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(71) Applicant: **SCANIA CV AB** [SE/SE]; S-151 87 Södertälje (SE).

(72) Inventor: **HANSSON, Jörgen**; Syringsgränd 4, S-129 42 Hägersten (SE).

(74) Agent: **WESTMAN, Mimmi**; Scania CV AB, S-151 87 Södertälje (SE).

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(54) Title: SIMULTANEOUS ESTIMATION OF AT LEAST MASS AND ROLLING RESISTANCE

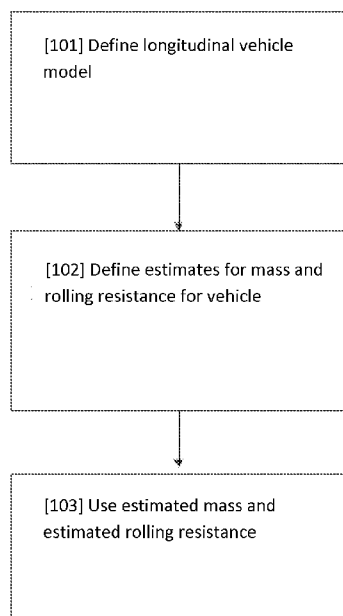


Fig. 1

(57) Abstract: The present invention presents a method and a system for the estimation of parameters impacting a driving resistance force $F_{drivingres}$ for a vehicle. The system comprises a model device and a determination device. The model device is arranged to define a longitudinal vehicle model, comprising representations of forces with a horizontal effect on the vehicle in valid driving conditions. The determination device is arranged to determine an estimated mass m^{est} for the vehicle and to determine a representation of an estimated rolling resistance force F_{roll}^{est} which acts on the vehicle. The determination device is arranged to base the determination of the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} on the longitudinal vehicle model, jointly with known values for the representations of the forces with a horizontal effect on the vehicle, in order to minimise a model error in the vehicle model.

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SIMULTANEOUS ESTIMATION OF AT LEAST MASS AND ROLLING RESISTANCE**Technical field**

The present invention pertains to a method for the estimation
5 of parameters which impact a driving resistance for a vehicle according to the preamble of patent claim 1, and a system for the estimation of parameters which impact a driving resistance for a vehicle according to the preamble of patent claim 21.

The invention also pertains to a computer program and a
10 computer program product, which implement the method according to the invention.

Background

The following background description constitutes a description
15 of the background to the present invention, which does not have to constitute prior art.

Control systems comprising one or more regulators are
currently used to control a large number of different types of
systems in a vehicle, e.g. systems for gear selection and
cruise control. The control is based on a number of parameters
20 necessary for enabling the control systems to carry out calculations and/or to make appropriate decisions.

A mass m of a vehicle, where the vehicle may consist of a
vehicle platoon, constitutes an important parameter in many
functions of a vehicle's control system. The mass m of the
25 vehicle impacts the vehicle considerably in many situations,
which is why it is very important to be able to estimate this
mass m accurately. The vehicle's mass m is typically included
in dynamic models of the vehicle, describing e.g. the forces
acting on the vehicle. Such models may be used for a number of

different calculations and controls in the vehicle, e.g. to control a brake system in the vehicle.

For a vehicle that may transport large loads, such as buses, which may transport a large number of people, or trucks, which may transport different types of cargo with heavy weights, the mass may vary considerably. For example, an unloaded truck weighs considerably less than the same truck when it is loaded to its maximum capacity. An empty bus also has a considerably smaller mass than the same bus when it is full of passengers. For e.g. a passenger car, the variations in mass are smaller than for vehicles designed to transport large loads, but even here the difference between an empty and a fully loaded passenger car, where the fully loaded passenger car may also comprise a connected and loaded trailer, may be relatively large in relation to the low mass of the passenger car.

A rolling resistance force F_{roll} which the vehicle experiences is also an important parameter for the control systems in the vehicle. The road gradient α for a road section where the vehicle is located, and/or for a road section in front of the vehicle, and an air resistance parameter C_{air} , which is related to the air resistance force F_{air} for the vehicle may constitute important parameters for the control systems in several applications.

The vehicle mass m , the rolling resistance force F_{roll} , the air resistance parameter C_{air} and the road gradient α impact a driving resistance force $F_{drivingres}$ for the vehicle, meaning that one or several of the vehicle's mass m , the rolling resistance force F_{roll} , the air resistance parameter C_{air} and the road gradient α are important parameters e.g. for automatic gear selection. Automatic gear selection is for example carried out

in an automated manual gearbox, where it is important to be able to determine the current driving resistance $F_{drivingres}$ and thus which gear should be selected at a given time.

The manner in which the topography of a road section impacts the vehicle is also heavily dependent on the road gradient α and the vehicle's mass m , since the mass m and the road gradient α are decisive for how much the vehicle is accelerated and retarded by a downhill and an uphill slope, respectively. Both the vehicle's mass m and a road gradient α of a road section are thus also important parameters in cruise controls taking into consideration the topography of a road section, so-called Look-Ahead cruise controls, where the size of a requested engine torque at any given time is dependent on how the topography of the road section ahead will impact the vehicle's speed.

Correct and robust calculations of the vehicle's driving resistance force $F_{drivingres}$ are also important to several vehicle systems, such as for example automatic gear selection, which needs to know how heavily the vehicle may be driven in order to select the correct gear, or so-called economic cruise control, which tries to optimise the vehicle speed in the event of reverse driving with the help of map data and GPS (Global Positioning System), , where the correctly estimated vehicle parameters are required in order to carry out simulations of the vehicle's future speed. Thus, the driving resistance force $F_{drivingres}$, which describes the sum of the external forces that must be overcome in order to accelerate the vehicle or maintain a constant speed, recurrently appears in e.g. these applications for gear selection and cruise control. Thus, correct estimations of the driving resistance force $F_{drivingres}$ are absolutely necessary to ensure correct

function for those systems in which the vehicle uses the driving resistance force $F_{drivingres}$ in its calculations.

The driving resistance $F_{drivingres}$ is the sum of rolling, air and gradient resistance forces, and may for valid driving conditions be expressed as:

$$F_{drivingres} = F_{air} + m \cdot g \cdot \sin\alpha + m \cdot g \cdot C_r, \quad (\text{equation 1})$$

or as:

$$F_{drivingres} = F_{trac} - m \cdot a. \quad (\text{equation 2})$$

where

- a is a vehicle acceleration;
- m is the total vehicle mass;
- g is the gravitational constant;
- C_r is a rolling resistance coefficient;
- $F_{air} = C_{air} \cdot v^2$ is the air resistance force, where C_{air} is the air resistance parameter;
- α is a current road gradient; and
- F_{trac} is a traction force.

Regardless of how the driving resistance $F_{drivingres}$ is determined, with equation 1 or 2, knowledge about the vehicle mass m is thus required, which, as a rule, may not be measured on the vehicle and therefore requires some form of estimation. If equation 1 is used in this determination, knowledge is further required of a number of parameters other than the

vehicle mass m , such as the rolling resistance force F_{roll} , which then has to be estimated.

Brief description of the invention

There are today several methods that may be applied in order to estimate the vehicle mass m . One such method uses information from an air suspension system in the vehicle. The air suspension system measures the shaft load on all the shafts with air suspension, and reports the load representing this shaft pressure to a control device, which, based on this load, may calculate the mass of the vehicle. This method functions well if all the shafts have air suspension. However, the method functions unsatisfactorily, or not at all, if one or several shafts lack air suspension. This method may be particularly problematic for vehicle platoons comprising trailers not reporting a shaft load. This may occur relatively often, as more or less unknown trailers are often connected to the vehicle platoon when the vehicle is used. This method is also problematic during the operation of the vehicle, since the shaft load varies when the vehicle drives over uneven sections in the road, which may lead to the mass estimation becoming inaccurate due to the changing shaft load.

Other prior art methods for mass estimation consist of acceleration-based mass estimations. These use the fact that the mass may be calculated based on a force which the engine adds to the vehicle and an acceleration resulting from this force. The force from the engine is known in the vehicle, but for these methods acceleration must be measured or estimated.

According to one method, the acceleration is estimated by carrying out a derivation of the vehicle's speed. This method functions well at high accelerations, i.e. on low gears at relatively low speeds, but a disadvantage of the method is

that it is impacted by the road gradient, since the road gradient is an unknown parameter for the method.

According to another method, acceleration is estimated with the use of an accelerometer. The accelerometer based method has an advantage in that the acceleration is measured directly. However, only a limited proportion of vehicles comprise an accelerometer today, which means that this method is not generally applicable to all vehicles. According to another method, the acceleration is estimated during shifting.

This method uses the assumption that the driving resistance remains unchanged during shifting and therefore compares the vehicle's acceleration before, during and after shifting to determine the vehicle's mass. This method results in very unsatisfactory estimations of the vehicle mass.

The acceleration-based mass estimations generally have disadvantages in that some driving conditions must be met, in order for a good estimation to be carried out. It is not at all certain that these conditions are met when the vehicle is driven, and in this case a good mass estimation is not possible. For example, the acceleration-based mass estimations require a sufficiently powerful acceleration in order to provide a reliable result. If such a sufficiently powerful acceleration does not occur when the vehicle is driven, such as where the vehicle starts driving on a downhill slope, e.g. at a filling station at a slip road to a motorway, where it may accelerate relatively slowly and subsequently maintain a substantially constant speed during the rest of the journey with the help of the downhill slope, these methods often do not provide a good estimation of the vehicle mass. Also in the event that the vehicle is so heavy that the engine is not capable of providing a sufficiently powerful acceleration,

these methods often provide a substandard estimation of the vehicle mass.

Prior art mass estimations also often require that assumptions about rolling resistance be made, e.g. that the rolling
5 resistance has a constant value determined in advance or that it may be disregarded. This deteriorates the accuracy of the mass estimations, since such assumptions are not always correct.

The rolling resistance force F_{roll} , or the rolling friction as
10 it is also called, depends among others on the material of the tyres and the type of driving surface. A gravel road, for example, produces a larger rolling resistance than asphalt.

The rolling resistance force F_{roll} may, according to prior art solutions, be determined by assuming that, in a dynamic
15 vehicle model, everything is known except the rolling resistance force F_{roll} , and then allowing the rolling resistance force F_{roll} to consist of the remaining forces in the model. The rolling resistance force F_{roll} may also be calculated based on data at two operating points, if the vehicle mass m , the
20 acceleration a , and the road gradient α are known at these two different points in time.

The road gradient α may be obtained based on a map jointly with GPS information (Global Positioning System), on radar
information, on camera information, on information from
25 another vehicle, on positioning information and on road gradient information stored earlier in the vehicle, or on information obtained from a traffic system related to said road section. The road gradient α may also be determined in the vehicle by using an accelerometer, a power equation and/or
30 an elevation change. In systems where information exchange

between vehicles is used, the road gradient α estimated by one vehicle may also be provided to other vehicles, either directly or via an intermediate unit such as a database or similar.

5 The air resistance force F_{air} , in a similar manner as for the rolling resistance force F_{roll} above, may be calculated based on data at two operating points, if the vehicle mass m , the acceleration α , and the road gradient α are known at these two different points in time. Prior art manners of determining the
10 air resistance force F_{air} have often assumed that the air resistance force F_{air} consists of a constant air resistance parameter C_{air} , multiplied by the vehicle speed squared, $F_{air}=C_{air}\cdot v^2$. This assumption, which is thus based on a constant air resistance parameter C_{air} , may result in inaccurate values
15 for the air resistance force F_{air} if e.g. an air resistance coefficient, which impacts the air resistance parameter C_{air} , actually varies in size, so that the air resistance parameter C_{air} is not at all constant.

In summary, prior estimations, which are carried out to
20 determine the driving resistance $F_{drivingres}$, i.e. estimations of the vehicle mass m , the rolling resistance F_{roll} , the air resistance F_{air} and the road gradient, are associated with driving condition problems and/or distribution problems.

In several estimation methods, the value to be estimated is
25 calculated directly, which often requires that the vehicle is in an approved driving condition, preferably in a static operational point with a small variation in measurement signals. This means, that if these driving conditions do not arise, then no new estimations are obtained. If no approved

driving conditions arise, e.g. following reloading, it may take a long time before the calculations of the vehicle mass m , and thus of the driving resistance $F_{drivingres}$, become accurate again.

5 Several methods sample data for a while when approved driving conditions arise. Subsequently, a calculation based on these sampled data is carried out, following which the estimated value is sent out and the previous sampled data are discarded and the method starts over again. The estimation thus does not
10 improve over time, but depends on the quality of the instantaneous data which are used specifically for this estimation. Thus a distribution problem arises, which must be resolved subsequently, e.g. by forming an average value of the estimations which are sent out.

15 One objective of the present invention is to address said problem(s).

This objective is achieved through the above-mentioned method in accordance with the characterising portion of patent claim 1. This objective is achieved also through the above-mentioned
20 system in accordance with the characterising portion of patent claim 21. The objective is also achieved through the above-mentioned computer program and computer program product.

According to the present invention, a longitudinal vehicle model is defined so that it comprises representations of
25 forces with horizontal impact on the vehicle in a valid driving condition. Subsequently, an estimated vehicle mass m^{est} and a representation of an estimated rolling resistance force F_{roll}^{est} for the vehicle are determined. In the determination of the vehicle mass m^{est} and the representation of the rolling
30 resistance force F_{roll}^{est} , a model error for the longitudinal vehicle model is used, so that the longitudinal vehicle model

is used jointly with known values for the representations of the forces in the model, to minimise the model error. The model error constitutes the error which is obtained for the longitudinal vehicle model, when representations of known forces and the parameters to be estimated are introduced into the vehicle model.

The concept of known values for the representations of the forces comprises, here and in this application, calculated values for the forces, having been calculated based on measured parameters and/or assumptions about parameters related to the representations of the forces. Thus, according to the invention, the longitudinal vehicle model is used together with calculations of known values for the representations of the forces, based on measured and/or assumed parameters related to the representations of the forces in the model, in order to minimise the model error in the longitudinal vehicle model, when the parameters which are to be estimated and the known values for the representations of the forces are introduced into the model.

Where the vehicle is newly manufactured, or if e.g. the control device which calculates the vehicle mass m^{est} and the rolling resistance force F_{roll}^{est} is replaced, there are no known values based on which estimations of e.g. the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} may be made. If known values are entirely missing, predetermined standard values are used for e.g. the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} , in the situation where, for the very first time, more exact values are estimated for these. . After values of e.g. the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} have been estimated for the very first time, the values which

were obtained at the previous estimation are used. Thus, successively more and more exact values are obtained of e.g. the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} .

5 The present invention provides a simultaneous and high quality estimate of the mass m^{est} and of the representation of the rolling resistance force F_{roll}^{est} , resulting in improved performance compared to prior art mass estimates, which often require that assumptions about rolling resistance are made,
10 for example that the rolling resistance has a predetermined constant value or may be ignored.

According to one embodiment of the present invention, a longitudinal vehicle mode is defined so that it fits into a recursive least-square method. The recursive method is used
15 here to estimate the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} , which minimises the error in this vehicle model. By using a recursive least-square method, the performance of the estimation has vastly improved.

The least-square algorithm produces a better estimate the more
20 time has lapsed and the more measuring data have been provided. Tests have shown that the algorithm very often very closely approximates the actual mass of the vehicle.

The estimated mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} are used, among others, for driving
25 resistance calculations in automatic gear selections. The estimated mass m^{est} is also used for calculations in different types of cruise control. Thus the present invention results in more optimised gear selections and cruise control in the vehicle.

In addition to estimating the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} , additional parameters may be estimated with the use of the present invention.

According to one embodiment, in addition to the mass m^{est} and
 5 the representation of the rolling resistance force F_{roll}^{est} , the air resistance parameter C_{air}^{est} is estimated through a simultaneous estimation of the vehicle mass m^{est} , the representation of the rolling resistance force F_{roll}^{est} and the air resistance parameter C_{air}^{est} . The representation of the air
 10 resistance force F_{air} depends on the vehicle's speed squared, $F_{air} = C_{air} \cdot v^2$, where C_{air} is the air resistance parameter, which means that changes in the vehicle's speed also produce large changes in the representation of the air resistance force F_{air} . The air resistance parameter C_{air} is dependent mainly on the
 15 vehicle's front area and on the vehicle's air resistance coefficient. The air resistance coefficient may be changed, e.g. if new equipment is mounted or dismounted on the vehicle, such as light-bars or other equipment, such as trimmings. The front area may be altered, e.g. if a trailer is connected to
 20 or disconnected from the vehicle and for instance protrudes outside the driver's cabin..

According to one embodiment, in addition to the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} , a road gradient α^{est} is also estimated through a simultaneous
 25 estimation of the vehicle mass m^{est} , the representation of the rolling resistance force F_{roll}^{est} and the road gradient α^{est} .

According to one embodiment, in addition to the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} , the air resistance parameter C_{air}^{est} and the road gradient α^{est} are

estimated through a simultaneous estimation of the vehicle mass m^{est} , the representation of the rolling resistance force F_{roll}^{est} , the air resistance parameter C_{air}^{est} and the road gradient α^{est} .

5 The present invention uses, and increases its accuracy regarding estimations, if the traction force varies in size when the measurements are carried out. Since the traction force F_{trac} naturally changes size during normal driving, the present invention will function well for normal driving of the
10 vehicle. Thus, the present invention uses a problem with prior art solutions to its advantage.

The present invention is thus less dependent on driving conditions than prior art solutions have been, since the method wants as much measurement data as possible in order to
15 carry out a good estimate. This means that the method may run basically as long as the vehicle is driven. This represents a big difference in relation to prior art estimates, which require special driving conditions where data are sampled for a while, and subsequently estimate a value which may be good
20 or bad, and without any knowledge about the quality of the estimate.

A covariance matrix, which is used for the recursion, describes the variance in the estimate and may therefore be used as a measure of quality on the estimate itself.

25 **Brief list of figures**

The invention will be illustrated in more detail below, along with the enclosed drawings where similar references are used for similar parts, and where:

Figure 1 shows a flow chart for a method according to the
30 invention,

Figure 2 shows a graphic illustration of the algorithm according to the invention,

Figures 3a-d show simulation results,

Figure 4 shows a control device.

5 **Description of preferred embodiments**

Figure 1 shows a flow chart for the method according to the present invention, where the method may be carried out by a system according to the present invention.

At a first step 101 of the method, which may be carried out by
10 e.g. a model unit, a longitudinal vehicle model is defined.
The vehicle model comprises representations of forces with a horizontal action on the vehicle in valid driving conditions.

According to one embodiment of the present invention, the valid driving conditions consist of the driving conditions
15 where the vehicle model is valid, i.e. a correct description of the vehicle. The vehicle model is valid when a turning force acting on the vehicle is negligible and when a traction force F_{trac} acting on the vehicle is known. Since the turning force is negligible, substantially no side forces are acting
20 on the vehicle, e.g. in the form of centrifugal-like forces when the vehicle is turning, in the valid driving conditions. The valid driving conditions, where the turning force is negligible, therefore comprise e.g. driving conditions where the vehicle is driven substantially straight forward, i.e.
25 without turning. In the event of the valid driving conditions, substantially no extra friction forces related to turns impact on the vehicle such extra friction forces arising e.g. for wheels in vehicles with several wheel pairs in the event of strong turns, e.g. by the wheels being dragged sideways, which
30 produces a greater ground friction. These extra friction

forces typically arise for vehicles with several wheel pairs, such as vehicles with trailers or several wheel shafts.

The vehicle model is thus valid when side forces acting on the vehicle are negligible and where a traction force F_{trac} acting on the vehicle is known. The traction force F_{trac} constitutes, here and in this document, the total driving or braking force which acts on the vehicle. The traction force F_{trac} is e.g. known in driving conditions where the vehicle is driven by a driving force provided by a combustion engine, such as a petrol engine, a diesel engine or electric machinery, where the driving force is known. The traction force F_{trac} is also known in driving conditions comprising braking with auxiliary brakes, for which the braking force is known, e.g. in the event of exhaust braking, retarder braking and/or braking through the use of a braking torque provided by electric machinery.

In a second step of the method, which may e.g. be carried out by a determination device, an estimated mass m^{est} is determined for the vehicle, as well as a representation of an estimated rolling resistance force F_{roll}^{est} which acts on the vehicle. The determination of the estimated mass m^{est} and the representation of the estimated rolling resistance force F_{roll}^{est} is carried out by using the longitudinal vehicle model jointly with the known values, which are available for the representations of the forces in the vehicle model, to minimise a model error in the longitudinal vehicle model defined in the first step 101. The known values for the representations of the forces may here be based on measured and/or assumed parameters which are related to the representations of the forces. Measured parameters in this context and in this document means parameter values which are e.g. measured during the operation of the vehicle, where

such measurement may occur in real time. The estimation of the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} by minimising the model error will be described in more detail below.

5 In a third step of the method 103, a utilisation device then uses the estimated mass m^{est} for the vehicle and the representation of the estimated rolling resistance force F_{roll}^{est} . According to one embodiment, the use comprises that control systems and other systems, using the vehicle mass m^{est} and/or
10 the representation of the estimated rolling resistance force F_{roll}^{est} as parameters in their calculations, are provided with these new estimated values, so that calculations may be based on the estimated values for the vehicle mass m^{est} and/or the representation of the rolling resistance force F_{roll}^{est} according
15 to the invention.

Through the method according to the present invention, a high quality and simultaneous estimation of both the vehicle mass m^{est} and the representation of the rolling resistance force F_{roll}^{est}
are obtained, which may be carried out substantially all the
20 time when the vehicle is in an approved driving condition, which during normal driving means very often.

The method for the estimation according to the invention may, according to one embodiment, be carried out in response to an indication that new estimates of the vehicle mass m^{est} and of
25 the representation of the estimated rolling resistance force F_{roll}^{est} should be carried out and/or speeded up because changes have occurred. Such an indication may, according to one embodiment of the present invention, be the result of a method where a longitudinal vehicle model is defined so that it
30 comprises representations of forces with horizontal action on

the vehicle in a valid driving condition. Subsequently, it is determined whether a change in one or several of a

representation of an actual rolling resistance force F_{roll}^{act} and an actual mass m^{act} for the vehicle has occurred. This

5 determination includes a determination of whether the representations of the forces with horizontal impact on the vehicle cancel each other out, when an estimated mass m^{est} and a representation of an estimated rolling resistance force F_{roll}^{est} are introduced into the longitudinal vehicle model. According

10 to one embodiment, a residual-based detector is arranged to identify changes in the mass m^{est} and/or in the representation of the rolling resistance force F_{roll}^{est} . Subsequently, these identifications are used to provide the indication that new

estimates are required and/or that estimates should be carried

15 out faster by adjusting the reinforcement in the least-square estimate, so that the estimate will reach a correct value faster than if the reinforcement had remained unchanged.

Similarly, a method for the estimate according to the invention may be carried out in response to an indication that
20 new estimates of the air resistance parameter C_{air}^{est} and the road gradient α^{est} should be carried out and/or accelerated because changes have occurred.

According to one embodiment of the present invention, the longitudinal vehicle model is based on Newton's second law,
25 i.e. the so-called force equation.

If a vehicle fails to turn or to be impacted by an unknown driving or braking force, the external forces which impact the vehicle are based on the air resistance, the rolling resistance and the gravity due to the road gradient.

30 These forces may be used to model the vehicle according to Newton's second law, where the representations of forces

constitute forces in Newton's second law, so that the vehicle's longitudinal movement may be described as:

$$m \cdot a = F_{trac} - F_{air} - F_{slope} - F_{roll} \quad (\text{equation 3})$$

If

$$F_{roll} = m \cdot g \cdot C_r \quad \text{and} \quad (\text{equation 4})$$

$$F_{slope} = m \cdot g \cdot \sin \alpha; \quad (\text{equation 5})$$

equation 3 may be written as:

$$m \cdot a = F_{trac} - F_{air} - m \cdot g \cdot \sin \alpha - m \cdot g \cdot C_r; \quad (\text{equation 6})$$

Where

- 10 - a is the above-mentioned vehicle acceleration, which may be calculated based on vehicle speed, e.g. with the use of a speed sensor on the vehicle's wheels, or may be determined with an accelerometer;
- m is the total vehicle mass, which is estimated;
- 15 - g is the gravitational constant;
- C_r is the above-mentioned rolling resistance coefficient, which may be estimated or assumed to be constant;
- 20 - $F_{air} = C_{air} \cdot v^2$ is the air resistance force, which consists of an air resistance parameter C_{air} times the speed v squared, where the air resistance parameter C_{air} may be estimated or a model may be created for it, in which the air resistance parameter C_{air} may be assumed to be constant, and where the speed v may be measured e.g. with
- 25 a speed sensor on the vehicle's wheels;

- α is the current road gradient, which may be measured with an accelerometer or obtained from GPS with map data;
- F_{trac} is the traction force, which constitutes the total driving or braking current torque, converted into a total driving or braking external force with the help of gearings in the vehicle's driveline and wheel radius. The current torques are typically provided by the torque sources which impact the vehicle, such as a combustion engine, electric machinery, or auxiliary brakes such as retarder or exhaust brakes. Thus, the traction force F_{trac} may be calculated based on reports from such torque sources, if the driveline's current gearings are known and if the wheel radius is known or may be estimated. The traction force may then be calculated according to $F_{trac} = T_{trac} \cdot n_{gear\ box} \cdot n_{final\ drive} / r_{wheel}$, where the torque T_{trac} is created before the gearbox, $n_{gear\ box}$ and $n_{final\ drive}$ consist of gearings for the gearbox and the end gear, and r_{wheel} is the wheel radius.

According to one embodiment of the present invention, the longitudinal vehicle model is based on Newton's second law for rotation speeds, inertias and torques, also called Newton's second law for rotation. Thus, the representations of forces with horizontal impact are here based on these rotation speeds, inertias and torques. Torques and speeds in the driveline depend, for purposes of Newton's second law for rotation, on a selection of a reference point in the driveline, i.e. at which point in the driveline the torque equilibrium is calculated, due to the driveline's gearings in e.g. the gearbox.

For a reference point at the vehicle's wheels, the vehicle's longitudinal movement may be expressed as:

$$m \cdot r_{wheel}^2 \cdot \dot{\omega}_{wheel} = T_{trac} - T_{resistance}$$

(equation 7)

5 where

- m is the total vehicle mass, which is estimated;
- r_{wheel} is a wheel radius for the vehicle's wheels;
- $\dot{\omega}_{wheel}$ is the angular acceleration for the current reference point, i.e. for the vehicle's wheel shaft, where the reference point in equation 6 is at the vehicle's wheels. The angular acceleration $\dot{\omega}_{wheel}$ may for example be calculated with a derivative of the signal from a speed sensor placed somewhere along the driveline, if the gearings between the sensor's position and the reference point are known. In many vehicles, e.g. in modern trucks, there is often a speed sensor on the engine and after the gearbox. Vehicles with some form of automated shifting system often also have sensors in the gearbox. Vehicles with electric brake systems often have sensors on one or several of the wheels. Angular acceleration may also be calculated with an accelerometer if the wheel radius is known;
- T_{trac} is a total traction torque, which constitutes the total driving or braking torque applied at the current reference point, i.e. to the vehicle's wheels for equation 6; and
- $T_{resistance}$ is a total driving resistance torque, which at the reference point at the vehicle's wheels consists of the

driving resistance forces F_{air} , F_{slope} and F_{roll} multiplied by the wheel radius r_{wheel} as follows:

$$T_{resistance} = T_{resistance} = (F_{air} + F_{slope} + F_{roll}) \cdot r_{wheel}, \text{ where } F_{air}, F_{slope} \text{ and } F_{roll} \text{ are defined as described above according to}$$

$$F_{air} = C_{air} \cdot v^2 \text{ and in equations 4-5.}$$

For Newton's second law for rotation, the traction torque T_{trac} depends on the placement of the reference point for balance, since the traction torque T_{trac} is a sum of the torques that impact different points along the driveline. Different actuators in the vehicle add torque at different places in the driveline, which means that the torques must be scaled with any gear ratios and efficiencies between the point where the torques affect the driveline and the reference point, when the total traction torque T_{trac} in the reference point is to be calculated. For example, the engine's torque operates before the gearbox while a retarder circuit torque operates after the gearbox, which means that different gearings are used for the engine and the retarder circuit, respectively, when the total traction torque T_{trac} is calculated. The driving resistance torque $T_{resistance}$ needs to be scaled for different reference points because of gearings along the driveline.

A person skilled in the art will realise that the traction torque T_{trac} is changed by gearings along the driveline and/or that the driving resistance torque $T_{resistance}$ may need to be scaled along the driveline, from the engine to the vehicle's wheels, and that the equation 6 applies generally to all different reference points along the driveline, while the expressions for traction torque T_{trac} and/or the driving resistance torque $T_{resistance}$ have different appearances and different scaling for different reference points.

The speed sensor's placement also impacts the balance and thus an appearance of the balance expression, since the engine speed must also be rescaled to the relevant reference point. If the speed sensor is placed between the engine and the reference point, for which the balance is calculated, the torque balance, and thus the vehicle model, may generally be described as:

$$m \cdot r_{wheel}^2 / n_{wheelToRef}^2 \cdot \dot{\omega}_{sensor} / n_{sensorToRef} = T_{trac} - T_{resistance} / n_{wheelToRef}$$

(equation 8)

where

- m is the total vehicle mass, which is estimated;
- r_{wheel} is the vehicle's wheel radius;
- ω_{sensor} is an angular acceleration for a given position for the speed sensor;
- T_{trac} is a total traction torque; and
- $T_{resistance}$ is a total driving resistance torque; $T_{resistance} = (F_{air} + F_{slope} + F_{roll}) \cdot r_{wheel}$, where F_{air} , F_{slope} and F_{roll} are defined in the manner described above according to $F_{air} = C_{air} \cdot v^2$ and in equations 4-5;
- $n_{sensorToRef}$ is a gear ratio between the speed sensor and the reference point, including potential losses in the gears; and
- $n_{wheelToRef}$ is a gear ratio between the wheels and the reference point, including potential losses in the gears.

If the speed sensor is placed, instead, between the reference point, for which the balance is calculated, and the wheels,

the torque balance, and thus the vehicle model, may generally be described as:

$$m \cdot r_{wheel}^2 / n_{wheelToRef}^2 \cdot \dot{\omega}_{sensor} \cdot n_{sensorToRef} = T_{trac} - T_{resistance} / n_{wheelToRef}$$

(equation 9)

where

- 5 - m is the total vehicle mass, which is estimated;
- r_{wheel} is the vehicle's wheel radius;
- ω_{sensor} is an angular acceleration for a given position for the speed sensor;
- T_{trac} is a total traction torque; and
- 10 - $T_{resistance}$ is a total driving resistance torque; $T_{resistance} = (F_{air} + F_{slope} + F_{roll}) \cdot r_{wheel}$, where F_{air} , F_{slope} and F_{roll} are defined in the manner described above according to $F_{air} = C_{air} \cdot v^2$ and in equations 4-5;
- 15 - $n_{sensorToRef}$ is a gear ratio between the speed sensor and the reference point, including potential losses in the gears; and
- $n_{wheelToRef}$ is a gear ratio between the wheels and the reference point, including potential losses in the gears.

Where the longitudinal vehicle model is based on Newton's
 20 second law for rotation, the representations of the forces are thus equivalent to torque, i.e. the traction force F_{trac} is equivalent to the traction torque T_{trac} and the driving resistance force $F_{drivingres}$ is equivalent to the driving resistance torque $T_{resistance}$. Thus, the rolling resistance force
 25 F_{roll} is equivalent to the rolling resistance torque T_{roll} , the

air resistance force F_{air} is equivalent to the air resistance torque T_{air} , and a force caused by the road's gradient F_{slope} is equivalent to a torque caused by the road's gradient T_{slope} . The acceleration a is equivalent to the angular acceleration $\dot{\omega}$.

5 Below is a description of how the estimation of e.g. the vehicle mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} according to the invention is carried out, where Newton's second law based on forces is used for the vehicle model, i.e. based on equation 6, so that the

10 representations of the forces constitute the forces with a horizontal effect according to the vehicle model. A similar estimation of e.g. the vehicle mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} according to the invention may also be carried out, where Newton's second law based on

15 rotation is used as a vehicle model, so that the representations of the forces constitute rotation speeds, inertias and torques, as described above. In other words, the estimation of e.g. the vehicle mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} according to the invention

20 may also be carried out based on any of equations 7-9. A person skilled in the art may, with the help of the above description of Newton's second law for rotation, derive method steps and/or expressions corresponding to the estimation, described below, of the vehicle mass m^{est} and the

25 representation of the rolling resistance force F_{roll}^{est} , according to the invention, also for Newton's second law for rotation.

As described above, the known values for the representations of the forces are the longitudinal vehicle model, e.g. described in equation 6, measured or determined with a model.

The driving resistance model may be obtained through a reformulation of the rolling resistance model in equation 6:

$$a + g \cdot \sin\alpha - \frac{1}{m^{est}} \cdot (F_{trac} - F_{air}) + C_r^{est} \cdot g = 0, \quad (\text{equation 10})$$

where

- 5 - a is the above-mentioned vehicle acceleration;
- m is a total vehicle mass, to be estimated;
- g is the above-mentioned gravity constant;
- $C_{r^{est}}$ is a rolling resistance coefficient, to be estimated;
- 10 - F_{air} is the above-mentioned air resistance force;
- α is the above-mentioned road gradient;
- F_{trac} is the above-mentioned traction force.

The expression in equation 10 is particularly suitable for the use of a recursive least-square estimation to minimise the model error, which will be described in more detail below. The division with vehicle mass to be estimated m^{est} is used here to separate the rolling resistance coefficient C_r^{est} from the vehicle mass m^{est} in equation 10.

As shown by equation 10, the representation of the rolling resistance force F_{roll}^{est} is estimated here by first determining an estimated rolling resistance coefficient C_r^{est} , following which the representation of the rolling resistance force is calculated as: $F_{roll}^{est} = C_r^{est} \cdot m^{est} \cdot g$.

According to one embodiment of the invention, the estimation of the vehicle mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} are determined by way of minimizing the model error, i.e. through minimizing the error obtained for the longitudinal vehicle model when the parameters to be estimated are introduced into the model, and when the representations of the known forces, which may be based on measured and/or assumed parameters related to the representations of the forces, are introduced into the model.

The minimisation may here be carried out through the use of a recursive method for identification of estimated values, which provide a least-square error for the longitudinal vehicle model, compared to similar known values for the representations of the forces. Other methods for minimising the model error may also be used at the determination, such as a least-mean-square method, a normalised least-mean-square method, and a recursive least-square method, a least-square method with a forgetting factor, a recursive least-square method with a forgetting factor, a maximum likelihood method, or a method using Kalman filtering. Below is a description of a least-square estimation. A person skilled in the art will realise, however, that a similar estimation using a least-mean-square method, a normalised least-mean-square method, a recursive least-square method, a least-square method with a forgetting factor, a recursive least-square method with a forgetting factor, a maximum likelihood method, or a method using Kalman filtering may be deduced. Substantially, all suitable methods which may find parameter values minimising a model error may be used for estimations according to the present invention, as a person skilled in the art will realise.

If the equation 10 is vector-factorised, the following is obtained:

$$a[n] + g \cdot \sin\alpha[n] - \begin{bmatrix} F_{trac}[n] - F_{air}[n], & -g \end{bmatrix} \cdot \begin{bmatrix} 1/m^{est}[n] \\ C_r^{est}[n] \end{bmatrix}$$

(equation 11)

5 and if the vectors are given the following names:

$$\hat{\theta}[n] = \begin{bmatrix} 1/m^{est} \\ C_r^{est} \end{bmatrix}, \quad \text{(equation 10)}$$

$$\varphi[n] = \begin{bmatrix} F_{trac}[n] - F_{air}[n] \\ -g \end{bmatrix} \quad \text{(equation 13)}$$

and

$$y[n] = a[n] + g \cdot \sin\alpha[n] \quad \text{(equation 14)}$$

10 equation 11 may be written as:

$$y[n] - \varphi^T[n] \cdot \hat{\theta}[n] \quad \text{(equation 15)}$$

Equation 15 may be used in a standard form for a recursive least-square estimation, which is very advantageous. A recursive least-square estimation is described in detail below.

15

According to one embodiment of the present invention, the determination of the parameters comprise a determination of the estimated vehicle mass m^{est} , the representation of the rolling resistance force F_{roll}^{est} and an estimated rolling resistance parameter C_{air}^{est} which acts one the vehicle.

20

The driving resistance model according to equation 6 may be re-written as:

$$a + g \cdot \sin \alpha - \frac{1}{m^{est}} \cdot F_{trac} + \frac{C_{air}^{est}}{m^{est}} \cdot v^2 + C_r^{est} \cdot g = 0, \quad (\text{equation 16})$$

where

- a is the above-mentioned vehicle acceleration;
- 5 - m^{est} is the above-mentioned total vehicle mass, to be estimated;
- g is the gravitational constant;
- C_{rest} is the above-mentioned rolling resistance coefficient, which is to be estimated;
- 10 - C_{airest} is the above-mentioned air resistance parameter, which is to be estimated;
- α is the above-mentioned current road gradient;
- F_{trac} is the above-mentioned traction force.

As shown by equation 16, the representation of the air resistance force F_{air}^{est} is estimated here by first determining an estimated air resistance parameter C_{air}^{est} , following which the representation of the air resistance force is calculated as: $F_{air}^{est} = C_{air}^{est} \cdot v^2$. Since varying values for the air resistance parameter C_{air}^{est} easily may be estimated through the present embodiment, the above-mentioned problems related to inaccurate assumptions about the air resistance parameter C_{air}^{est} being a predetermined constant may be avoided, e.g. at the reconstruction and connection or disconnection of trailers which typically give rise to changed values for the air resistance force.

According to one embodiment of the invention, in a similar manner as described above, the estimation of the vehicle mass m^{est} , the representation of the rolling resistance force F_{roll}^{est} and the air resistance parameter C_{air}^{est} are determined through minimising the model error for the vehicle model. The minimisation may here be carried out through the use of a recursive method for identification of estimated values, which provide a least-square error for the longitudinal vehicle model with the estimated values introduced, and with the above-mentioned known values for other representations of the forces introduced. This method will be described below. However, e.g. a least-mean-square method, a normalised least-mean-square method, a recursive least-square method, a least-square method with a forgetting factor, a recursive least-square method with a forgetting factor, a maximum likelihood method, or a method using Kalman filtering may be used to find estimated values minimising the model error.

Equation 16 may be factored as follows:

$$a[n] + g \cdot \sin\alpha[n] - \begin{bmatrix} F_{trac}[n], & -g, & -v^2 \end{bmatrix} \cdot \begin{bmatrix} 1/m^{est}[n] \\ C_r^{est}[n] \\ \frac{C_{air}^{est}}{m^{est}} \end{bmatrix} \quad (\text{equation 17})$$

If the vectors are named as follows:

$$\theta\hat{\theta}[n] = \begin{bmatrix} 1/m^{est}[n] \\ C_r^{est}[n] \\ \frac{C_{air}^{est}}{m^{est}} \end{bmatrix} \quad (\text{equation 18})$$

$$\varphi[n] = \begin{bmatrix} F_{trac}[n] \\ -g \\ -v^2 \end{bmatrix}, \quad (\text{equation 19})$$

and

$$y[n] = a[n] + g \cdot \sin \alpha[n] \quad (\text{equation 20})$$

equation 14 may be written as:

$$y[n] - \varphi^T[n] \cdot \hat{\theta}[n] \quad (\text{equation 21})$$

Equation 21 may be used in a standard form for a recursive
 5 least-square estimation, which is very advantageous. A
 recursive least-square estimation is described in detail
 below.

According to one embodiment of the invention, the
 determination of parameters comprises a determination of the
 10 estimated vehicle mass m^{est} , the representation of the
 estimated rolling resistance force F_{roll}^{est} and an estimated road
 gradient α^{est} experienced by the vehicle.

Here the longitudinal vehicle model may be described as:

$$a + g \cdot \sin \alpha^{est} - \frac{1}{m^{est}} \cdot (F_{trac} - F_{air}) + C_r^{est} \cdot g = 0 \quad (\text{equation 22})$$

15 where

- a is a vehicle acceleration;
- m^{est} is a total vehicle mass, to be estimated;
- g is the gravitational constant;
- C_r^{est} is a rolling resistance coefficient, to be
 20 estimated;
- F_{air} is an air resistance;
- α^{est} is a current road gradient, to be estimated
- F_{trac} is a traction force.

According to one embodiment of the invention, the estimated vehicle mass m^{est} , the representation of the rolling resistance force F_{roll}^{est} and the road gradient α^{est} are determined in the manner described above, through minimising the model error for the vehicle model. The minimisation may also in this case be carried out through the use of a recursive method for the identification of estimated values, which provide a least-square error for the longitudinal vehicle model with the estimated parameters introduced, and with the known values for other representations of the forces introduced, or through the use of any of the above-mentioned methods for the minimisation minimising the model error.

If the equation 19 is vector-factorised, the following is obtained:

$$a[n] = \begin{bmatrix} F_{trac}[n] - F_{air}[n], & -g \end{bmatrix} \cdot \begin{bmatrix} 1/m^{est}[n] \\ C_r^{est}[n] + \sin(\alpha^{est}[n]) \end{bmatrix} \quad (\text{equation 23})$$

and the vectors are named as follows:

$$\hat{\theta}[n] = \begin{bmatrix} 1/m^{est} \\ C_r^{est} + \sin(\alpha^{est}[n]) \end{bmatrix}, \quad (\text{equation 24})$$

$$\varphi[n] = \begin{bmatrix} F_{trac}[n] - F_{air}[n] \\ -g \end{bmatrix} \quad (\text{equation 25})$$

and

$$y[n] = a[n] \quad (\text{equation 26})$$

equation 20 may be written as:

$$y[n] = \varphi^T[n] \cdot \hat{\theta}[n]. \quad (\text{equation 27})$$

Equation 27 may be used in a standard form for a recursive least-square estimation, which is very advantageous. A recursive least-square estimation is described in detail below.

5 According to one embodiment of the invention, the determination of parameters comprises a determination of the estimated vehicle mass m^{est} , the representation of the estimated rolling resistance force F_{roll}^{est} , an estimated air resistance parameter C_{air}^{est} and an estimated road gradient α^{est}
 10 experienced by the vehicle.

Here the longitudinal vehicle model may be described as:

$$a + g \cdot \sin \alpha^{est} - \frac{1}{m^{est}} \cdot F_{trac} + \frac{C_{air}^{est}}{m^{est}} \cdot v^2 + C_r^{est} \cdot g = 0 \quad (\text{equation 28})$$

where

- a is a vehicle acceleration;
- 15 - m^{est} is a total vehicle mass, to be estimated;
- g is the gravitational constant;
- C_r^{est} is a rolling resistance coefficient, to be estimated;
- C_{air}^{est} is the above-mentioned air resistance parameter,
 20 which is to be estimated;
- α^{est} is a current road gradient, to be estimated
- F_{trac} is a traction force

According to one embodiment of the invention, in a similar manner as described above, the estimation of the vehicle mass
 25 m^{est} , the representation of the rolling resistance force F_{roll}^{est} ,

the air resistance parameter C_{air}^{est} and the road gradient α^{est} are determined through minimising the model error for the vehicle model. The minimisation may also in this case be carried out through the use of a recursive method for the identification of estimated values, which provide a least-square error for the longitudinal vehicle model with the estimated parameters introduced, and with the known values for other representations of the forces introduced, or through the use of any of the above-mentioned methods for to minimise the model error.

Equation 25 may be factorised as follows:

$$[n] - \begin{bmatrix} F_{trac}[n], & -g, & -v^2 \end{bmatrix} \cdot \begin{bmatrix} 1/m^{est}[n] \\ C_r^{est}[n] + \sin(\alpha^{est}[n]) \\ \frac{C_{air}^{est}}{m^{est}} \end{bmatrix} \quad (\text{equation 29})$$

If the vectors are named as follows:

$$\hat{\theta}[n] = \begin{bmatrix} 1/m^{est}[n] \\ C_r^{est}[n] + \sin(\alpha^{est}[n]) \\ \frac{C_{air}^{est}}{m^{est}} \end{bmatrix}, \quad (\text{equation 30})$$

$$\varphi[n] = \begin{bmatrix} F_{trac}[n] \\ -g \\ -v^2 \end{bmatrix} \quad (\text{equation 31})$$

and

$$y[n] = a[n] \quad (\text{equation 32})$$

equation 29 may be written as:

$$y[n] - \varphi^T[n] \cdot \hat{\theta}[n] \quad (\text{equation 33})$$

Equation 33 may be used in a standard form for a recursive least-square estimation, which is very advantageous. A recursive least-square estimation is described in detail below.

5 According to one embodiment the above-mentioned recursive least-square method for to minimise the model error squared entails that the calculations are updated at each time step, i.e. each time new measurement data are provided. When new measurement data are provided, only these new data, i.e.
 10 measurement data sampled at this time step, need to be used when calculations are made. Thus the recursive minimising of the model error has an advantage in that the calculations do not require providing long measurement vectors of gathered data, which means that the memory requirement is reduced. The
 15 recursive method also comprises the use of a forgetting factor, which specifies a filter constant λ determining how long the measurement data must be remembered in the calculations.

The recursion at the time step n , which uses calculated values
 20 for a previous time step $n-1$, may be described as:

$$\hat{\theta}[n] = \hat{\theta}[n-1] + K[n] \cdot (y[n] - \varphi^T[n] \cdot \hat{\theta}[n-1]) \quad (\text{equation 34})$$

$$K[n] = P[n] \cdot \varphi[n] \quad (\text{equation 35})$$

$$P[n] = \left(P[n-1] - \frac{P[n-1] \cdot \varphi[n] \cdot \varphi^T[n] \cdot P[n-1]}{\lambda + \varphi^T[n] \cdot P[n-1] \cdot \varphi[n]} \right) / \lambda. \quad (\text{equation 36})$$

25 Here $\hat{\theta}[n]$, $y[n]$ and $\varphi[n]$ are obtained from equations 15, 21, 27 or 33, where $y[n]$ and $\varphi[n]$ constitute measurements at the point in time n .

The parameter λ is a filter constant constituting a so-called forgetting factor, which specifies how long data measured must remain in the recursion. For the parameter value $\lambda=1$ the estimate adapts to all previously measured data. According to one embodiment of the invention, the filter constant is set at a value of less than one, $\lambda < 1$, since the rolling resistance may be altered while driving, which is why forgetting old measurements after a suitably selected time period often improves the quality of the estimates.

$P[n]$ is a covariance matrix with a size depending on the number of rows in the vector $\hat{\theta}[n]$. If the vector $\hat{\theta}[n]$ has N rows, then the matrix $P[n]$ is a $N \times N$ matrix. The covariance matrix $P[n]$ may also be used to provide a quality measurement of the estimate, since the variance for the estimation may be read from the matrix $P[n]$

The recursion may be seen as though the estimation $\hat{\theta}[n]$ at the time step n is updated with a reinforcement $K[n]$ times the model error. The reinforcement $K[n]$ depends on the variance for the measurement data and on the forgetting factor λ .

Figure 2 shows a non-limiting graphic illustration of the problem which the present invention is designed to resolve. Vehicle acceleration α and the road gradient α are specified along the y-axis as a function of traction force minus air resistance, $F_{trac} - F_{air}$, along the x-axis. If data collected from valid driving conditions while driving are introduced in the diagram, it becomes apparent that the data are located relatively gathered, so that it is possible to draw a line straight through the amount of data.

The line may be analysed with the help of the equation of the straight line:

$$y = k \cdot x + b, \quad (\text{equation 37})$$

where k is the gradient of the line and b is the crossing point with the y-axis. Let the variables for the line be provided by:

$$y = a + g \cdot \sin \alpha \quad (\text{equation 38})$$

and

$$x = F_{trac} - F_{air} \quad (\text{equation 39})$$

If equation 10 is compared to equation 37 for the line in Figure 2, it may be concluded that the gradient k for the line should be $k = 1/m$ and the crossing with the y-axis should be $b = -g \cdot C_r$ in order for equation 37 to be adapted to equation 10. In order to find the line that best suits the measurement data, the vehicle mass m and the rolling resistance coefficient C_r must be estimated, which is precisely what the present invention does.

Figure 2 also illustrates an advantage with the method according to the present invention, since the picture clearly shows that it is easier to achieve a suitable gradient of the line if there is a lot of data spread over the x-axis to align against. Thus, it is actually a good thing if the traction force minus the air resistance force, $F_{trac} - F_{air}$ varies in size when the measurements are carried out. Since the traction force F_{trac} naturally changes size during normal driving, the present invention will function well during a large part of the time for normal driving of the vehicle, since during this time it is more common that the forces are varied than that

they are in static operating points. This is a great advantage compared to prior art solutions.

Figures 3a-d show a non-limiting example of the method according to the present invention during actual operation. In this example, the vehicle has an actual mass of around 60 tonnes.

Figure 3a shows the vehicle speed during driving and Figure 3b shows the estimated rolling resistance coefficient C_r . At a point in time just after 500 s, the vehicle drives from gravel/sand to asphalt, so that the rolling resistance coefficient C_r falls significantly, which corresponds well to reality.

Figure 3c shows the actual mass, i.e. approximately 60 tonnes, with a dashed line. The vehicle has initially been at a standstill and a trailer has been connected to the vehicle. The thick solid curve shows the mass estimate according to the present invention. The dashed curve shows a median value of prior art estimates, i.e. estimates that require a certain driving condition, during which they sample for a while and subsequently make a calculation. The more estimates of the prior art type that are carried out, the closer the actual values approximate to the estimate. However, sometimes this takes a considerable amount of time.

Figure 3d shows the condition number for the covariance matrix $P[n]$. The curve is drawn on a logarithmic scale, since it has a relatively high value at the beginning of the driving. Here it is clear that the curve falls relatively quickly at the beginning of driving, when the estimate becomes better and the quality of the estimate improves. Subsequently, it remains around a relatively low value, which entails that the quality

remains good. The fluctuations around the low value are caused by changes in the signal noise.

A person skilled in the art will realise that a method for estimation of parameters impacting a driving resistance

5 *F_{drivingres}* for a vehicle according to the present invention, may also be implemented in a computer program, which when executed in a computer achieves that the computer carries out the method. The computer program usually consists of a part of a computer program product 403, where the computer program
10 product comprises a suitable digital storage medium on which the computer program is stored. Said computer readable medium consists of a suitable memory, e.g.: ROM (Read-Only Memory), PROM (Programmable Read-Only Memory), EPROM (Erasable PROM), Flash, EEPROM (Electrically Erasable PROM), a hard disk
15 device, etc.

Figure 4 schematically shows a control device 400. The control device 400 comprises a calculation device 401, which may consist of essentially a suitable type of processor or microcomputer, e.g. a circuit for digital signal processing
20 (Digital Signal Processor, DSP), or a circuit with a specific function (Application Specific Integrated Circuit, ASIC). The calculation device 401 is connected to a memory unit 402 installed in the control device 400, which provides the calculation device 401 with e.g. the stored program code
25 and/or the stored data, which the calculation device 401 needs in order to be able to carry out calculations. The calculation device 401 is also set up to store interim or final results of calculations in the memory device 402.

Further, the control device 400 is equipped with devices 411,
30 412, 413, 414 for receiving and sending of input and output signals. These input and output signals may contain wave

shapes, pulses, or other attributes, which by the devices 411, 413 for the receipt of input signals may be detected as information, and may be converted into signals that may be processed by the calculation device 401. These signals are then provided to the calculation device 401. The devices 412, 414 for sending of output signals are arranged to transform signals received from the calculation device 401 for the creation of output signals by e.g. modulating the signals, which may be transmitted to other parts of the vehicle.

Each one of the connections to the devices for receiving and sending of input and output signals may consist of one or several of a cable; a data bus, such as a CAN (Controller Area Network) bus, a MOST (Media Oriented Systems Transport) bus, or any other bus configuration; or of a wireless connection.

A person skilled in the art will realise that the above-mentioned computer may consist of the calculation device 401 and that the above-mentioned memory may consist of the memory device 402.

Generally, control systems in modern vehicles consist of a communications bus system, consisting of one or several communications buses to connect a number of electronic control devices (ECUs), or controllers, and different components localised on the vehicle. Such a control system may comprise a large number of control devices, and the responsibility for a specific function may be distributed among more than one control device. Vehicles of the type shown thus often comprise significantly more control devices than what is shown in Figure 4, which is well known to a person skilled in the art within the technology area.

The present invention is implemented in the embodiment displayed in the control device 400. The invention may,

however, also be implemented wholly or partly in one or several other control devices already existing in the vehicle, or in a control device dedicated to the present invention.

According to one aspect of the present invention, a system is

5 provided for the estimation of parameters impacting the driving resistance $F_{drivingres}$ for the vehicle. The system

comprises a model device and a determination device. The model device is arranged to define the above described longitudinal vehicle model, which comprises representations of forces with a horizontal effect on the vehicle in one of the above-

10 mentioned valid driving conditions. The determination device is arranged to determine an estimated mass m^{est} for the vehicle and to determine a representation of an estimated rolling resistance force F_{roll}^{est} which impacts the vehicle. The

15 determination device is, as described above, arranged to base the determination of the mass m^{est} and the representation of the rolling resistance force F_{roll}^{est} on the longitudinal vehicle model in combination with known values for the representations of the forces with a horizontal effect on the vehicle, whereby
20 the parameter values minimising the model error on the vehicle model may be identified.

A person skilled in the art will also realise that the above system may be modified according to the different embodiments of the method according to the invention, as specified by the
25 system's non-independent patent claims below.

In addition, the invention pertains to a motor vehicle, e.g. a truck or a bus, comprising at least one system for the estimation of parameters impacting a driving resistance force $F_{drivingres}$ for a vehicle.

The present invention is not limited to the embodiments of the invention described above, but pertains to and comprises all embodiments within the protected scope of the enclosed independent claims.

Patent claims

1. Method for the estimation of parameters impacting a driving resistance force $F_{drivingres}$ for a vehicle, **characterised by**

- 5 - a definition of a longitudinal vehicle model, comprising representations of forces with a horizontal effect on said vehicle in a valid driving condition;
- a determination of an estimated mass m^{est} for said vehicle and of a representation of an estimated rolling resistance force F_{roll}^{est} acting on said vehicle, said longitudinal vehicle model being used jointly with known values for said
- 10 representations of forces in order to minimise a model error in said longitudinal vehicle model; and
- a utilisation of said estimated mass m^{est} and said
- 15 representation of said estimated rolling resistance force F_{roll}^{est} .

2. Method according to claim 1, wherein said valid driving conditions constitute a driving condition for which a turning force acting on said vehicle is negligible and for which a traction force F_{trac} acting on said vehicle is known.

- 20 3. Method according to claim 2, wherein said traction force F_{trac} is known for the driving conditions in the group of:
- driving with driving force provided by a combustion engine;
 - driving with driving force provided by electric machinery;
 - exhaust braking;
 - 25 - retarder-braking; and
 - braking with the utilisation of electric machinery.

4. Method according to any of claims 1-3, wherein said known values for said representations of forces are measured or determined with a model.

5. Method according to any of claims 1-4, wherein said determination of said representation of said estimated rolling resistance force F_{roll}^{est} comprises a determination of an estimated rolling resistance coefficient C_r^{est} .

6. Method according to any of claims 1-5, wherein said longitudinal vehicle model is described by the equation:

$$a + g \cdot \sin \alpha - \frac{1}{m^{est}} \cdot (F_{trac} - F_{air}) + C_r^{est} \cdot g = 0$$

where

- a is the vehicle acceleration;
- m is a total vehicle mass, to be estimated;
- g is the gravity constant;
- C_{rest} is a rolling resistance coefficient, to be estimated;
- F_{air} is the air resistance force;
- α is the current road gradient;
- F_{trac} is the traction force.

7. Method according to any of claims 1-4, wherein said determination comprises a determination of said estimated mass m^{est} , said representation of said rolling resistance force F_{roll}^{est} and a representation of an estimated air resistance force F_{air}^{est} acting on said vehicle.

8. Method according to claim 7, wherein said determination of said representation of said estimated air resistance force F_{air}^{est} comprises a determination of an estimated air resistance coefficient C_{air}^{est} .

9. Method according to any of claims 7-8, wherein said longitudinal vehicle model is described by the equation:

$$a + g \cdot \sin \alpha - \frac{1}{m^{est}} \cdot F_{trac} + \frac{C_{air}^{est}}{m^{est}} \cdot v^2 + C_r^{est} \cdot g = 0$$

where

- a is a vehicle acceleration;
- m^{est} is a total vehicle mass, to be estimated;
- g is the gravitational constant;
- C_r^{est} is a rolling resistance coefficient, to be estimated;
- C_{air}^{est} is the air resistance parameter, to be estimated;
- α is a current road gradient;
- F_{trac} is a traction force

10. Method according to any of claims 1-4, wherein said determination comprises a determination of said estimated mass m^{est} , said representation of said estimated rolling resistance force F_{roll}^{est} and an estimated road gradient α^{est} experienced by said vehicle.

11. Method according to claim 10, wherein said longitudinal vehicle model is described by the equation:

$$a + g \cdot \sin \alpha^{est} - \frac{1}{m^{est}} \cdot (F_{trac} - F_{air}) + C_r^{est} \cdot g = 0$$

where

- a is a vehicle acceleration;
- m_{est} is a total vehicle mass, to be estimated;
- g is the gravitational constant;
- 5 - C_r^{est} is a rolling resistance coefficient, to be estimated;
- F_{air} is the air resistance force;
- α^{est} is a current road gradient, to be estimated
- F_{trac} is a traction force

10 12. Method according to any of claims 1-4, wherein said determination comprises a determination of said estimated mass m^{est} , said representation of said estimated rolling resistance force F_{roll}^{est} , an estimated air resistance coefficient C_{air}^{est} and an estimated road gradient α^{est} experienced by said vehicle.

15 13. Method according to claim 12, wherein said longitudinal vehicle model is described by the equation:

$$a + g \cdot \sin \alpha^{est} - \frac{1}{m^{est}} \cdot F_{trac} + \frac{C_{air}^{est}}{m^{est}} \cdot v^2 + C_r^{est} \cdot g = 0$$

where

- a is a vehicle acceleration;
- 20 - m_{est} is a total vehicle mass, to be estimated;
- g is the gravitational constant;
- C_r^{est} is a rolling resistance coefficient, to be estimated;

- C_{air} is an air resistance parameter, to be estimated;
- α^{est} is a current road gradient, to be estimated;
- F_{trac} is a traction force

5 14. Method according to any of claims 1-13, wherein said longitudinal vehicle model is based on Newton's second law.

15. Method according to any of claims 1-14, wherein said known values comprise calculated values for said representation of said forces, said calculated values having
10 been calculated based on measured parameters and/or assumptions about parameters which are related to said representations of said forces.

16. Method according to any of claims 1-15, wherein minimising the model error is carried out through the use of a
15 recursive method for the identification of estimated values, which provide a least-square error for said longitudinal vehicle model, with said estimated values introduced, and with said known values for other representations of forces introduced.

20 17. Method according to any of claims 1-16, wherein minimising said model error is carried out through the use of one of the methods in the group of:

- a least-mean-square method;
- a normalised least-mean-square method;
- 25 - a method using Kalman filtering;
- a recursive least-square method;
- a least-square method with forgetting factor;
- a recursive least-square method with forgetting factor, and
- a maximum likelihood method.

18. Method according to any of claims 16-17, wherein a description of said longitudinal vehicle model is adapted, so that said method may be used to minimise said model error.

5 19. A computer program comprising a program code which, when said program code is executed in a computer, achieves said computer carrying out the method according to any of claims 1-18.

10 20. A computer program product comprising a computer-readable medium and a computer program according to claim 19, said computer program being comprised in said computer-readable medium.

15 21. System for the estimation of parameters impacting a driving resistance force $F_{drivingres}$ for a vehicle, **characterised by**

- a model device arranged to define a longitudinal vehicle model, comprising representations of forces with a horizontal effect on said vehicle in a valid driving condition;

20 - a determination device arranged to determine an estimated mass m^{est} for said vehicle and of a representation of an estimated rolling resistance force F_{roll}^{est} acting on said vehicle, said longitudinal vehicle model being used jointly with known values for said representations of said forces, in
25 order to minimise a model error in said longitudinal vehicle model; and

- a utilisation device arranged to use said estimated mass m^{est} and said representation of said estimated rolling resistance force F_{roll}^{est} .

22. System according to claim 21, wherein said valid driving conditions constitute a driving condition for which a turning force acting on said vehicle is negligible and for which a traction force F_{trac} acting on said vehicle is known.

23. System according to claim 22, wherein said traction force F_{trac} is known for the driving conditions in the group of:

- driving with driving force provided by a combustion engine;

- driving with driving force provided by electric machinery;

- exhaust braking;

- retarder-braking; and

- braking with the utilisation of electric machinery.

24. System according to any of claims 21-23, wherein said known values for said representations of forces are measured or determined with a model.

25. System according to any of claims 21-24, wherein said determination of said representation of said estimated rolling resistance force F_{roll}^{est} comprises a determination of an estimated rolling resistance coefficient C_r^{est} .

26. System according to any of claims 21-25, wherein said longitudinal vehicle model is described by the equation:

$$a + g \cdot \sin \alpha - \frac{1}{m^{est}} \cdot (F_{trac} - F_{air}) + C_r^{est} \cdot g = 0$$

where

- a is the vehicle acceleration;

- m is a total vehicle mass, to be estimated;

- g is the gravitational constant;

- *Crest* is a rolling resistance coefficient, to be estimated;
- *Fair* is the air resistance force;
- α is the road gradient;
- 5 - *Ftrac* is the traction force.

27. System according to any of claims 21-24, wherein said determination comprises a determination of said estimated mass m^{est} , said representation of said rolling resistance force F_{roll}^{est} and a representation of an estimated air resistance force F_{air}^{est} which acts on said vehicle.

28. System according to claim 27, wherein said determination of said representation of said estimated air resistance force F_{air}^{est} comprises a determination of an estimated air resistance coefficient C_{air}^{est} .

15 29. Method according to any of claims 27-28, wherein said longitudinal vehicle model is described by the equation:

$$a + g \cdot \sin \alpha - \frac{1}{m^{est}} \cdot F_{trac} + \frac{C_{air}^{est}}{m^{est}} \cdot v^2 + C_r^{est} \cdot g = 0$$

where

- a is a vehicle acceleration;
- 20 - m^{est} is a total vehicle mass, to be estimated;
- g is the gravitational constant;
- C_r^{est} is a rolling resistance coefficient, to be estimated;

- C_{air}^{est} is the air resistance parameter, which is to be estimated;
- α is a current road gradient;
- F_{trac} is a traction force

30. System according to any of claims 21-24, wherein said determination comprises a determination of said estimated mass m^{est} , said representation of said estimated rolling resistance force F_{roll}^{est} and an estimated road gradient α^{est} which is experienced by said vehicle.

31. System according to claim 30, wherein said longitudinal vehicle model is described by the equation:

$$a + g \cdot \sin \alpha^{est} - \frac{1}{m^{est}} \cdot (F_{trac} - F_{air}) + C_r^{est} \cdot g = 0$$

where

- a is a vehicle acceleration;
- m^{est} is a total vehicle mass, to be estimated;
- g is the gravitational constant;
- C_r^{est} is a rolling resistance coefficient, to be estimated;
- F_{air} is the air resistance parameter;
- α^{est} is a current road gradient, to be estimated
- F_{trac} is a traction force

32. System according to any of claims 21-24, wherein said determination comprises a determination of said estimated mass m^{est} , said representation of said estimated rolling resistance

force F_{roll}^{est} , an estimated air resistance coefficient C_{air}^{est} and an estimated road gradient α^{est} which is experienced by said vehicle.

33. System according to claim 32, wherein said longitudinal vehicle model is described by the equation:

$$a + g \cdot \sin \alpha^{est} - \frac{1}{m^{est}} \cdot F_{trac} + \frac{C_{air}^{est}}{m^{est}} \cdot v^2 + C_r^{est} \cdot g = 0$$

where

- a is a vehicle acceleration;
- m^{est} is a total vehicle mass, to be estimated;
- g is the gravitational constant;
- C_r^{est} is a rolling resistance coefficient, to be estimated;
- C_{air} is the air resistance parameter, to be estimated;
- α^{est} is a current road gradient, to be estimated
- F_{trac} is a traction force

34. System according to any of claims 21-33, wherein said longitudinal vehicle model is based on Newton's second law.

35. System according to any of claims 21-34, wherein said known values comprise calculated values for said representation of said forces, said calculated values having been calculated based on measured parameters and/or assumptions about parameters related to said representations of said forces.

36. System according to any of claims 21-35, wherein the determination device is arranged to carry out the minimisation of said model error through the use of a recursive method for the identification of estimated values, which provide a least-square error for said longitudinal vehicle model with said estimated values introduced, and with said known values for other representations of forces introduced.

37. System according to any of claims 21-36, wherein said determination device is arranged to carry out the minimisation of said model error with the use of any of the methods in the following group:

- a least-mean-square method;
- a normalised least-mean-square method;
- a method using Kalman filtering;
- a recursive least-square method;
- a least-square method with forgetting factor;
- a recursive least-square method with forgetting factor, and
- a maximum likelihood method.

38. System according to any of claims 36-37, wherein said model device is arranged to adapt a description of said longitudinal vehicle model, so that the determination device may be used to minimise said model error.

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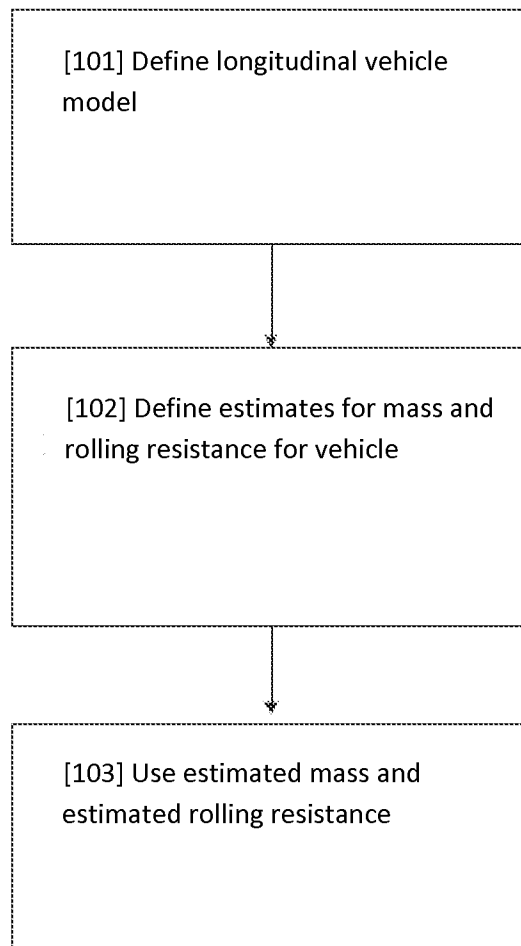


Fig. 1

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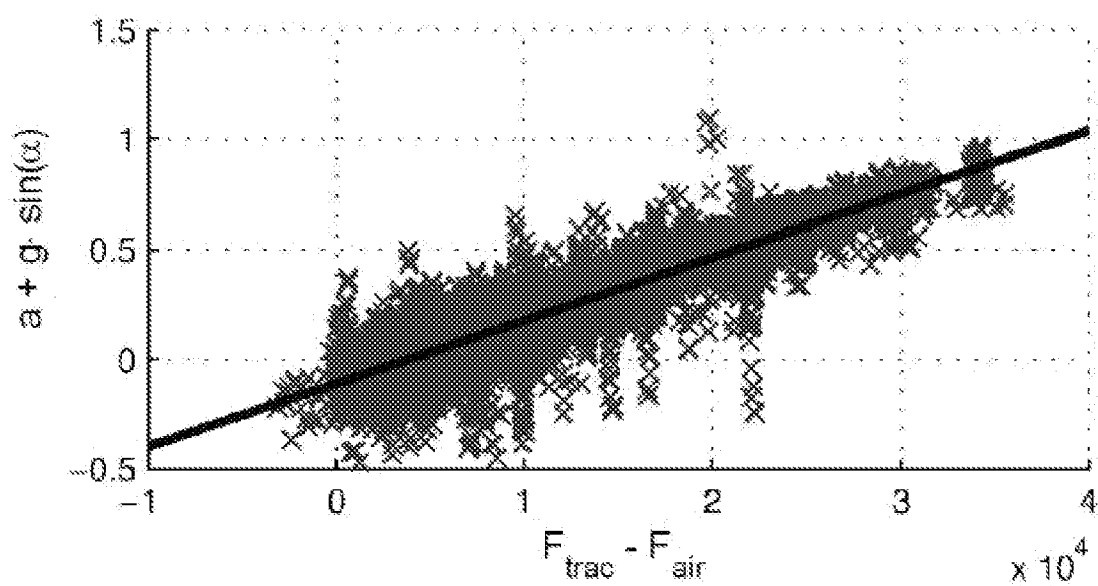
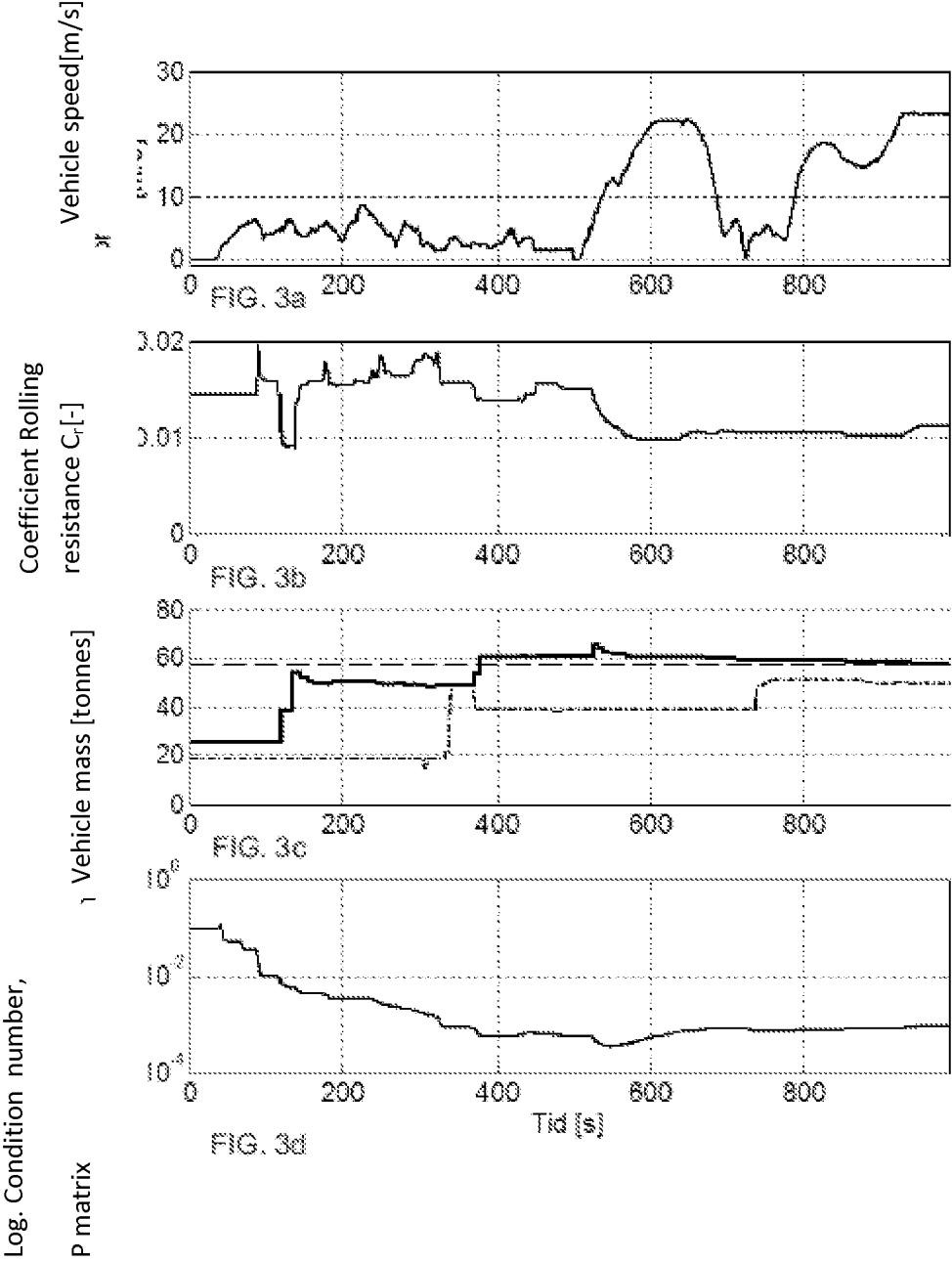


Fig. 2

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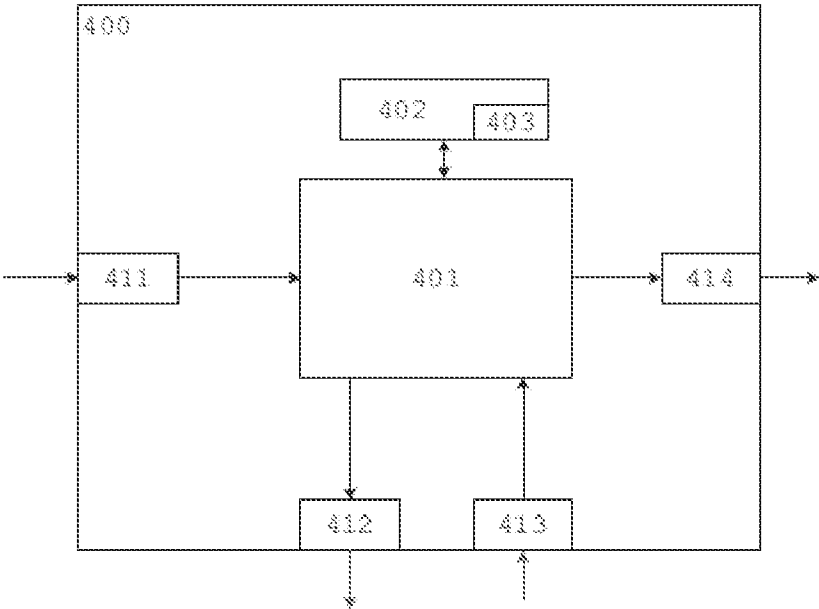


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2014/050125

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: B60W, G01G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, PAJ, WPI data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6314383 B1 (LEIMBACH KLAUS-DIETER ET AL), 6 November 2001 (2001-11-06); column 1, line 47 - line 63; column 3, line 26 - line 44; column 4, line 5 - column 5, line 22; column 6, line 45 - line 46 --	1-38
A	US 20070162210 A1 (KITAORI ICHIRO ET AL), 12 July 2007 (2007-07-12); paragraphs [0054]-[0055] --	1-38
A	US 20120083985 A1 (JOHANSSON OSKAR ET AL), 5 April 2012 (2012-04-05); abstract; paragraphs [0056]-[0058] --	1-38

☒ 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

14-05-2014

Date of mailing of the international search report

15-05-2014

Name and mailing address of the ISA/SE

Patent- och registreringsverket
Box 5055
S-102 42 STOCKHOLM
Facsimile No. + 46 8 666 02 86

Authorized officer

Agneta Seidel

Telephone No. + 46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2014/050125

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	SE 536326 C2 (SCANIA CV AB), 28 December 2012 (2012- 12-28); abstract; figure 2; claims 1-20 -- -----	1-38

Continuation of: second sheet**International Patent Classification (IPC)*****B60W 10/00*** (2006.01)***B60W 10/10*** (2012.01)***B60W 30/14*** (2006.01)***B60W 40/10*** (2012.01)***B60W 40/13*** (2012.01)***G01G 19/03*** (2006.01)

INTERNATIONAL SEARCH REPORT

Information on patent family members

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