VENICLKE MASS ESTIMATION METHOD AND SYSTEM

Abstract: In a vehicle mass estimation method and system, wheel speed, driving torque and longitudinal acceleration of the vehicle are obtained, and an estimated vehicle mass is calculated using an estimation equation group which comprises wheel speed, driving torque and longitudinal acceleration as input parameters, and vehicle mass and driving resistance of the vehicle as variables. Lower and upper thresholds are considered in the calculating process of the estimated vehicle mass.
VEHICLE MASS ESTIMATION METHOD AND SYSTEM

Technical Field

The invention relates to a mass estimation method and system for a vehicle, in particular, for an electric vehicle.

Background Art

In existing vehicle control systems, various sensors are used for providing vehicle and environment information, such as wheel speed, vehicle body acceleration, environment temperature and the like. However, there is still some information, such as vehicle mass, road adhesion coefficient, etc., which cannot be obtained directly by sensors. Control effect of a vehicle control system will be significantly improved if some unknown parameters can be obtained by effective estimation. For example, in vehicle ASR and ABS systems, wheel vertical load information provides importance reference effect for controlling wheel slip or skid.

One of the key factors which determine the wheel vertical load is vehicle mass. Thus, vehicle mass information is very helpful for wheel slip control in an ASR system.

Various vehicle mass estimation researches have been conducted, and existing methods for estimating vehicle mass are mainly classified into sensor based methods and dynamic model based methods.

Sensor based estimation methods provide a simple way in vehicle mass estimation by adding corresponding sensors. When started from a vehicle suspension, which carries the vehicle mass directly, it has been found that sensors for real time mass estimation can be mounted to the suspension (see, for example, Rajamani, R., and Hedrick, J. K., 1995, “Adaptive Observers for Active Automotive Suspensions: Theory and Experiment”, IEEE Transactions on Control System Technology, 3(1), pp. 86-93; and Fremd, R., 1987, “Apparatus for Measuring the Mass of a Motor Vehicle”, U.S. Patent No. 4,656,876). In sensor based estimation methods, expensive sensors which increase the cost of the vehicle are necessary.

Dynamic model based estimation methods generally use a vehicle dynamic model and estimate vehicle mass on the basis of vehicle data, such as engine torque, vehicle speed,
engine speed, transmission ratio and the like, which are previously known or are obtained directly from a CAN bus.

Dynamic model based estimation methods concerning lateral/yaw dynamics utilize the fact that vehicle mass affects directly the relation between lateral acceleration and lateral force which are resulted from laterally slanted road surface, steering of vehicle or the like. Some lateral/yaw dynamics methods estimate vehicle state and parameters use Kalman filtering. Lateral/yaw dynamics methods suffer from complex models, difficulty in getting input parameters and low estimation accuracy (see, for example, Best, M. C., and Gordon, T. J., 2000, “Combined State and Parameter Estimation of Vehicle Handling Dynamics”, Proceedings of the 5th International Symposium on Advanced Vehicle Control (AVEC), Ann Arbor, MI; and Wenzel, T. A., Burnham, K. J., Blundell, M. V., and Williamsn, R. A., 2004, “Approach to Vehicle State and Parameter Estimation Using Extended Kalman Filtering“, Proceedings of the International Symposium on Advanced Vehicle Control (AVEC)).

On the other hand, dynamic model based estimation methods concerning longitudinal dynamics are initiated from the direct effect of vehicle mass to the relation between vehicle longitudinal force and longitudinal acceleration. For example, some longitudinal dynamics methods provide online estimation of vehicle mass and road grade using recursive least square calculation. The methods of longitudinal dynamics are promising, but the total longitudinal force acted on a vehicle is affected not only by inertial inputs, but also by road banking/grade, aerodynamic drag, etc. Thus, existing methods based on longitudinal dynamics are still depending on the measurement of rolling resistance, air drag, or pre-set of vehicle velocity, which is affected by varied road slopes and longitudinal velocity (see, for example, Ardalan Vahidi, Anna Stefanopoulou and Huei Peng, “Recursive Least Squares with Forgetting for Online Estimation of Vehicle Mass and Road Grade: Theory and Experiments”; and Vincent Winstead and Ilya V. Kolmanovsky, 2008, “Online Vehicle Mass Estimation Using Recursive Least Squares and Supervisory Data Extraction”, 2008 American Control Conference).

In exiting dynamic model based estimation methods, the effects of running resistance and grade resistance are not comprehensively considered, and thus these methods cannot follow up the complex real running conditions of a vehicle. Further, in exiting dynamic model based estimation methods, vehicle mass and road grade are estimated as unknown parameters, and
rolling resistance and air resistance are input as known parameters, while the change of the resistances in different conditions are not considered. Meanwhile, the estimation accuracy of road grade affects directly the estimated mass. For these reasons, estimation accuracy of exiting dynamic model based estimation methods is low.

In summary, existing vehicle mass estimation methods are either quite high-cost or low accuracy for economic electric vehicles.

Summary of the Invention

An object of the invention is to provide a mass estimation method and system for a vehicle, in particular, for an electric vehicle, which meets both cost and accuracy requirements.

For this end, the invention provides a vehicle mass estimation method comprising the steps of:

1) establishing a vehicle longitudinal dynamic equation for a vehicle;

2) establishing an estimation equation group from the longitudinal dynamic equation, the estimation equation group comprising wheel speed, driving torque and longitudinal acceleration as input parameters, and vehicle mass and driving resistance of the vehicle as variables;

3) determining the wheel speed, the driving torque and the longitudinal acceleration of the vehicle when the vehicle is running;

4) calculating current vehicle mass value and driving resistance together using the estimation equation group repetitively until the current vehicle mass value is convergent; and

5) outputting the current vehicle mass value as an estimated vehicle mass;

wherein, in step 4), when the longitudinal acceleration is lower than a lower threshold, only the driving resistance is estimated, while the vehicle mass is fixed to the previously estimated value; and when the longitudinal acceleration is higher than a higher threshold, only the vehicle mass is estimated, while the driving resistance is fixed to the previously estimated value.
According to a preferred embodiment of the invention, the driving resistance of the vehicle is a sum of at least rolling resistance and air resistance.

According to a preferred embodiment of the invention, a roughly estimated vehicle mass value is used as the first vehicle mass value.

According to a preferred embodiment of the invention, the estimation method is performed during the vehicle starting stage.

According to a preferred embodiment of the invention, the vehicle is an electric vehicle, such as an electric vehicle having wheels each driven by an individual electric motor.

According to a preferred embodiment of the invention, the driving torque is obtained form electric current information of an electric motor of the electric vehicle.

According to a preferred embodiment of the invention, the wheel speed is obtained with a wheel speed sensor which senses the rotational speed of a wheel or obtained from the output speed information of an electric motor of the electric vehicle.

According to a preferred embodiment of the invention, the vehicle longitudinal dynamic equation comprises inherent physical parameters which comprise at least the moment of inertia and the radius of a wheel.

According to a preferred embodiment of the invention, in step 4), the calculating of the current vehicle mass value and the calculating of the driving resistance are decoupled from each other.

The invention also provides a vehicle mass estimation system which comprises means for determining the wheel speed and means for determining the driving torque of a vehicle, when the vehicle is running; a longitudinal acceleration sensor for measuring the longitudinal acceleration of the vehicle; and a calculating module configured for calculating an estimated vehicle mass using the vehicle mass estimation method.

According to a preferred embodiment of the invention, the vehicle mass estimation system is mounted in an electric vehicle, for example, mounted in an electric vehicle having wheels each driven by an individual electric motor.

The main improvement of the invention is to estimate vehicle mass with cheap sensors.
without needing for obtaining rolling resistance, air drag and vehicle longitudinal velocity as pre-condition. Calculation load is very small and the algorithm is easy to implement for real time application.

Further, the present invention is able to ‘decouple’ the estimation of vehicle mass and the estimation of driving resistance to make the vehicle mass estimation more accuracy and robust to driving resistance variance and easy for application.

Thus, an important idea of the invention is when the longitudinal acceleration (determined with accelerator signal) is small enough, only driving resistance is estimated while vehicle mass is fixed to the previously estimated value. When the longitudinal acceleration is large enough, vehicle mass is only estimated while driving resistance is set as the previously estimated value. In this way, the estimation of vehicle mass will have less influence from driving resistance. The estimation method is based on cheap sensors and simple algorithm so that it is easy to implement for real time applications.

Brief Description of the Drawings

Some preferred embodiments of the invention will be described with reference to the drawings in which:

Figure 1 is a schematic view showing longitudinal dynamics of a vehicle and a wheel of it;

Figure 2 shows a flow chart of estimation process according to a preferred embodiment of the invention; and

Figure 3 shows diagrams of estimation results for different vehicle masses.

Detailed Description of Preferred Embodiments

The subject matter for which the inventive research has been conducted is a vehicle, in particular an electric vehicle. Some experiments of the invention are conducted to a vehicle having wheels each driven by an individual electric motor, such as an electric vehicle with wheel hub motor at each wheel. For vehicles run on traditional fuels, wheel speeds and vehicle driving torques are measured by additional sensors. For electric vehicles the wheels of which are driven directly or indirectly by electric motors, vehicle driving torques can be derived directly or indirectly from electrical signals from electric motors, and thus vehicle
driving torques of high accuracy can be obtained without using any additional wheel speed sensor. For an electric motor having an integrated speed sensor, the wheel speed may be obtained from the motor speed information provided by the integrated speed sensor.

The invention provides a novel dynamic model based vehicle mass estimation method in which road grade information is not treated individually, and the rolling resistance and the air resistance are combined into a single variable, running resistance. In the method, it does not need to calculate out any resistance by mathematical fitting, and vehicle speed information is not necessary. Only the vehicle mass and the running resistance are estimated as two unknown parameters. The estimation method has reduced calculation load, increased estimation speed, and better real time treatment ability.

The mass estimation method of the invention is applicable to a vehicle, in particular an electric vehicle, especially a vehicle having 4 wheels each driven by an individual electric motor as used in a preferred embodiment of the invention as described later. Acceleration information can be provided by a longitudinal acceleration sensor, and wheel speed and torque information of the wheels can be obtained by speed sensors and torque sensors or obtained from the electric motors. The vehicle has a relatively low speed during starting stage, and thus the running resistance is relatively, which is advantageous for increasing the accuracy of mass estimation. For this reason, the estimation method is performed preferably in the vehicle starting stage. In view that the vehicle mass has little change when the vehicle is running, the vehicle mass can be regarded as a constant. Thus, once the vehicle mass estimation has been finished during the vehicle starting stage, no further estimation is conducted again, and the estimated value keeps unchanged. However, it can be understood that, the vehicle mass estimation process of the invention can be additionally or alternatively conducted during the vehicle running stage.

The mass estimation method of the invention is initiated from the vehicle longitudinal dynamics as described below.

As shown in Figure 1, during normal running state of a vehicle, the wheel dynamic is expressed by:

$$J_w \ddot{\omega}_i = T_i - F_m i R - F_r R$$  \hspace{1cm} (1)
\[ F_{xi} = \left( \frac{T_i - J_w \dot{\omega}_i}{R} \right) / R - F_{ri} \] (2)

where

\[ F_x = \sum \xi F_{xi}, \quad F_r = \sum r F_{ri} = \mu_r mg \cos \beta \]

Then

\[ F_x = \sum \xi \left( \frac{T_i - J_w \dot{\omega}_i}{R} \right) - \mu_r Mg \cos \beta \] (3)

where \( F_x \) is the total longitudinal force in a longitudinal direction, \( F_r \) is the total rolling resistance force, \( T_i \) is the driving torque on each wheel, \( J_w \) is the wheel moment of inertia, \( \dot{\omega}_i \) is the wheel speed, \( R \) is the wheel rolling radius, \( \mu_r \) is the rolling resistance coefficient, and \( M \) is the vehicle mass or curb weight.

Now the longitudinal dynamic of a vehicle having wheels each driven by an individual electric motor will be analyzed with reference to Figure 1.

The longitudinal dynamic of the vehicle satisfies the following equation:

\[ M \ddot{v}_x = \sum \xi \left( F_{xi} - F_{gi} - F_w \right) \]
\[ = \sum \xi \left( \frac{T_i - J_w \dot{\omega}_i}{R} \right) - \mu_r Mg \cos \beta - Mg \sin \beta - \frac{1}{1.63} C_d Av_x^2 \] (4)

and:

\[ M(\ddot{v}_x + g \sin \beta) = \sum \xi \left( \frac{T_i - J_w \dot{\omega}_i}{R} \right) - \mu_r Mg \cos \beta - \frac{1}{1.63} C_d Av_x^2 \] (5)

where \( v_x \) is the vehicle speed in the longitudinal direction, \( F_g \) is the grade resistance, \( F_w \) the air resistance, \( \beta \) is the road grade, \( C_d \) is the coefficient of drag, \( A \) is the frontal area of the vehicle, and CoG is the mass center or weight center of the vehicle.

The value of the longitudinal acceleration sensor includes the longitudinal acceleration of the vehicle and the acceleration caused by the road grade:

\[ a_{sens,x} = \dot{v} + g \sin \beta \] (6)

Then, equation (5) can be written as:
\[
Ma_{\text{sensor, } x} = \sum_{i=1}^{4} \left[ \frac{T_i - J_w \dot{\omega}_i}{R} \right] - \mu_r Mg \cos \beta - \frac{1}{1.63} C_d Av_x^2
\]

(7)

The total driving resistance is defined as

\[
F_R = \mu_r Mg \cos \beta + \frac{1}{1.63} C_d Av_x^2
\]

(8)

Then,

\[
\sum_{i=1}^{4} \left[ \frac{T_i - J_w \dot{\omega}_i}{R} \right] = Ma_{\text{sensor, } x} + F_R
\]

(9)

By means of equation (9), an estimation algorithm of the invention can be established as described below.

If \( \bar{M} \) is the true value of vehicle mass, we can estimate the driving resistance with:

\[
\sum_{i=1}^{4} \left[ \frac{T_i - J_w \dot{\omega}_i}{R} \right] = \bar{M}a_{\text{sensor, } x} + \hat{F}_R + \omega_1(t)
\]

(10)

where \( \hat{F}_R \) is the estimated driving resistance, and \( \omega_1(t) \) is the estimation error caused by sensors signal noise or measurement error of e-torque, wheel rolling radius and moment inertia.

Similarly, if \( \bar{F}_R \) is the true value of driving resistance, we can estimate the vehicle mass with:

\[
\sum_{i=1}^{4} \left[ \frac{T_i - J_w \dot{\omega}_i}{R} \right] = \hat{M}a_{\text{sensor, } x} + \bar{F}_R + \omega_2(t)
\]

(11)

where \( \hat{M} \) is the estimated vehicle mass, and \( \omega_2(t) \) is the estimation error caused by sensors signal noise or measurement error of e-torque, wheel rolling radius and moment inertia.

As the two variables are estimated at the same time, the true value \( \bar{M} \) and \( \bar{F}_R \) normally are not known. We actually use the approximate \( \hat{M} \) and \( \hat{F}_R \) separately, where

\[
\bar{M} = \hat{M} + \epsilon_M
\]

(12)

\[
\bar{F}_R = \hat{F}_R + \epsilon_{FR}
\]

(13)

Then equations (10) and (11) are changed to:
\[ \sum_{i=1}^{4} \left[ \frac{T_i - J \ddot{\omega}_i}{R} \right] = \dot{M}a_{\text{sensor}, x} + \varepsilon_M a_{\text{sensor}, x} + \hat{F}_R + w_i(t) \]  
(14)

\[ \sum_{i=1}^{4} \left[ \frac{T_i - J \ddot{\omega}_i}{R} \right] = \dot{M}a_{\text{sensor}, x} + \hat{F}_R + \varepsilon_{FR} + w_2(t) \]  
(15)

Two switching thresholds of longitudinal acceleration, \( a_L \) and \( a_H \), are set for the estimation process, wherein \( a_L < a_H \).

At the beginning of estimation, half-load weight is assumed as the first \( \hat{M} \) since there is not any information about real vehicle mass now. It can be understood that other roughly estimated vehicle mass value, such as 1 to 1.5 times of the curb weight of the vehicle, may be used as the first \( \hat{M} \).

When \( a_{\text{sensor}, x} < a_L \) and \( a_L \) are small enough, equation (14) is used to estimate driving resistance.

The process is always to estimate first the driving resistance and then the vehicle mass since the acceleration is always increase from 0 to a certain value. Therefore, once the first driving resistance is estimated from equation (14), when \( a_H \) is large enough, equation (15) is used to estimate vehicle mass with the previously estimated driving resistance as \( \hat{F}_R \).

By using RLS method, we have the estimation equations below:

\[ y = \phi \theta \]  
(16)

The solution can be deduced from the equations:

\[ \begin{aligned}
\hat{\theta}(k) &= \hat{\theta}(k-1) + L(k)(y(k) - \phi^T(k)\hat{\theta}(k-1)) \\
L(k) &= P(k-1)\phi(k)(1 + \phi^T(k)P(k-1)\phi(k))^{-1} \\
P(k) &= (I - L(k)\phi^T(k))P(k-1)
\end{aligned} \]  
(17)

So in the condition that \( a_{\text{sensor}, x} < a_L \), the driving resistance can be calculated by substituting the related variables into \( \theta \), \( y \) and \( \phi \).

\[ \begin{aligned}
\theta &= \hat{F}_R \\
y &= \sum_{i=1}^{4} \left[ \frac{T_i - J \ddot{\omega}_i}{R} \right] - \dot{M}a_{\text{sensor}, x} \\
\phi &= 1
\end{aligned} \]  
(18)
So when $a_{\text{sensor,x}} > a_{\text{H}}$, the vehicle mass can be calculated by substituting the related variables into \( \theta, y \) and \( \phi \).

\[
\begin{align*}
\theta &= \dot{\hat{M}} \\
y &= \sum_{i=1}^{\hat{T}} \left[ \frac{T_i - J_x \dot{\omega}_i}{R} \right] - \hat{F}_R \\
\phi &= a_{\text{sensor,x}}
\end{align*}
\]  

(19)

The whole estimation process and its switching logic are described as figure 2.

Now the convergence determination of the algorithm will be described.

Once the algorithm starts, the estimation result is sampled every \( t_s \) second, we store only the last \( n \) estimated values, and calculate the variance as follows:

\[
\hat{\sigma} = \sum_{i=1}^{n} \left( \frac{\hat{m}_i - \bar{m}}{\bar{m}} \right)^2
\]

(20)

where \( \hat{m}_i \) is one of the estimated values (sample time=\( t_s \) seconds), and \( \bar{m} \) is the average value of these last \( n \) estimated mass. The real value of \( t_s, n, \sigma_b \) will be adjusted in the vehicle experiment. When \( \hat{\sigma} \) is smaller than \( \sigma_b \), it is believed that the estimated mass is convergent, and the algorithm stops.

With regard to the longitudinal accelerator signal, it is noted that, if the vehicle is started on a sloped road, the signal of longitudinal sensor, \( a_{\text{sensor,x}} \) will include the acceleration due to the gravity at the road slope. By comparing the signal of longitudinal sensor before the vehicle is started and after it is started, the influence of road slope on the estimation method can be eliminated easily. On the other hand, the acceleration change due to road slope is detected easily from longitudinal sensor signal and driving torque info because dramatic change happens when the vehicle moving from an even road to a slope road, or from a slope road to an even road, or from a slope to another slope. So the acceleration resulted from gravity at the road slope can be derived easily.

Further, it has been found that, for obtaining accurate estimation results, the longitudinal acceleration should fall in a range defined by lower threshold \( a_L \) and higher threshold \( a_H \).

It is found that the vehicle mass estimation is not sensitive to the upper threshold \( a_H \). The lower threshold \( a_L \) has influence on estimation accuracy of vehicle mass. Larger value of \( a_L \)
will cause larger error, but $a_L$ cannot too small. Certainly, according to the proportion of load capacity to vehicle curb weight, $a_L$ can be selected easily.

For checking the effectiveness of the vehicle mass estimation method, some experiments have been conducted on a 4-wheel drive electric vehicle. Estimation processes for five experimental cases with different experimental conditions performed on an asphalt road, the experimental results of which are shown in Figures 3 and summarized in Table 1. It can be seen from Table 1 that the experimental results that estimated vehicle mass can be obtained with high accuracy in each case.

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<td>Error rate (%)</td>
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<td>1.5</td>
<td>-1.5</td>
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It can be seen that the invention provides a novel vehicle mass estimation method which is able to perform vehicle mass estimation by using fewer sensors or using cheaper sensors when compared which traditional vehicle mass estimation methods. The invention does not use rolling resistance, air resistance and vehicle longitudinal speed as presetting conditions, as a result of which, the calculation load is very low and the estimation method is easy to be used in real time.

The possible applications of the invention include traction control, braking control, start control at the slope, ACC and the like for electric vehicles.
CLAIMS

1. A vehicle mass estimation method comprising the steps of:

1) establishing a vehicle longitudinal dynamic equation for a vehicle;

2) establishing an estimation equation group from the longitudinal dynamic equation, the estimation equation group comprising wheel speed, driving torque and longitudinal acceleration as input parameters, and vehicle mass and driving resistance of the vehicle as variables;

3) determining the wheel speed, the driving torque and the longitudinal acceleration of the vehicle when the vehicle is running;

4) calculating current vehicle mass value and driving resistance together using the estimation equation group repetitively until the current vehicle mass value is convergent; and

5) outputting the current vehicle mass value as an estimated vehicle mass;

wherein, in step 4), when the longitudinal acceleration is lower than a lower threshold, only the driving resistance is estimated, while the vehicle mass is fixed to the previously estimated value; and when the longitudinal acceleration is higher than a higher threshold, only the vehicle mass is estimated, while the driving resistance is fixed to the previously estimated value.

2. The vehicle mass estimation method of claim 1, wherein the driving resistance of the vehicle is a sum of at least rolling resistance and air resistance.

3. The vehicle mass estimation method of claim 1 or 2, wherein a roughly estimated vehicle mass value is used as the first vehicle mass value.

4. The vehicle mass estimation method of any one of claims 1 to 3, wherein the estimation method is performed during the vehicle starting stage.

5. The vehicle mass estimation method of any one of claims 1 to 4, wherein the vehicle is an electric vehicle.

6. The vehicle mass estimation method of claim 5, wherein the driving torque is obtained
form electric current information of an electric motor of the electric vehicle.

7. The vehicle mass estimation method of claim 5, wherein the wheel speed is obtained from a speed sensor which senses the rotational speed of a wheel or obtained from the output speed information of an electric motor of the electric vehicle.

8. The vehicle mass estimation method of any one of claims 5 to 7, wherein the vehicle is an electric vehicle having wheels each driven by an individual electric motor.

9. The vehicle mass estimation method of any one of claims 1 to 8, wherein the vehicle longitudinal dynamic equation comprises inherent physical parameters which comprise at least the moment of inertia and the radius of a wheel.

10. A vehicle mass estimation system comprising:
    means for determining the wheel speed and means for determining the driving torque of a vehicle, when the vehicle is running;
    a longitudinal acceleration sensor for measuring the longitudinal acceleration of the vehicle; and
    a calculating module configured for calculating an estimated vehicle mass using the vehicle mass estimation method of any one of claims 1 to 9.

11. The vehicle mass estimation system of claim 10, wherein the vehicle mass estimation system is mounted in an electric vehicle.

12. The vehicle mass estimation system of claim 10, wherein the vehicle mass estimation system is mounted in an electric vehicle having wheels each driven by an individual electric motor.
Figure 1
Start

Set initial value of $M$ as half-load weight, $F_R$ as zero

Signal of accelerator is read in. Driving torque and wheel speeds are determined.

- Signal value $< a_l$?
  - Yes: Driving resistance is estimated with the current value of $M$
  - No: Update $F_R$ with the estimated driving resistance

- Signal value $> a_H$?
  - Yes: Vehicle mass is estimated with the current value of $F_R$
  - No: Update $M$ with the estimated vehicle mass

Estimation value of vehicle mass is convergent?

- Yes: End
- No: Repeat process
Figure 3
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

G01G 19/08 (2006.01) i
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: G01G

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)

CNKISPRINGERLINK,CNAB,CTNX,DWPL,ISPOAB: vehicle?,ear?,mass,wheel,speed,velocity,driv?,torque,longitudinal,acceleration,resistance,feng,yuan,xiong,lu,yu,zhuoping

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>YU, Zhuoping et al., Vehicle Mass Estimation for Four In-Wheel-Motor Drive Vehicle, Electrical Engineering and Control, Lecture Notes in Electrical Engineering, 22 Jun. 2011, Volume 98, Pages 117-125, ISSN 1876-1100</td>
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<td>T</td>
<td>CN102486400A (ROBERT BOSCH GMBH) 06 Jun. 2012 (06.06.2012) See claims 1-11, description paragraphs [0034]-[0106]</td>
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☐ 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
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"&" document member of the same patent family

Date of the actual completion of the international search 13 Jul. 2012 (13.07.2012)

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Telephone No. (86-10)62413454

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