an embodiment where the unsprung wheel mass motions are

10 measured in addition to the sprung chassis motions. This configuration might be used if high precession measurement of the inertial parameters is required, or for example this embodiment may be used if the unsprung wheel masses are significant compared to the sprung chassis mass. FIG 4 shows an embodiment using an off board camera being used to measure the response of the sprung mass by tracking the displacement, velocity or

15 acceleration of selected points. The embodiments shown in FIG 1, 2, 3 and 4 can be reconfigured to measure the sprung mass, lateral centre of gravity and roll mass moment of inertia. FIG 5 shows an embodiment where the user wishes to estimate the sprung mass, lateral and longitudinal centre of gravity and roll and pitching mass moments of inertia. In this embodiment the sprung mass has three accelerometers located on the

20 sprung mass measuring the vertical acceleration at these points. Each acceleration reading is a combination of the bounce, pitch and roll modes. FIG 6 shows an embodiment where the user wishes to estimate the sprung mass, lateral and longitudinal centre of gravity and roll and pitching mass moments of inertia. In this embodiment the sprung mass has one vertical accelerometer located on the sprung mass measuring the

25 vertical acceleration and two angular gyroscopes measuring the sprung mass roll and pitching angular velocity. In this embodiment either the accelerometer is integrated or the gyroscope differentiated so that both sensors are measuring in the same rate of change units. This preserves mode shape and scale factor information. The acceleration reading is a combination of the bounce, pitch and roll modes

30 It will be appreciated that a number of alternative sensor configurations are possible. The reader will also note that extension of the embodiments are possible to include other inertial parameters, such as yaw mass moment of inertia and the centre of gravity height. Measurement of the products of mass moments of inertia and

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measurement of the inclination angle of the roll axis may also be included.

Measurement of the inertial parameters enables measurement of the lateral, longitudinal and vertical tire forces which may, in some embodiments, further improve vehicle control systems.

- 5 From the sensor measurements the free decay response (FDR), or measurement responses equivalent to the FDR, is extracted. The FDR or equivalent contains all the information of the system including frequencies, damping ratios and modeshapes. In the preferred embodiments the method used to extract the FDR is dependant on the type of mechanical excitation being applied to the vehicle, which can be either deterministic
- 10 (impulsive or forced sine or cosine vibration) or stochastic (random) in nature or a combination of both. If the input is deemed to be deterministic the FDR can be extracted by picking the maximum inflection points from the sensor measurements or by the following method. There are numerous methods available to extract the FDR or equivalent from the measured responses of a system subject to stochastic or forced
- 15 vibration inputs. Some methods include the random decrement technique, impulse response function, power spectral density or autocorrelation function to name a few. For all embodiments both the auto FDR (for example accelerometer FDR captured at maximum accelerometer inflection) and cross FDR (for example accelerometer FDR captured at maximum gyroscope inflection) are required to be extracted to ensure that
- 20 mode shape (phase and amplitude) information between the measurement points is recorded, which is an integral requirement for estimation of the inertial properties of mass, centre of gravity and mass moments of inertia. The extracted FDR may not be a pure FDR and may contain measurement noise and other transient events and may be scaled by a factor. This is due to impulsive inputs never being purely impulsive and due
- 25 to road profiles being not purely random events but following certain spectral density profiles. However, the results do contain information about the FDR and this can be extracted using state space methods.

- From the FDR the system's modal parameters, such as natural frequencies, damping ratios (damping loss factors) and modeshapes can be extracted. There are
- 30 numerous methods available to extract the natural frequencies, damping ratios and modeshapes from FDR. Some methods include the state variable method (SVM), Ibrahim time domain method or least squares time domain method to name a few.

These methods aim to find the systems state transition matrix from the discrete

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sensor measurements. Due to the presence of measurement noise and other transient events being imbedded in the measurements a method of calculating and identifying these events is required. This may be accomplished by increasing the size of the state matrices by inclusion of pseudo noise measurements. The state transition matrix is then estimated using least squares analysis from which the modal parameters, such as mode shapes, damping ratios and natural frequencies, can be extracted by solving the eigenvalue problem of the state transition matrix. For each pseudo measurement added to the state matrices there exists a possible set of modal parameters that will be those of the physical dynamic system, while others will be caused by measurement noise and other transient events. A method for estimating and rejecting the noise modes is required. The first detection method employed in this embodiment is that the range of frequencies and damping ratios for the vehicle sprung mass is known and therefore this information can be used to detect and eliminate noise modes. This is not an unreasonable assumption to make, it is well known that the sprung mass bounce and pitch modes of vibration lie within the 1-3Hz range with damping ratios between 0.1 and 0.4 for the sprung mass. The second detection method is that for an under damped system the eigenvalues (natural frequencies and damping ratios) must appear in complex conjugate pairs. If a result has no complex conjugate it can be stated categorically that it is a noise mode. Further noise detection criteria are available, such as modal participation factors, and the detection methods used are one possible embodiment.

Once the noise modes have been detected and removed the eigenvalues (natural frequencies and damping ratios) and eigenvector (mode shapes) matrices can be reformulated to the required degree of freedom size. The size of this matrix depends on the number of sensors used and what inertial parameters the user wishes to measure. The new eigenvalue and eigenvector matrices can then be used to determine the system characteristic matrix A_{sym} using equation 1

$$A_{sym} = \begin{bmatrix} \lambda & \lambda^* \\ \lambda\Psi & \lambda^*\Psi^* \end{bmatrix} \begin{bmatrix} \Psi & 0 \\ 0 & \Psi^* \end{bmatrix} \begin{bmatrix} \lambda & \lambda^* \\ \lambda\Psi & \lambda^*\Psi^* \end{bmatrix}^{-1} \quad (1)$$

Where λ is the diagonal matrix of frequencies and damping ratios (eigenvalues), Ψ are the mode shapes (eigenvectors) and $*$ denotes the complex conjugate.

Further explanation of the state variable method can be found in the following publications, the contents of which are incorporated herein by reference, Zhang, N. and

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Hayama, S., 1990, Identification of structural system parameters from time domain data (Identification of global modal parameters of structural system by improved state variable method), *International Journal of Japanese Society of Mechanical Engineers, Series 3*, Vol. 33, No.2, pp. 168-175 and Zhang, N. and Hayama, S., 1991, Identification of structural system parameters from time domain data (A method for the identification of physical parameters of structural system from experimental data), *International Journal of Japanese Society of Mechanical Engineers, Series 3*, Vol.34, No.1, pp. 64-71. Methods other than the state variable method may be used as described herein. The estimation procedure for the preferred embodiment requires that the stiffness or equivalent stiffness values for the front and rear, left to right suspensions systems are available. These can be found by using manufactures data for vertical compliance of springs, bushes and tires or in a physical scenario, where there may be a lack of a detailed computer model or manufacturers data, these can be obtained from measuring the total suspension deflection (including tires) to a number of different loading conditions and finding an average value for the equivalent stiffness. Those skilled in the art will realize that other methods can be used to measure the spring stiffness values, such as pressure sensors for fluid springs or strain gauges on wire springs. Those skilled in the art will also realize that damping or equivalent damping parameters can be used in combination with or instead of the stiffness or equivalent stiffness parameters to estimate the inertial parameters.

The measured equivalent stiffness parameters may be affected by the vehicles high levels of damping which may need to be considered when measuring the equivalent stiffness. In one embodiment the equivalent stiffness and equivalent damping parameters can be measured using a forced vibration test. In another embodiment if the damping coefficients are known an equivalent stiffness equation can be derived to include these values. In other embodiments where the damping coefficients are unknown, or vary with time through heat and degradation, an alternative equation can be derived around the damping ratio, which can easily be measured using the SVM or similar method.

Each embodiment of the invention requires an estimation model of the vehicle. The estimation model is specific to each case and is dependant on the type and location of sensors used, and is also dependant on the information required to be estimated by the user. The estimation model should be derived to have the generalized co-ordinates at

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the location of the physical measurement sensors to reduce model complexity. An estimation model with differing generalized co-ordinates can be used if a transfer matrix between the estimation models generalized co-ordinates and physical measurement locations is known.

- 5 For simplicity the damping or equivalent damping matrix may be omitted by the user in the least squares estimator without a significant increase in error, but if damping information is available this may be included as shown in *equation 2*. For embodiments where the damping matrix may be known the characteristic matrix is defined in *equation 2*

$$10 \quad A_{est} = \begin{bmatrix} A_{est(1,1)} & A_{est(1,2)} \\ A_{est(2,1)} & A_{est(2,2)} \end{bmatrix} = \begin{bmatrix} 0 & I \\ -M_{est}^{-1}K_{est} & -M_{est}^{-1}C_{est} \end{bmatrix} \quad (2)$$

$$A_{est(2,1)} = -M_{est}^{-1}K_{est} \quad (3)$$

$$A_{est(2,2)} = -M_{est}^{-1}C_{est} \quad (4)$$

- Where , M , C and K are the mass, damping and stiffness matrices respectively and I is an identity matrix. If damping is unknown $A_{est(2,2)}$ can be set to zero in the estimation model.

- 15 A least squares solver, or similar error minimizing formulation, aims to find the best estimates for the inertial parameters based on the estimated characteristic matrix and the simplified vehicle model. It accomplishes this by minimizing the error function between the measured and estimated characteristic matrices. If damping is neglected the only section of importance in this embodiment for each characteristic matrix is the lower left hand sub matrix relating the mass, stiffness and geometric properties, denoted as sub matrix (2,1). The equation to be minimized using least squares is shown in *equation 5*

$$S_1 = \sum_{i=1}^n (A_{svm(2,1)} - A_{est(2,1)})^2 \quad (5)$$

- 25 where $A_{svm(2,1)}$ is the lower left hand sub matrix of the characteristic matrix found using equation 1, and $A_{est(2,1)}$ is the lower left hand sub matrix of the estimated characteristic matrix in *equation 2*. When the error function S_1 is minimised the values of mass, mass moments of inertia and center of gravity have converged to a solution.

- 30 It is noted that *equation 5* can be used to estimate the stiffness coefficients of suspension if the inertial parameters are pre-known. Therefore, it also provides an

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alternative method to identify the suspension stiffness coefficients of a vehicle. In a similar manner, the inertial parameters can also be used to estimate the damping parameters.

The maximum range of mass, mass moment of inertia and center of gravity location is used as the maximum bounds for the inertial estimates to prevent convergence to unrealistic solutions. This is a realistic assumption to make as this data would be known by the manufacturer and is commonly referred to as the vehicle mass property envelope. A least squares analysis is performed for each pseudo noise measurement where a set of modal parameters was found using the detection algorithms noted previously. The last test to determine the accuracy of the identified inertial parameters is how well the results correlate. Results that appear erratic from one noise mode to the next can be assumed to still be effected by the measurement noise components imbedded in the signal. Those skilled in the art will realize that other methods, such as stability plots, can be used to estimate when the solution has converged.

The damping coefficient of suspension of a vehicle can be identified without the pre-knowledge of stiffness. But it requires the pre-knowledge of masses (inertial parameters), or estimated masses. The estimates of the damping coefficients can be used, for example, to determine when the vehicle dampers require replacement. A least squares solver, or similar error minimizing formulation, can be used to find the best estimates for the damping or equivalent damping coefficients based on the estimated characteristic matrix, estimated inertial parameters and the simplified vehicle model. It accomplishes this by minimising the error function between the measured and estimated characteristic matrices. The only section of importance in this embodiment for each characteristic matrix is the lower right hand sub matrix relating the mass, damping and geometric properties, denoted as sub matrix (2, 2). The equation to be minimized using least squares in this embodiment is shown in *equation 6*

$$S_2 = \sum_{i=1}^n (A_{mm(2,2)} - A_{ei(2,2)})^2 \quad (6)$$

Embodiments of the invention will now be described to show how the invention can be practically applied to the estimation of vehicle inertial parameters. The equivalent damping coefficients of a vehicle suspension system can be estimated in the

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manner explained above and hence is omitted in the following embodiments. In each of the embodiments data is manipulated by computing techniques and as such, features of the systems described are embodied in a system, such as an embedded system, including a electronic processor. In many embodiments, the processor is controlled by software. In some cases, the system includes a suitably programmed general purpose computer..

In the following embodiments the systems include a sensor or instrument for measuring in the form of a combination of an accelerometer and gyroscope or accelerometers only. They further include a decay response determiner and a parameter estimator embodied in a computing system.

Embodiment 1 - Identification of inertial parameters from unknown impulsive bump input using one accelerometer and two gyroscopes

In this embodiment a method of using a single accelerometer and two gyroscopes, as shown in FIG 7, is used to measure the sprung mass response to a mechanical input from an unknown impulsive input, from a speed bump or pothole for example. In the configuration shown this will enable the sprung mass, longitudinal and lateral centre of gravity, pitch and roll mass moment of inertia to be estimated. For this embodiment the vehicle parameters are chosen to represent a light duty commercial vehicle. They are shown in *Table 1*.

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Table 1 Light Commercial Vehicle Suspension and Inertial Parameters

Parameter	Symbol	Value	Unit
Front Unsprung Mass	m_1, m_2	40	kg
Rear Unsprung Mass	m_3, m_4	65	kg
Sprung Mass	m	2300	kg
Pitch Inertia	I_{yy}	4000	kg.m ²
Roll Inertia	I_{xx}	500	kg.m ²
Longitudinal Centre of Gravity	a	1.8	m
Longitudinal Centre of Gravity	b	1.2	m
Lateral Centre of Gravity	d	0.75	m
Lateral Centre of Gravity	e	0.65	m
Tyre Stiffness	k_1, k_2, k_3, k_4	200000	N/m
Front Suspension Stiffness	k_5, k_6	45000	N/m
Rear Suspension Stiffness	k_7, k_8	80000	N/m
Anti-roll Bar	k_R	50000	N/m
Tyre Damping	c_1, c_2, c_3, c_4	50	N.s/m
Front Damping	c_5, c_6	2800	N.s/m
Rear Damping	c_7, c_8	3500	N.s/m

The mechanical excitation to the system is a random impulsive input, with the rear accelerometer and pitch and roll gyroscope responses shown in FIG 8. In this embodiment the measured responses of the gyroscopes are differentiated so that all measurements are in the same rate of change units.

In this embodiment the FDR is extracted simply by picking the maximum inflection point. The auto FDR and the cross FDR are shown in FIG 9.

From the auto and cross FDR the sprung mass frequencies, damping ratios and mode shapes are estimated. In this embodiment the modal parameters are detected by the SVM. For each pseudo measurement added to the state matrices using the SVM there exists a possible set of modal parameters of the vehicle, plus false modes caused by measurement noise and other transient signals. From the detected modal parameters the system characteristic matrix can be found using *equation 1*.

The vehicle estimation model is dependant on the sensor locations. For this embodiment the sensors are a vertical accelerometer and a pitch and a roll gyroscope, as shown in FIG 7. For simplicity the generalized co-ordinates for the estimation model should correspond to the sensor locations shown in FIG 7, but other formulations are possible but will require a transfer matrix to be used to transfer from one generalized coordinate set to another. The vehicle estimation model is depicted in FIG 10. The equations of motion are as follows, where Z is the displacement vector, M and K represents the mass and stiffness matrices respectively

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$$Z = \begin{bmatrix} z_{rear} \\ g \\ \alpha \end{bmatrix} \quad M = \begin{bmatrix} m & -mb & -mq \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{xx} \end{bmatrix} \quad (7, 8)$$

$$K = \begin{bmatrix} k_9 + k_{10} + k_{11} + k_{12} & -k_9(a+b) - k_{10}(a+b) & \\ -k_9a - k_{10}a + k_{11}b + k_{12}b & k_9a(a+b) + k_{10}a(a+b) & \\ -k_9d + k_{10}e - k_{11}d + k_{12}e & k_9d(a+b) - k_{10}e(a+b) & \\ & k_9(-q-d) + k_{10}(-q+e) + k_{11}(-q-d) + k_{12}(-q+e) & \\ & -k_9a(-q-d) - k_{10}a(-q+e) + k_{11}b(-q-d) + k_{12}b(-q+e) & \\ & -k_9d(-q-d) + k_{10}e(-q+e) - k_{11}d(-q-d) + k_{12}e(-q+e) & \end{bmatrix} \quad (9)$$

Where q is the offset between the lateral geometric centre of the lateral centre of gravity location. In this embodiment a bounded least estimator is used with maximum bounds set as sprung mass equal to 1500 to 2800kg, longitudinal centre of gravity equal to 1 to 2m, lateral centre of gravity 0.55 to 0.9m, pitch mass moment of inertia equal to 2000 to 7000kg.m² and roll mass moment of inertia equal to 400 to 1500kg.m². In this embodiment the mathematical relationship between the equivalent spring stiffness and damping ratio can be found using the following equations 10, 11 and 12.

$$k_y = \frac{(k_1 k_5)}{(k_1 + k_5)} (2.52(\delta^2) - 0.187(\delta) + 1) \quad (10)$$

$$k_{11} = \frac{(k_3 k_7)}{(k_3 + k_7)} (2.398(\delta^2) - 0.252(\delta) + 1) \quad (11)$$

$$k_{roll_eq} = k_R (0.5844(\delta^2) - 0.0444(\delta) + 0.4594) \quad (12)$$

Where δ is the damping ratio. These damping ratio equivalent stiffness equations are problem dependant and are derived using the mass property envelopes and known suspension stiffness and compliance values. Differing vehicles will have differing equivalent stiffness equations.

For each pseudo measurement added to the state matrices there exists a possible characteristic matrix estimated using the SVM. And for each characteristic matrix there exists a possible set of inertial parameters. In this embodiment the inertial parameters can be found using the estimated characteristic matrices, equations 3, 5, 7, 8, 9, 10, 11 and 12 and a bounded least squares minimization scheme. The inertial parameter estimates versus pseudo noise modes for this example are shown in FIG 11. The

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average values for the inertial parameters are found as follows: Mass 2289.4 kg (relative error of -0.4647%) pitch inertia 3800 kg.m² (relative error -5.2423 %), roll inertia 493.96 kg.m² (relative error of -1.2217 %), longitudinal centre of gravity of 1.847m (error of 2.5355 %) and lateral centre of gravity location of 0.77m (relative error of 2.6225 %).

Embodiment 2 - Identification of inertial parameters from unknown random road input using one accelerometer and two gyroscopes

In this embodiment a method of using a single accelerometer and two gyroscopes, as shown in FIG 7, is used to measure the sprung mass response to a mechanical input from an unknown random road profile. In the configuration shown this will enable the sprung mass, longitudinal and lateral centre of gravity, pitch and roll mass moment of inertia to be estimated. For this embodiment the vehicle parameters are identical to embodiment one, listed in *Table 1*.

The mechanical excitation to the system is a random road profile input, with the accelerometer, roll and pitch gyroscope responses shown in FIG 12.

In this embodiment the FDR is extracted using the auto and cross correlation function. The auto and cross correlation functions are proportional to FDR. The auto FDR and the cross FDR are shown in FIG 13.

From the auto and cross FDR the sprung mass frequencies, damping ratios and mode shapes are estimated. In this embodiment the modal parameters as detected by the SVM. For each pseudo measurement added to the state matrices using the SVM there exists a possible set of modal parameters of the vehicle, plus false modes caused by measurement noise and other transient signals. From the detected modal parameters the system characteristic matrix can be found using *equation 1*.

The vehicle estimation model is dependant on the sensor locations. For this embodiment the sensors are a vertical accelerometer and a pitch and roll gyroscope, as shown in FIG 7. For simplicity the generalized co-ordinates for the estimation model should correspond to the sensor locations shown in FIG 7, but other formulations are possible but will require a transfer matrix to be used to transfer from one generalized coordinate set to another. The vehicle estimation model is depicted in FIG 10 and the equations of motion described in embodiment 1 in equations 7, 8 and 9. In this embodiment a bounded least estimator is used with maximum bounds set as sprung

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mass equal to 1500 to 2800kg, longitudinal centre of gravity equal to 1 to 2m, lateral centre of gravity 0.55 to 0.9m, pitch mass moment of inertia equal to 2000 to 7000kg.m² and roll mass moment of inertia equal to 400 to 1500kg.m². In this embodiment the mathematical relationship between the equivalent spring stiffness and damping ratio can be found using the equations 10, 11 and 12 from embodiment 1.

For each pseudo measurement added to the state matrices there exists a possible characteristic matrix estimated using the SVM. And for each characteristic matrix there exists a possible set of inertial parameters. In this embodiment the inertial parameters can be found using the estimated characteristic matrices, equations 3, 5, 7, 8, 9, 10, 11 and 12 and a bounded least squares minimization scheme. The inertial parameter estimates versus pseudo noise modes for this example are shown in FIG 14. The average values for the inertial parameters are found as follows: Mass 2295kg (relative error of -0.218%), pitch inertia 3722.5 kg.m² (relative error -7.455%), roll inertia 487.3kg.m² (relative error of -2.59%), longitudinal centre of gravity of 1.86 m (error of 3.226%) and lateral centre of gravity location of 0.757m (relative error of 0.925%).

Embodiment 3 - Identification of inertial parameters from unknown random road input using one accelerometer and two gyroscopes

In embodiment 3, the example presented in embodiment 2 is re-examined. However in this embodiment the Ibrahim time domain method, instead of the SVM, is used to extract the modal parameters and system characteristic matrices. In this embodiment the inertial parameters can be found using the estimated characteristic matrices, equations 3, 5, 7, 8, 9, 10, 11 and 12 and a bounded least squares minimization scheme. The inertial parameter estimates versus pseudo noise modes for this example are shown in FIG 15. The average values for the inertial parameters are found as follows: Mass 2303.6kg (relative error of 0.155%), pitch inertia 3731.4kg.m² (relative error -7.197%), roll inertia 488.12kg.m² (relative error of -2.432%), longitudinal centre of gravity of 1.853m (error of 2.839%) and lateral centre of gravity location of 0.7544m (relative error of 0.588%).

Embodiment 4 - Identification of inertial parameters from unknown random road input using one accelerometer and two gyroscopes

In embodiment 4, the example presented in embodiment 2 is re-examined.

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However in this embodiment the decay responses are extracted using the random decrement technique instead of the autocorrelation function. The extracted decay responses are shown in FIG 16.

The SVM is used to extract the modal parameters and system characteristic matrices. For each pseudo measurement added to the state matrices there exist a possible characteristic matrix and a possible set of inertial parameters. In this embodiment the inertial parameters can be found using the estimated characteristic matrices, equations 3, 5, 7, 8, 9, 10, 11 and 12 and a bounded least squares minimization scheme. The inertial parameter estimates verses pseudo noise modes for this example are shown in FIG 17. The average values for the inertial parameters are found as follows: Mass 2284.7kg (relative error of -0.668%), pitch inertia 3816.4kg.m² (relative error -4.812%), roll inertia 491.7kg.m² (relative error of -1.677%), longitudinal centre of gravity of 1.84m (error of 2.189%) and lateral centre of gravity location of 0.7202 m (relative error of -4.133%).

Embodiment 5 - Identification of inertial parameters from unknown random road input using one accelerometer and two gyroscopes

In embodiment 5, the example presented in embodiment 2 is re-examined using an alternative formulation for the equivalent stiffness parameters. For this embodiment the following equations for equivalent stiffness can be used

$$k_y = \left(\frac{k_s k_1^2 + k_s^2 k_1 + \omega^2 k_1 c_s^2}{(k_s + k_1)^2 + \omega^2 c_s^2} \right) \quad (13)$$

$$k_{11} = \left(\frac{k_7 k_3^2 + k_7^2 k_3 + \omega^2 k_3 c_7^2}{(k_7 + k_3)^2 + \omega^2 c_7^2} \right) \quad (14)$$

Using this embodiment the damping coefficient values are required to calculate the equivalent spring stiffness parameters.

For each pseudo measurement added to the state matrices there exists a possible characteristic matrix estimated using the SVM. And for each characteristic matrix there exists a possible set of inertial parameters. In this embodiment the inertial parameters can be found using the estimated characteristic matrices, equations 3, 5, 7, 8, 9, 10, 13 and 14 and a bounded least squares minimization scheme. The inertial parameter estimates verses pseudo noise modes for this example are shown in FIG 18. The average values for the inertial parameters are found as follows: Mass 2369.0kg (relative

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error of 2.913%), pitch inertia 4009.4kg.m^2 (relative error 0.234%), roll inertia 507.9kg.m^2 (relative error of 1.569%), longitudinal centre of gravity of 1.812m (error of 0.624%) and lateral centre of gravity location of 0.756m (relative error of 0.824%).

5 Embodiment 6 - Identification of inertial parameters from unknown random road input using three accelerometers

In this embodiment a method of using three accelerometers, as shown in FIG 19, are used to measure the sprung mass response to a mechanical input from an unknown random road profile. In the configuration shown this will enable the sprung mass,
 10 longitudinal and lateral centre of gravity, pitch and roll mass moment of inertia to be estimated. For this embodiment the vehicle parameters are identical to embodiment one, listed in *Table 1*.

The mechanical excitation to the system is a random road profile input identical to that used in embodiment 1, with the accelerometer responses shown in FIG 20.

15 In this embodiment the FDR is extracted using the auto and cross correlation function. The auto and cross correlation functions are proportional to FDR and are shown in FIG 21.

From the auto and cross FDR the sprung mass frequencies, damping ratios and mode shapes are estimated. In this embodiment the modal parameters as detected by the
 20 SVM. For each pseudo measurement added to the state matrices using the SVM there exists a possible set of modal parameters of the vehicle, plus false modes caused by measurement noise and other transient signals. From the detected modal parameters the system characteristic matrix can be found using *equation 1*.

The vehicle estimation model is dependant on the sensor locations. For this
 25 embodiment the sensors are three vertically mounted acceleration transducers, as shown in FIG 19. For simplicity the generalized co-ordinates for the estimation model should correspond to the sensor locations shown in FIG 19, but other formulations are possible but will require a transfer matrix to be used to transfer from one generalized coordinate set to another. The vehicle estimation model is depicted in FIG 22. The equations of
 30 motion are as follows, where Z is the displacement vector, M and K represents the mass and stiffness matrices respectively

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$$Z = \begin{bmatrix} z_{LF} \\ z_{LR} \\ z_{RR} \end{bmatrix} \quad M = \begin{bmatrix} \frac{m(be+bd)}{(a+b)(d+e)} & \frac{m(-bd+ae)}{(a+b)(d+e)} & \frac{m(bd+ad)}{(a+b)(d+e)} \\ \frac{-I_{yy}}{(a+b)} & \frac{I_{yy}}{(a+b)} & 0 \\ 0 & \frac{-I_{xx}}{(d+e)} & \frac{I_{xx}}{(d+e)} \end{bmatrix} \quad (15, 16)$$

$$K = \begin{bmatrix} k_9 + k_{10} & -k_{10} + k_{11} & k_{10} + k_{12} \\ -k_9 a - k_{10} a & k_{10} a + k_{11} b & -k_{10} a + k_{12} b \\ -k_9 d + k_{10} e & -k_{10} d - k_{11} e - k_R d - k_R e & k_{10} e + k_{12} e + k_R d + k_R e \end{bmatrix} \quad (17)$$

In this embodiment a bounded least estimator is used, with maximum bounds set as sprung mass equal to 1500 to 2800kg, longitudinal centre of gravity equal to 1 to 2m, lateral centre of gravity 0.55 to 0.9m, pitch mass moment of inertia equal to 2000 to 7000kg.m² and roll mass moment of inertia equal to 400 to 1500kg.m². In this embodiment the mathematical relationship between the equivalent spring stiffness and damping ratio can be found using Equations 10, 11 and 12 noted previously. Alternatively, equations 14 and 15 could be used if the damping coefficient values are known.

For each pseudo measurement added to the state matrices there exists a possible characteristic matrix estimated using the SVM. And for each characteristic matrix there exists a possible set of inertial parameters. In this embodiment the inertial parameters can be found using the estimated characteristic matrices, equations 3, 5, 10, 11, 12, 15, 16 and 17 and a bounded least squares minimization scheme. The inertial parameter estimates versus pseudo noise modes for this example are shown in FIG 23. The average values for the inertial parameters are found as follows: Mass 2286.4kg (relative error of -0.593%), pitch inertia 3860.1 kg.m² (relative error -3.623%), roll inertia 496.24kg.m² (relative error of -0.758 %), longitudinal centre of gravity of 1.819 m (error of 1.08%) and lateral centre of gravity location of 0.7565m (relative error of 0.86 %).

Other embodiments

In the above described embodiments the vehicle in question was a light commercial vehicle. Similarly, the invention is applicable to passenger cars, trucks, train cars, aircraft whilst taxiing, military and off road vehicles and other wheeled

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vehicles. The invention also has application to vehicles which move on skids, caterpillar tracks and the like.

In the above described embodiments, measurements are taken on-board the vehicle and these are used in determining inertial parameters. In another embodiment, measurements may be taken using remote sensors. Examples of these for monitoring movement of the vehicle include optical sensors. These may include, for example, a machine vision system, digital video camera, a laser and associated detectors or the like as shown in FIG 4. These measured movements can then be used in determining inertial parameters. The digital video camera could be mounted at a road side or other location and used to monitor the movement of passing vehicles. Such a system could determine if passing vehicles were overloaded or were otherwise posing a safety risk. Such vehicles could then be stopped or otherwise flagged for further investigation. This arrangement could be used in highway safety monitoring, or customs security monitoring.

Particularly, but not exclusively, in embodiments using sensors on the vehicle 104, the estimated (or even measured) changes in the inertial parameters of the vehicle may be used to favorably adjust one or more vehicle parameters. For example, the dampening or stiffness of the vehicle's 104 suspension system may be adjusted after the vehicle's load changes.

In the embodiments described above the pitch and roll moment of inertia was estimated. In other embodiments the yaw mass moment of inertia can be estimated in a similar method if the lateral stiffness of the tires is known. In other embodiments the pitch moment of inertia has been found to correlate closely with yaw moment of inertia. An estimation of pitch moment of inertia can thus be used as a basis for estimating yaw moment of inertia with minimal error if lateral tire stiffness is not known. An estimate of yaw moment of inertia is of particular importance to traction control systems to predict and guard against an oversteer situation. In other embodiments the products of mass moments of inertia and the inclination angle of the roll axis can be measured. Therefore an estimate of sprung mass, lateral and longitudinal centre of gravity location and roll, pitch and yaw mass moments of inertia, and any combination thereafter is possible depending on the users' application.

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It can be seen that embodiments of the invention provide convenient systems and methods which are able to estimate inertial parameters and equivalent suspension damping coefficients of vehicles. Most, if not all, vehicles may benefit from the use of the methods and systems described herein. Vehicles where the percentage change in passenger and cargo loading can vary significantly over time are expected to be particularly improved.

It will be appreciated that some embodiments of the inventions have some of the following advantages:

- 10 • inertial parameters may be estimated to the benefit of current and future vehicle control systems, and this information may be used to improve control system performance;
- changes in the vehicle payloads (from loading or unloading cargo or passengers, fuel changes, or by changes to the distribution of the payload on a vehicle, for example) can be compensated for using estimates of the inertial parameters;
- 15 • a change in vehicle handling characteristics resulting from a change in a measured inertial parameter may be compensated for, potentially reducing the probability of a vehicle crash by using estimates of the inertial parameters;
- compensation for estimated changes in inertial parameters may also improve the vehicles fuel consumption and engine emissions;
- 20 • a vehicles ride quality, performance and safety may be improved by compensating for changes in the estimated inertial parameters;
- real-time monitoring of the suspension damping system may allow the vehicle to continuously adjust the shock absorber parameters for maintaining desirable ride and road handling performance over time despite degradation of the components; and
- 25 • real-time monitoring of the damping ratio and damping coefficients may allow a performance comparison against a baseline model to enable fault identification

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of shock absorbers and suspension components for replacement during scheduled servicing.

Any reference to prior art contained herein is not to be taken as an admission that the information is common general knowledge, unless otherwise indicated.

- 5 Finally, it is to be appreciated that various alterations or additions may be made to the parts previously described without departing from the spirit or ambit of the present invention.

Claims

1. A method of estimating parameters of a vehicle, the method comprising the steps of:
 - 5 subjecting the vehicle to mechanical excitation;
 - measuring movements of the vehicle during the excitation;
 - determining the decay response of the vehicle from the measured movements; and
 - estimating at least one parameter of the vehicle based on the decay
 - 10 response.
2. A method according to claim 1 wherein the parameters include inertial parameters.
3. A method according to claim 1 wherein the parameters include damping coefficients.
- 15 4. A method according to claim 1 wherein the parameters include stiffness coefficients.
5. A method according to any preceding claim wherein the step of subjecting the vehicle to mechanical excitation is carried out by way of the vehicle travelling over an uneven surface.
- 20 6. A method according to claim 5 wherein the uneven surface includes a hump or step.
7. A method according to any preceding claim wherein the step of measuring the movements includes measuring either translational or angular displacement, velocity or acceleration at a location on the vehicle.
- 25 8. A method according to any preceding claim wherein the step of measuring the movements is carried out at at least two locations on the vehicle.
9. A method according to any preceding claim wherein the step of determining the decay response includes the step of applying an autocorrelation function, random decrement, or similar techniques.
- 30 10. A method according to any preceding claim wherein the step of estimating at least one parameter includes the step of applying a state variable, Ibrahim time domain or similar method to the determined decay response to identify modal parameters of the vehicle.

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11. A method according to claim 10 wherein the step of estimating at least one parameter further includes the step of establishing a vehicle characteristic matrix based on the modal parameters.
12. A method according to claim 11 wherein the step of estimating at least one parameter further includes the step of performing a least squares analysis on the vehicle characteristic matrix.
13. A method according to any one of the previous claims wherein the step of measuring movements includes the step of measuring movements using on vehicle and/or off vehicle sensors.
14. A system for estimating parameters of a vehicle, the system comprising:
 - a sensor or instrument for measuring movements of the vehicle;
 - a decay response determiner for determining the decay response of the vehicle from the measured movements; and
 - a parameter estimator for estimating at least one parameter of the vehicle based on the decay response.
15. A vehicle fitted with a system according to claim 14.
16. A method of changing a vehicle parameter, the method comprising the steps of:
 - subjecting the vehicle to mechanical excitation;
 - measuring movements of the vehicle during the excitation;
 - determining the decay response of the vehicle from the measured movements;
 - estimating the parameter based on the decay response; and
 - adjusting the vehicle parameter using the estimated parameter.
17. A system for changing a vehicle parameter, the system comprising:
 - a sensor or instrument for measuring movements of the vehicle;
 - a decay response determiner for determining the decay response of the vehicle from the measured movements;
 - a parameter estimator for estimating the parameter based on the decay response; and
 - a vehicle parameter adjustor for adjusting the vehicle parameter using the estimated parameter.
18. A computer program comprising instructions for controlling a computer to implement a method defined by claim 1.

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19. A computer readable medium providing a computer program defined by claim 16.
20. A computer program comprising instructions for controlling a computer to implement a method defined by claim 14.
- 5 21. A computer readable medium providing a computer program defined by claim 20.

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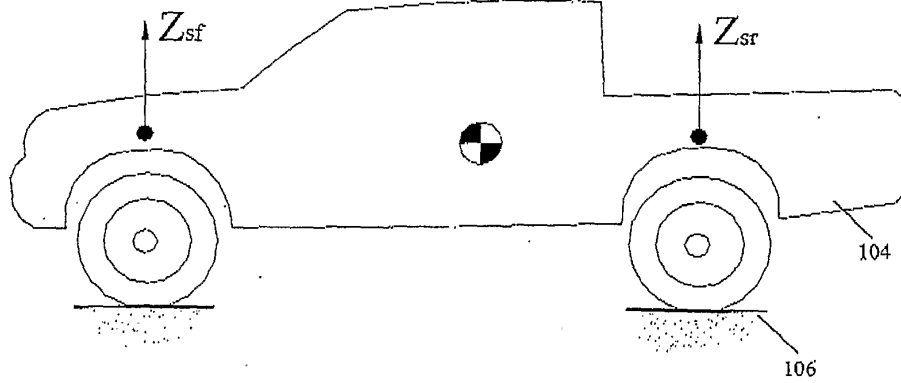


Figure 1

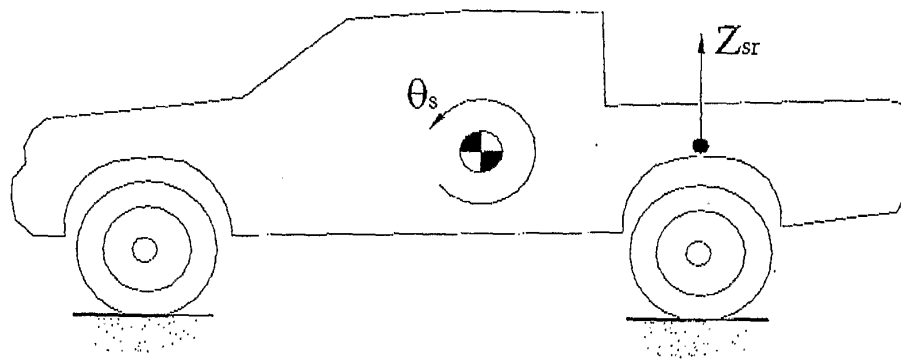


Figure 2

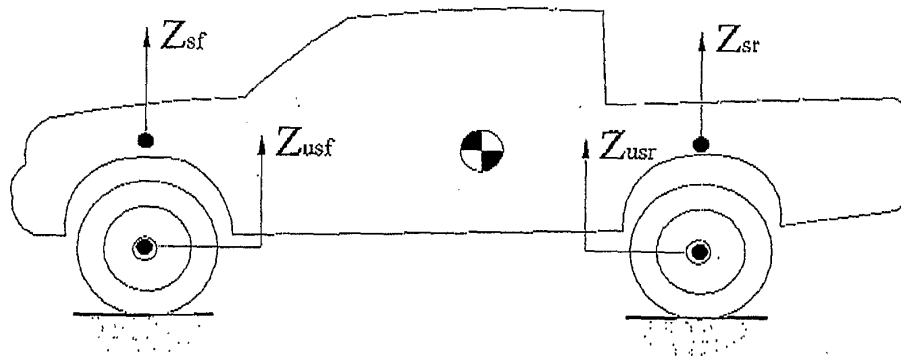


Figure 3

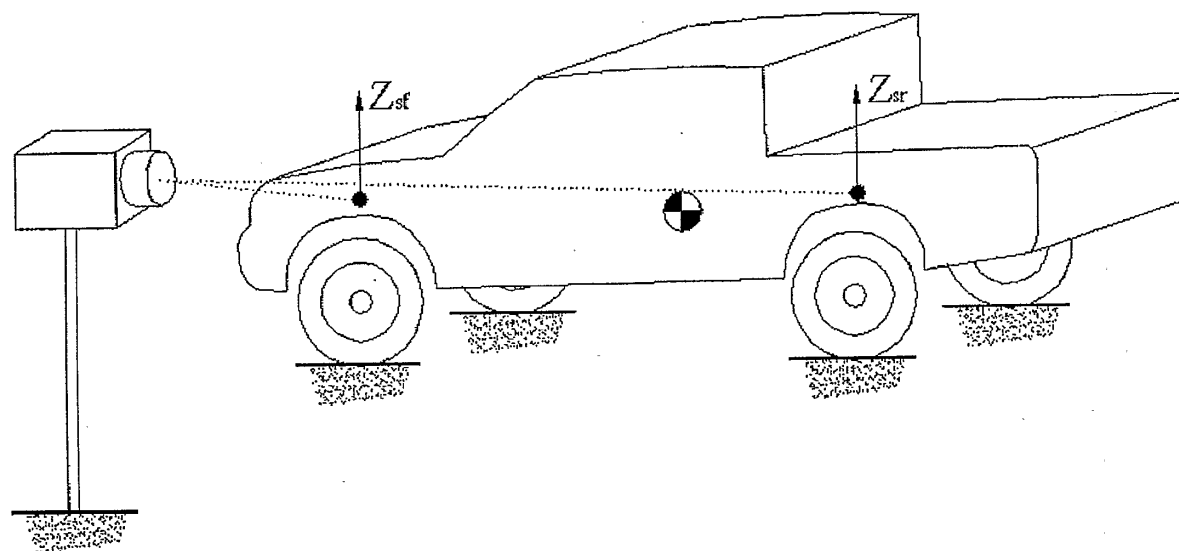


Figure 4

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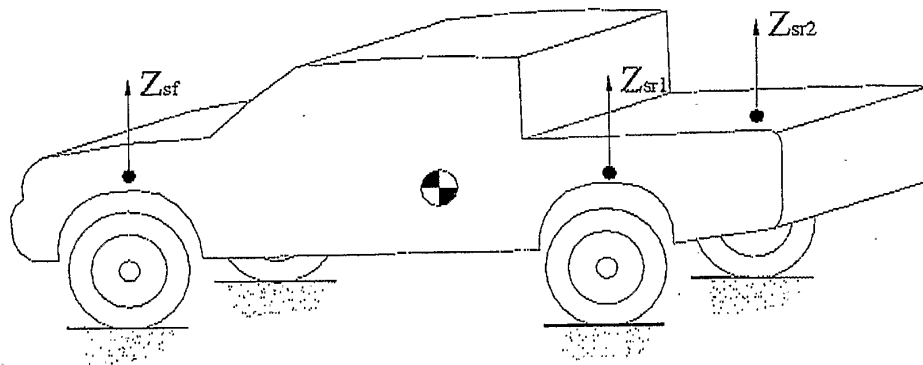


Figure 5

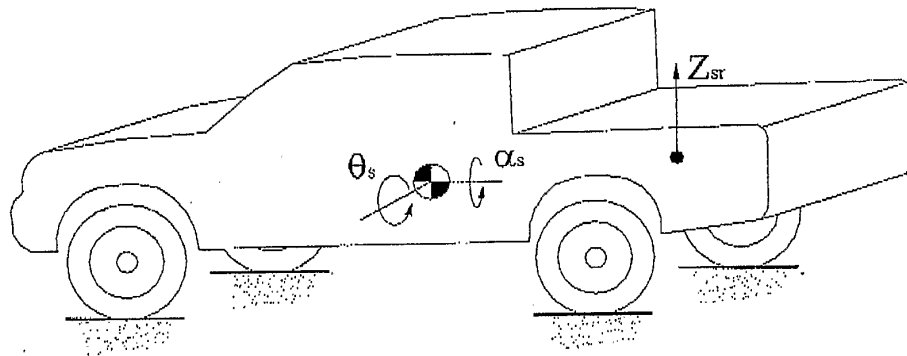


Figure 6

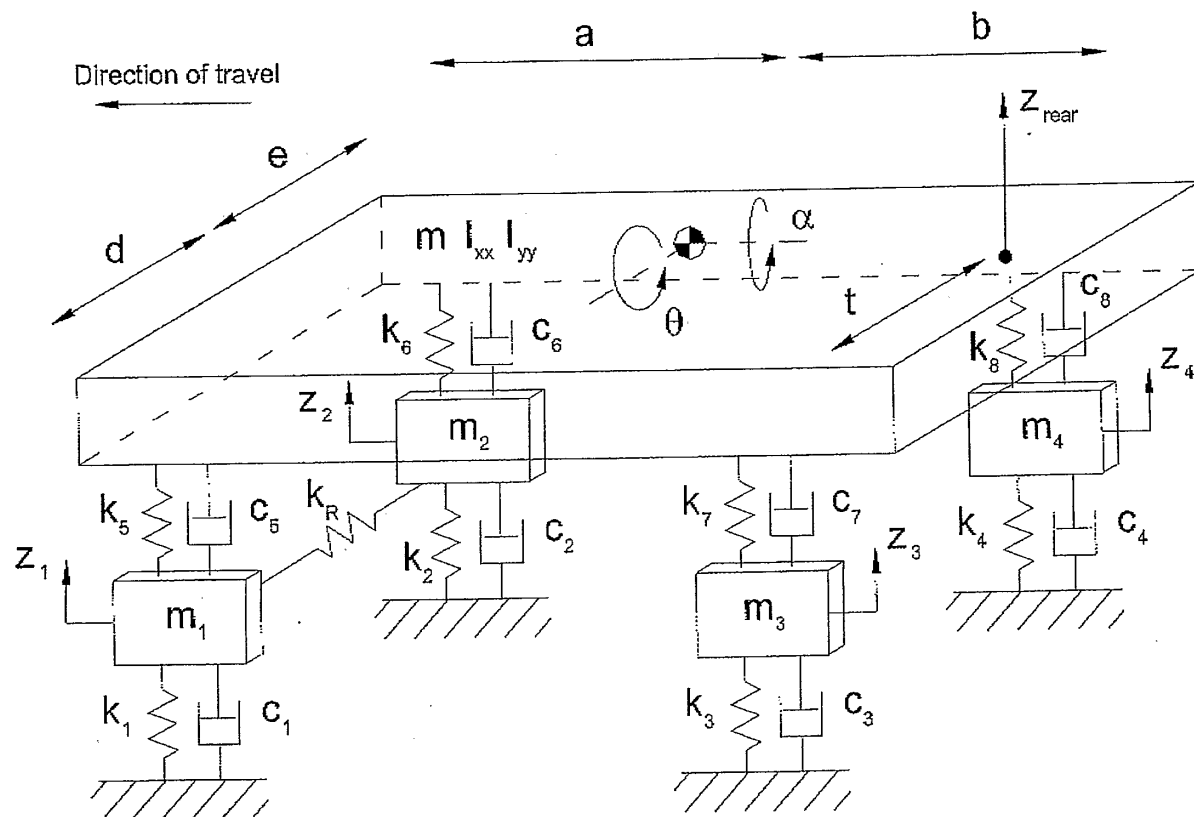


Figure 7

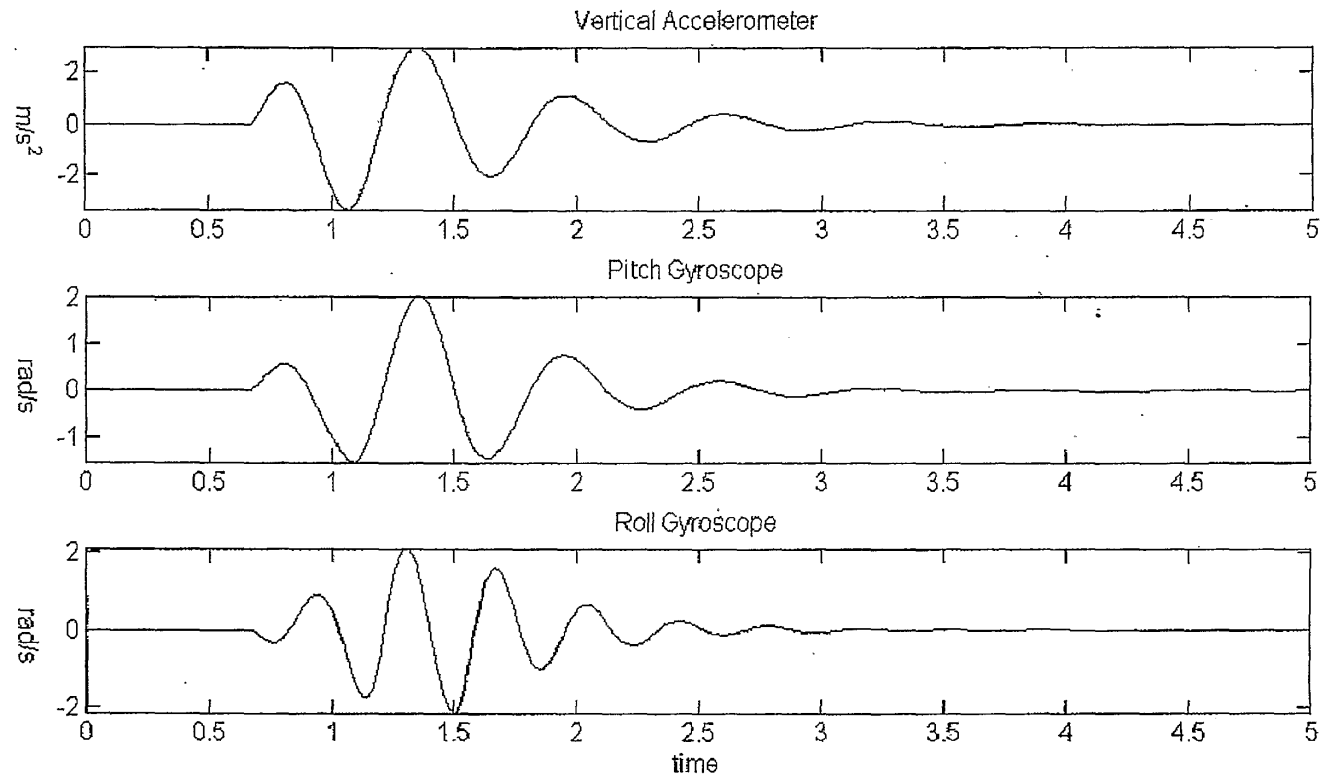


Figure 8

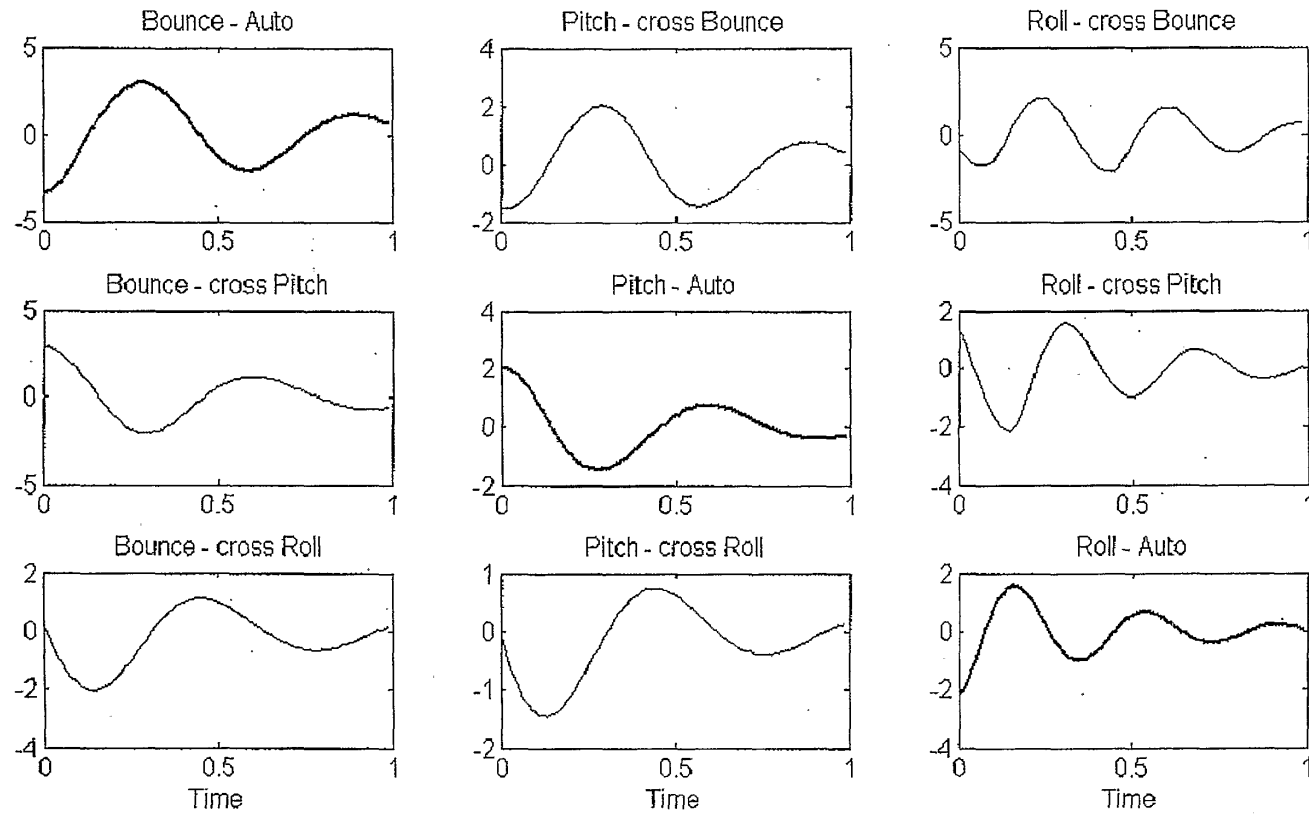


Figure 9

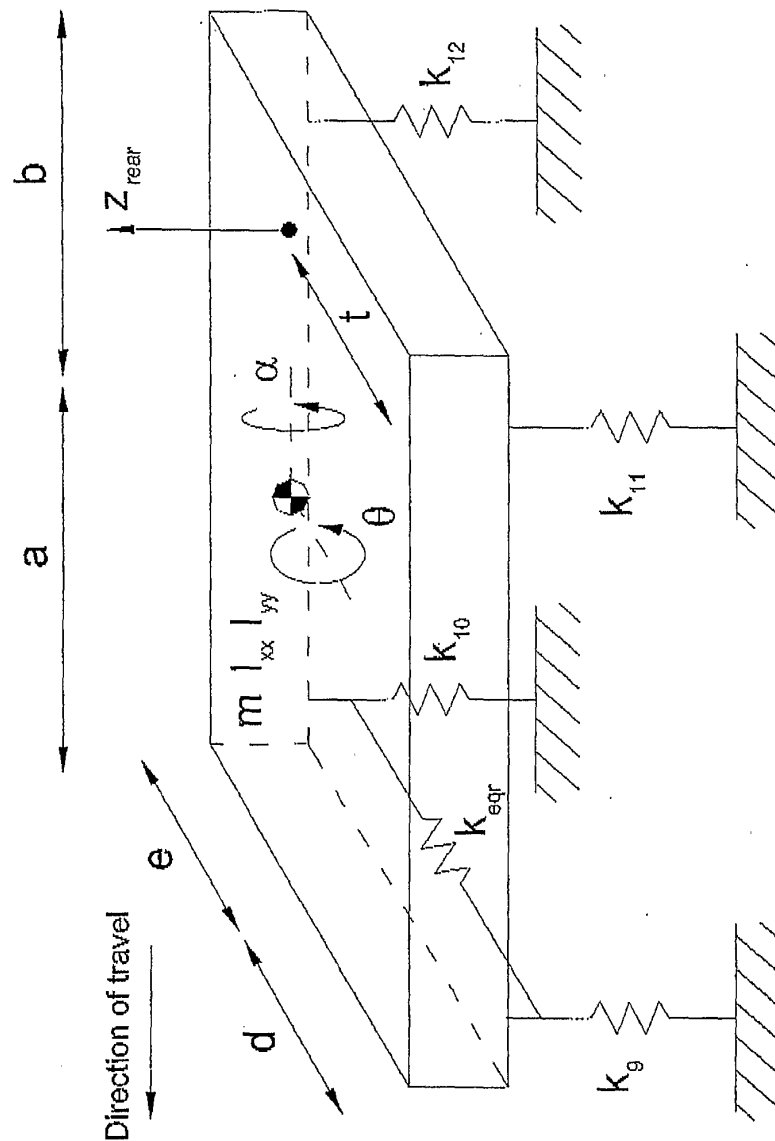


Figure 10

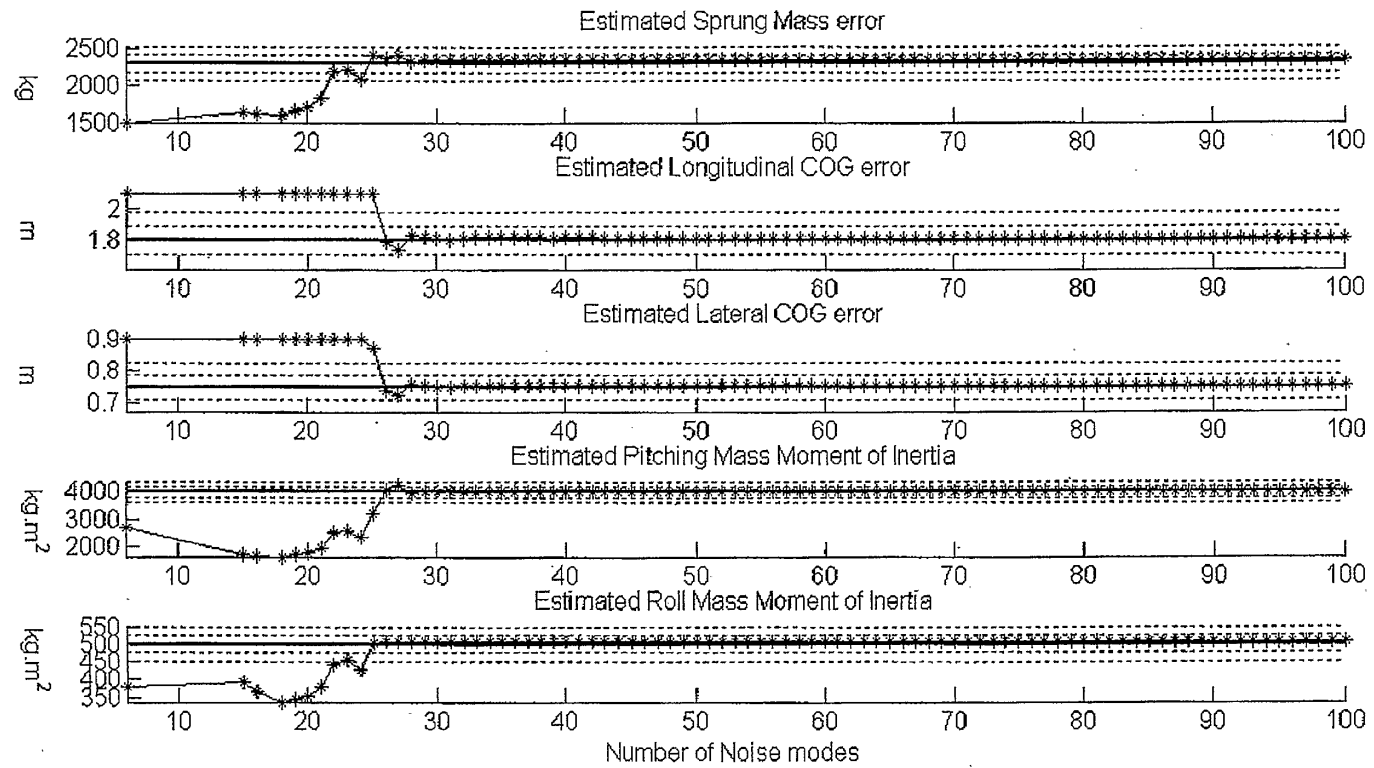


Figure 11

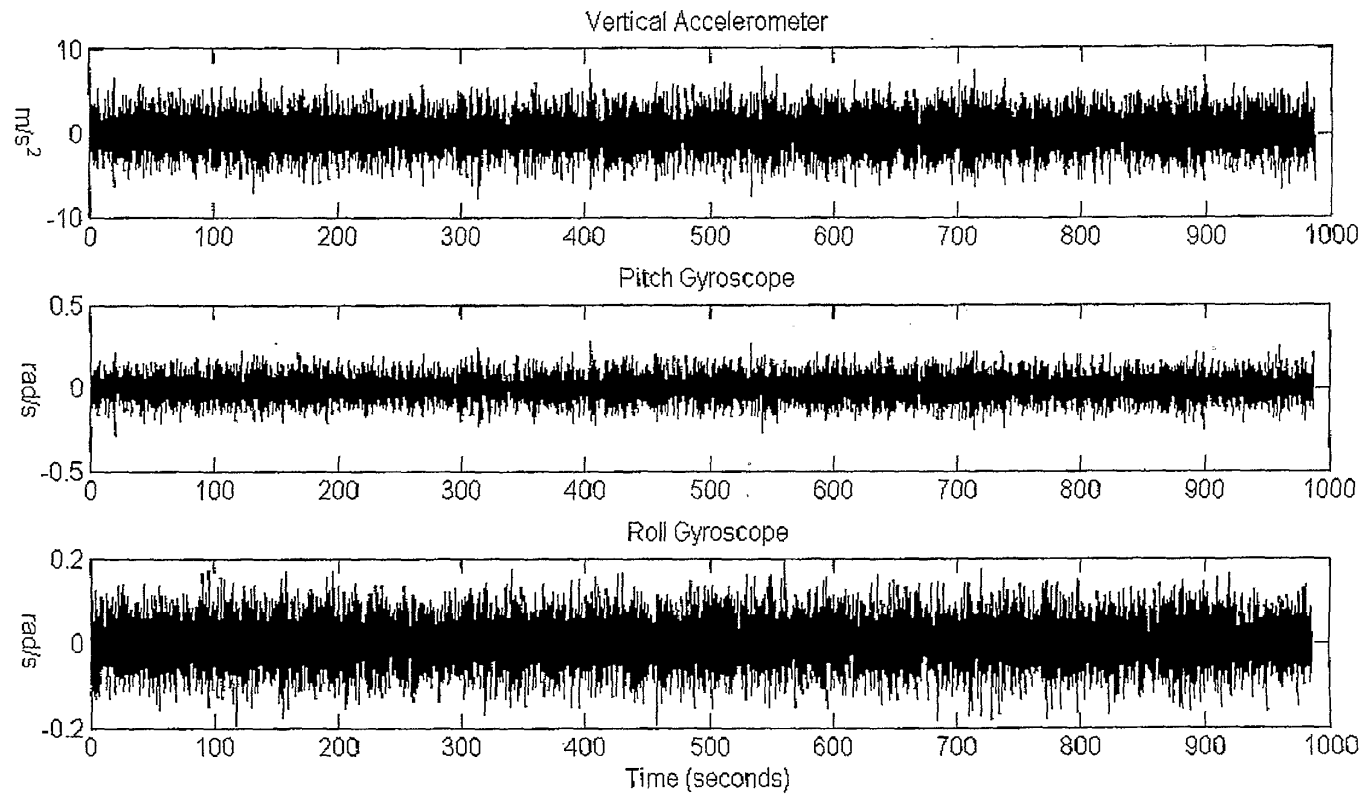


Figure 12

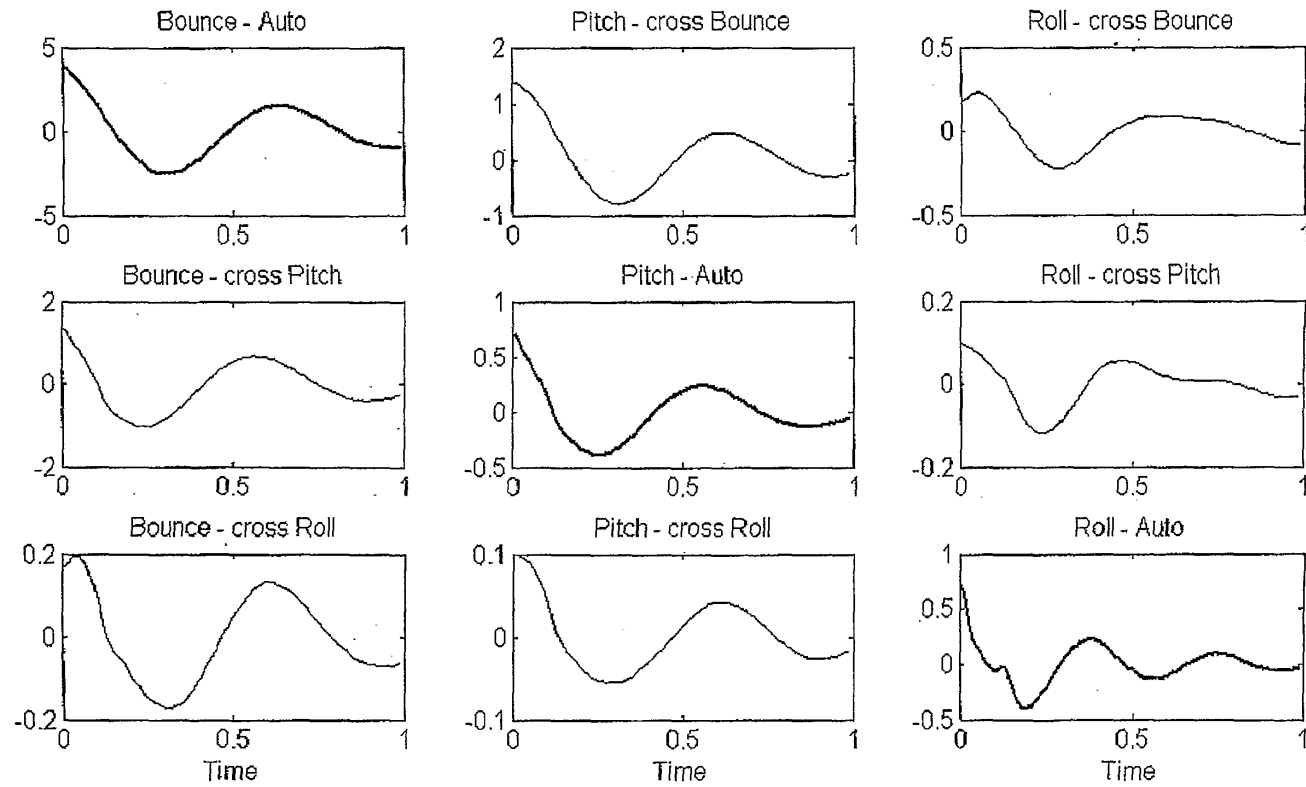


Figure 13

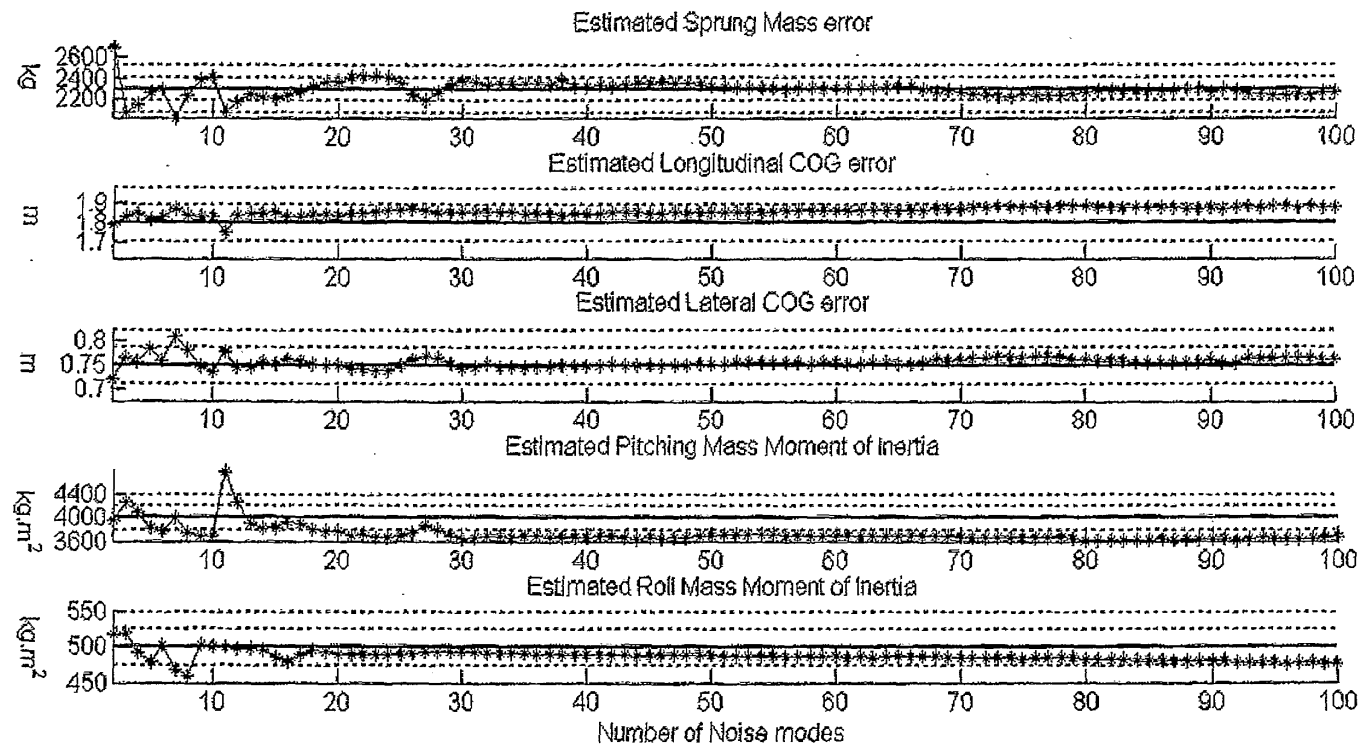


Figure 14

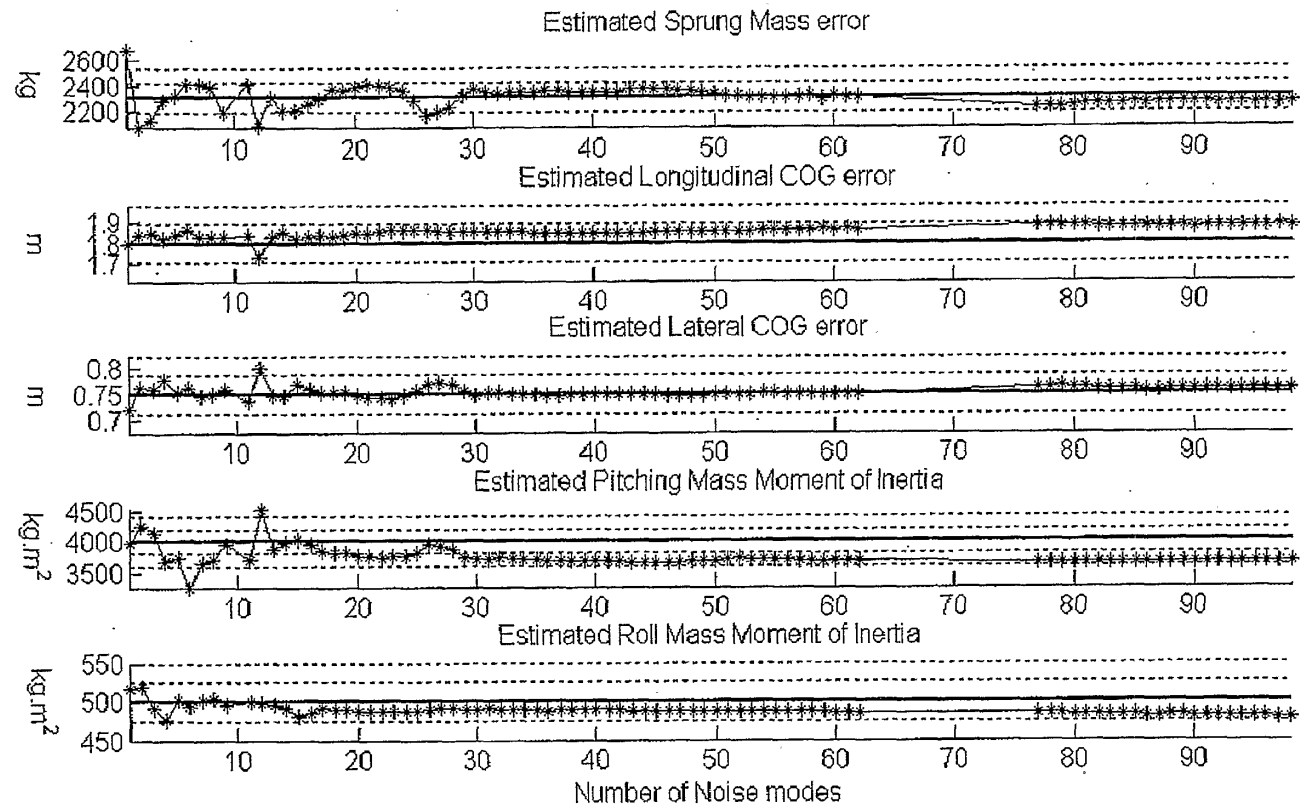


Figure 15

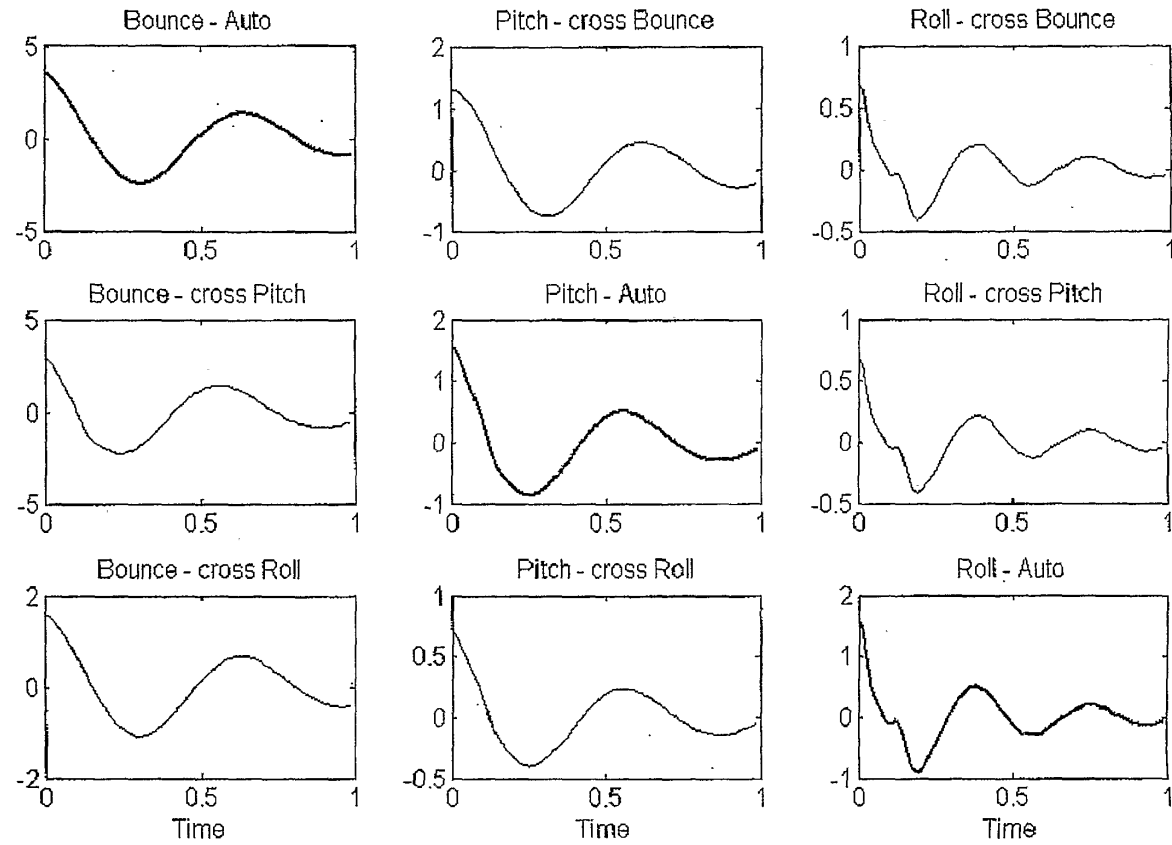


Figure 16

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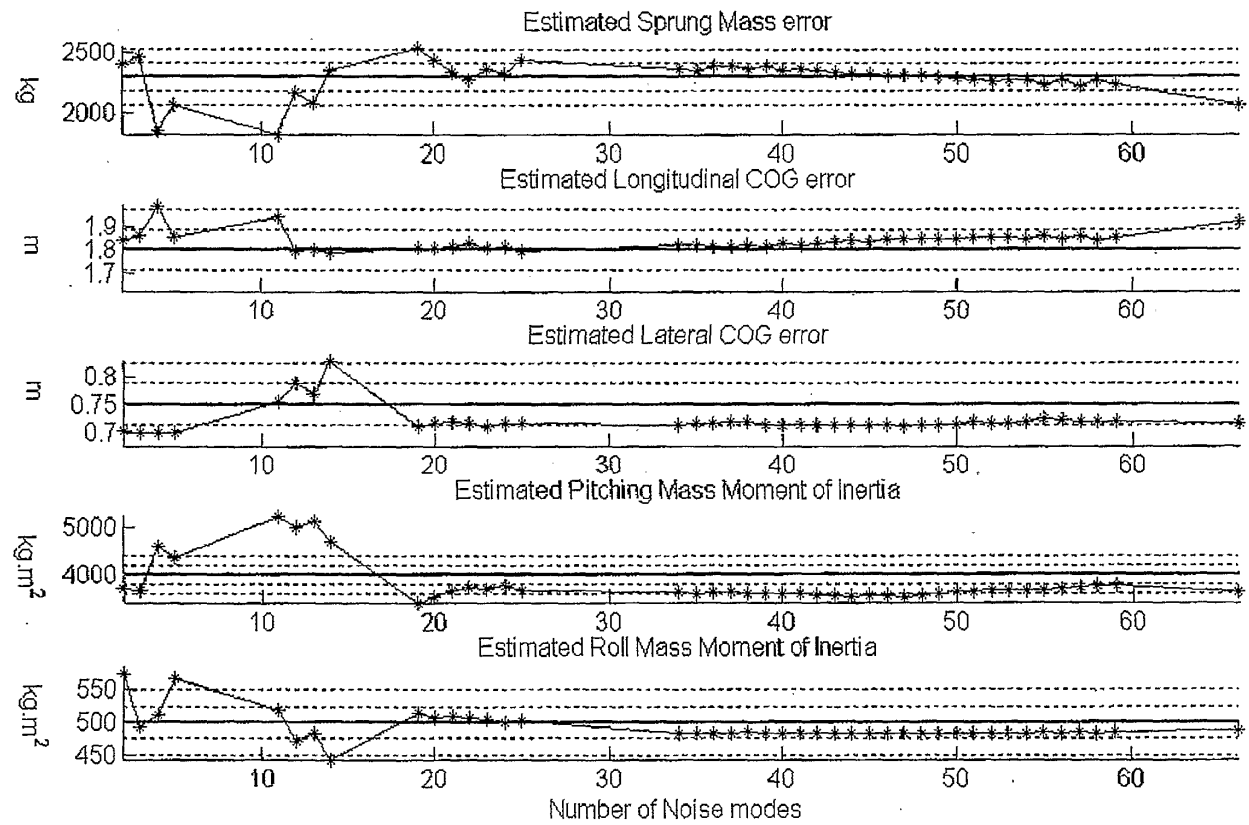


Figure 17

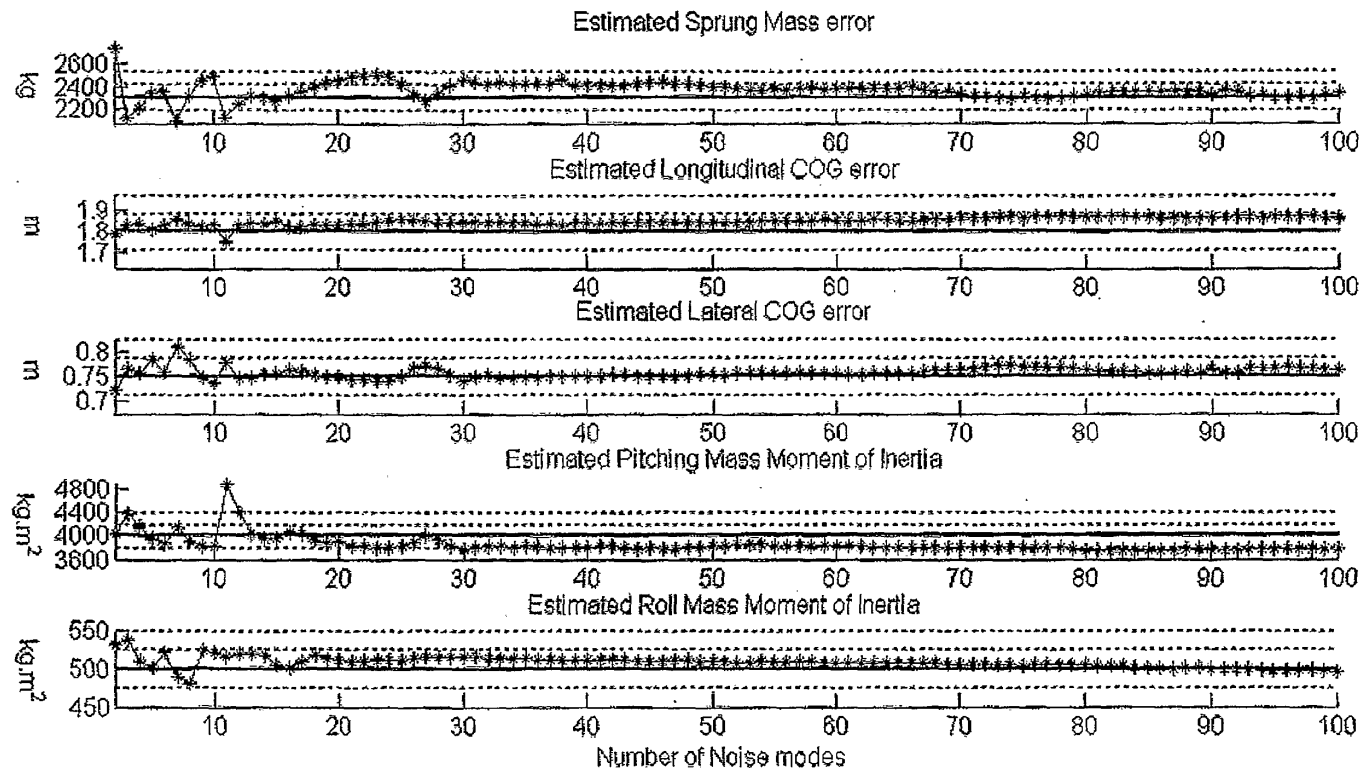


Figure 18

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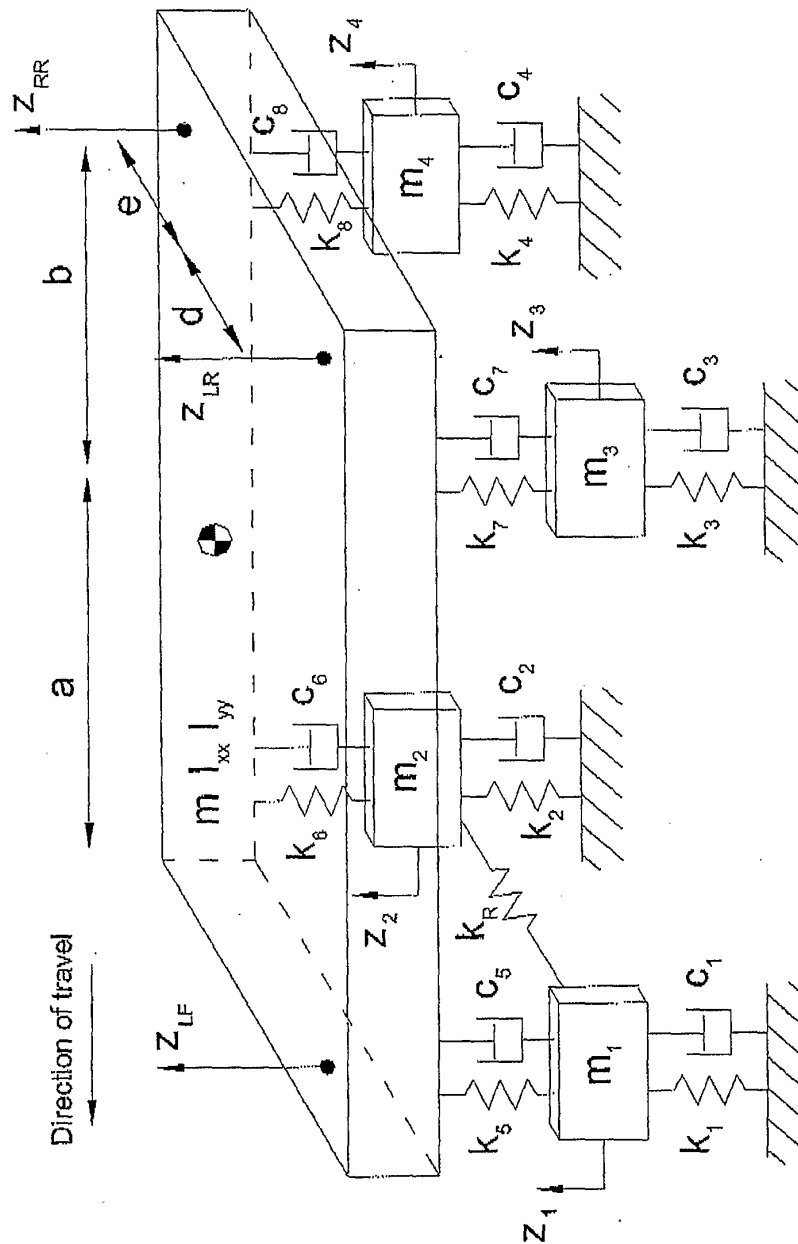


Figure 19

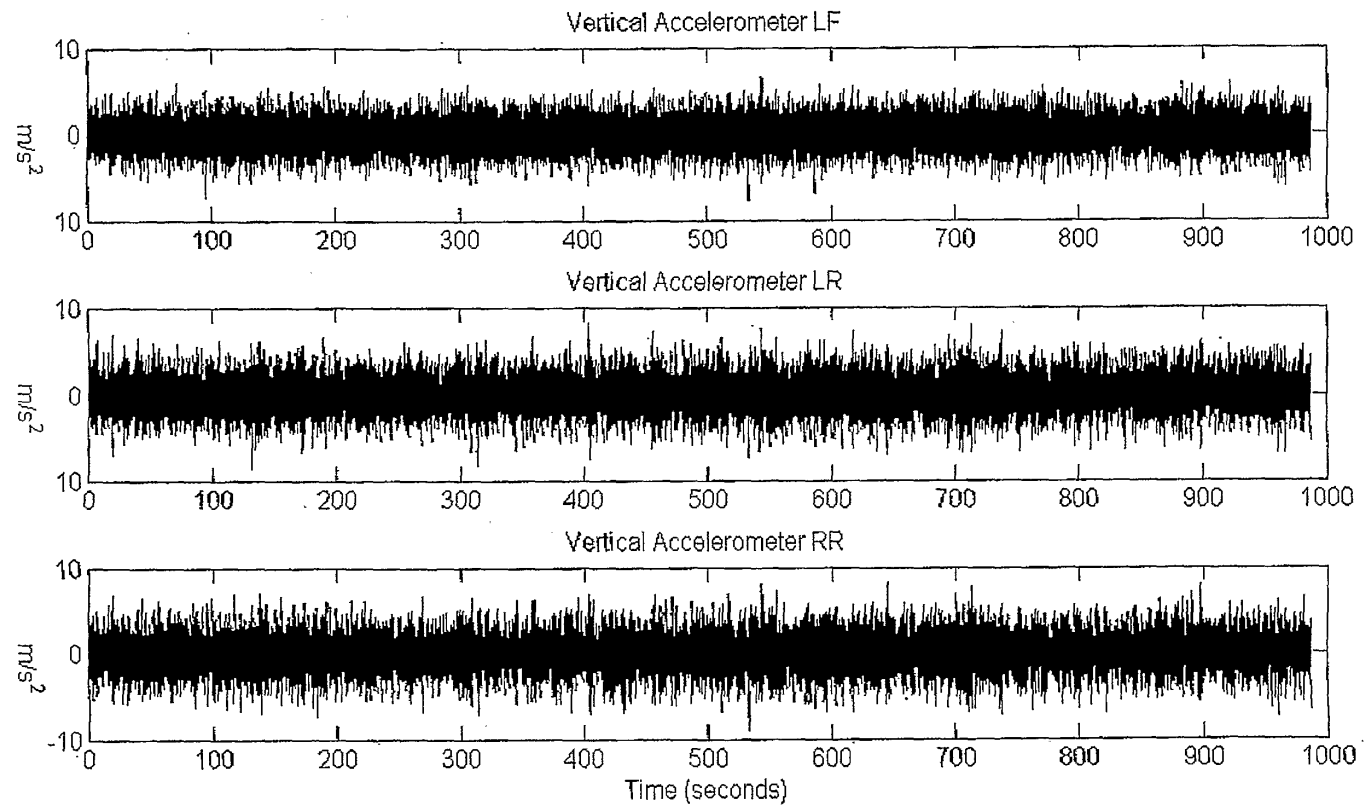


Figure 20

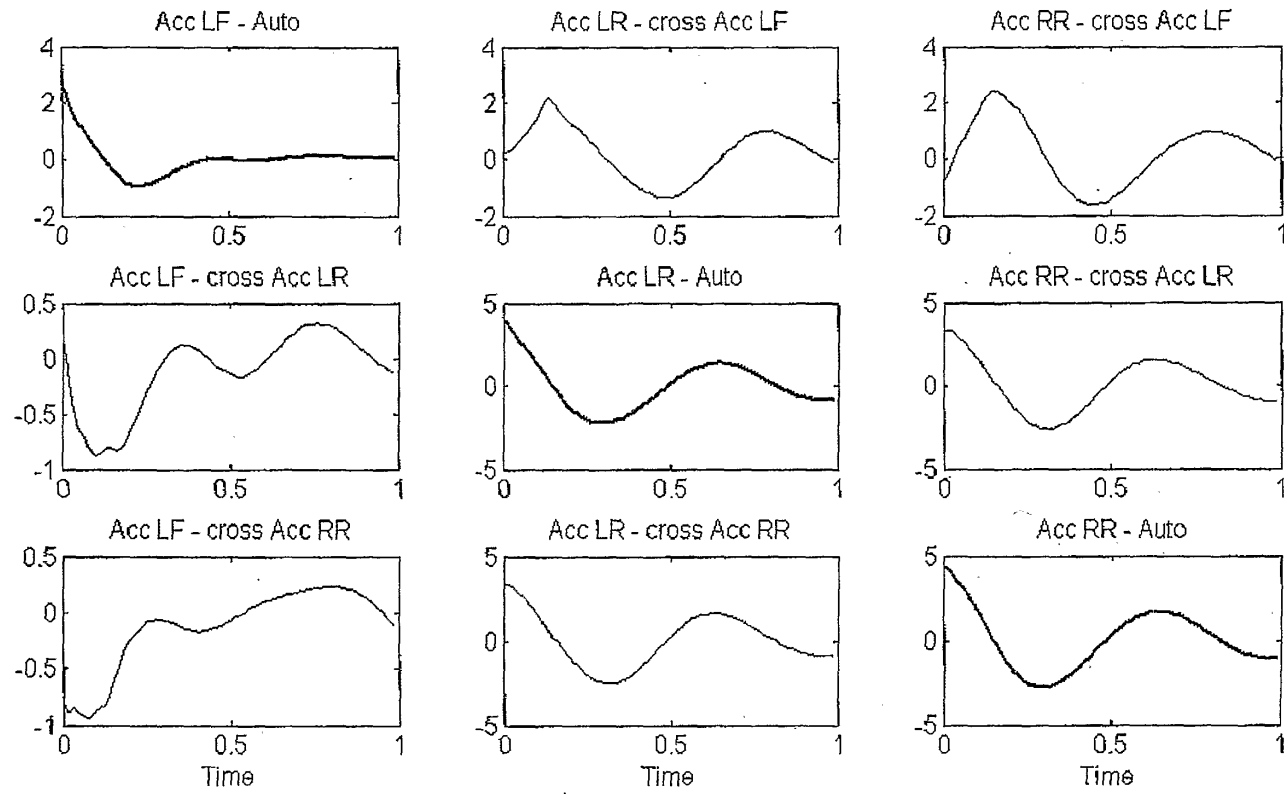


Figure 21

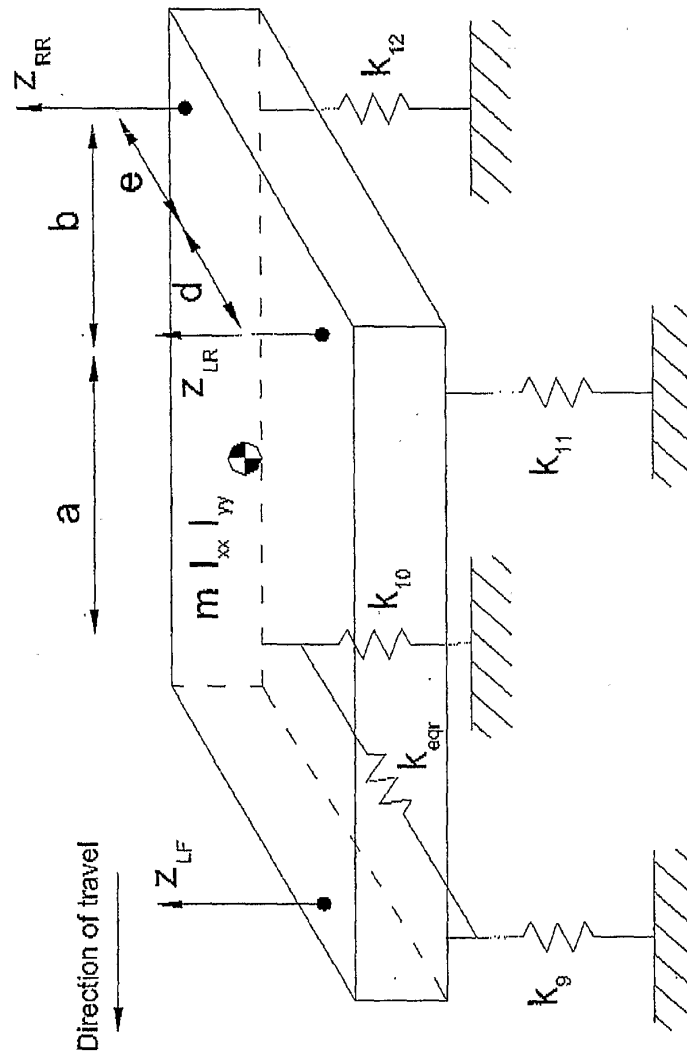


Figure 22

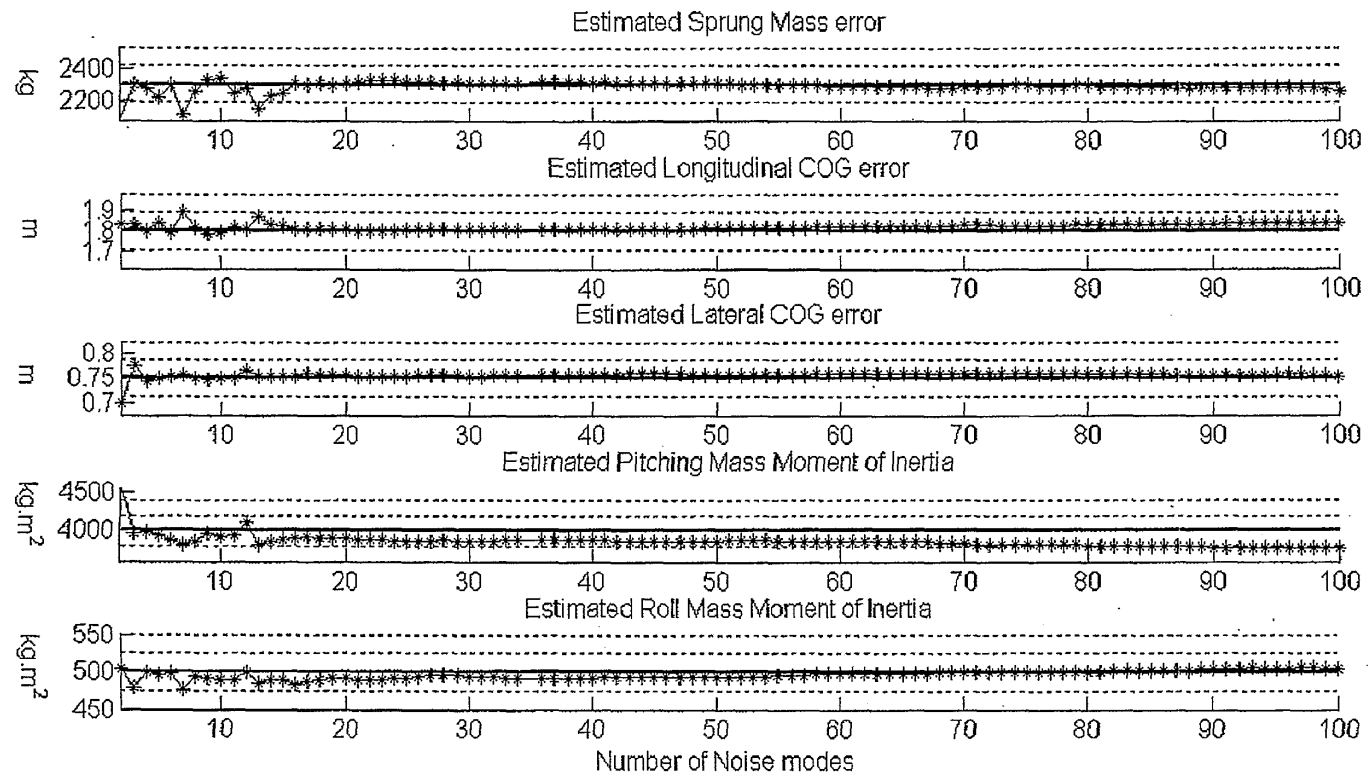


Figure 23

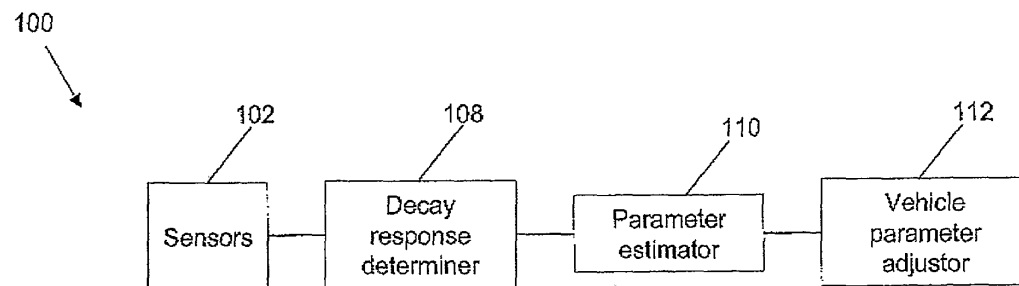


Figure 24

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2008/000681

A. CLASSIFICATION OF SUBJECT MATTER		
B60G 17/00 (2006.01), B60K 28/00 (2006.01), G01M 7/00 (2006.01), B60G 17/08 (2006.01), B62D 6/00 (2006.01), G01M 17/00 (2006.01)		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) DWPI: IPC B62D, B60G, G01M, B60K and keywords VEHICLE, TRUCK, SUSPENSION, DAMP, PARAMETER, VARIABLE, ESTIMATE, MEASURE and similar terms.		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5987368 A (KAMIMAE et al.) 16 November 1999 Whole document	1-21
X	US 6314342 B1 (KRAMER et al.) 06 November 2001 Whole document	1-21
X	US 2007/0100532 A1 (MIYAJIMA et al.) 3 May 2007 Whole document	1-21
X	US 5434782 A (HENRY) 18 July 1995 Whole document	1-21
☒ Further documents are listed in the continuation of Box C ☒ See patent family annex		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 22 July 2008		Date of mailing of the international search report 28 JUL 2008
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustalia.gov.au Facsimile No. +61 2 6283 7999		Authorized officer L. DESECAR AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No : +61 2 6283 2381

Form PCT/ISA/210 (second sheet) (July 2008)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2008/000681

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/0067080 A1 (MESSIH et al.) 22 March 2007 Whole document	1-21
X	US 5935181 A (IWASAKI) 10 August 1999 Whole document	1-21
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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