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(54) Title of the Invention: **A controller for a vehicle system**
Abstract Title: **A controller for a vehicle system for estimating traction**

(57) A controller for estimating traction 60, 160 for a motor vehicle system is provided. The controller 60, 160 comprises: a monitoring module 66 which monitors torque values; a determining module 68 for determining a maximum torque value 100 by obtaining and storing empirical data while driving on a surface, the maximum torque value 100 being the torque immediately prior to wheel slip; a predicting module 70 for predicting a traction threshold 102 based on the maximum torque value 100; and a control module 72 for outputting a signal indicative of the traction threshold 102.

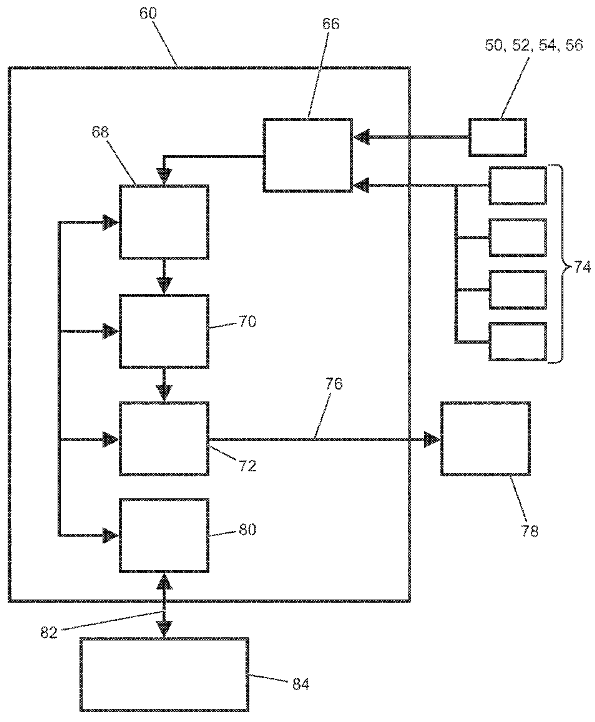

Figure 2

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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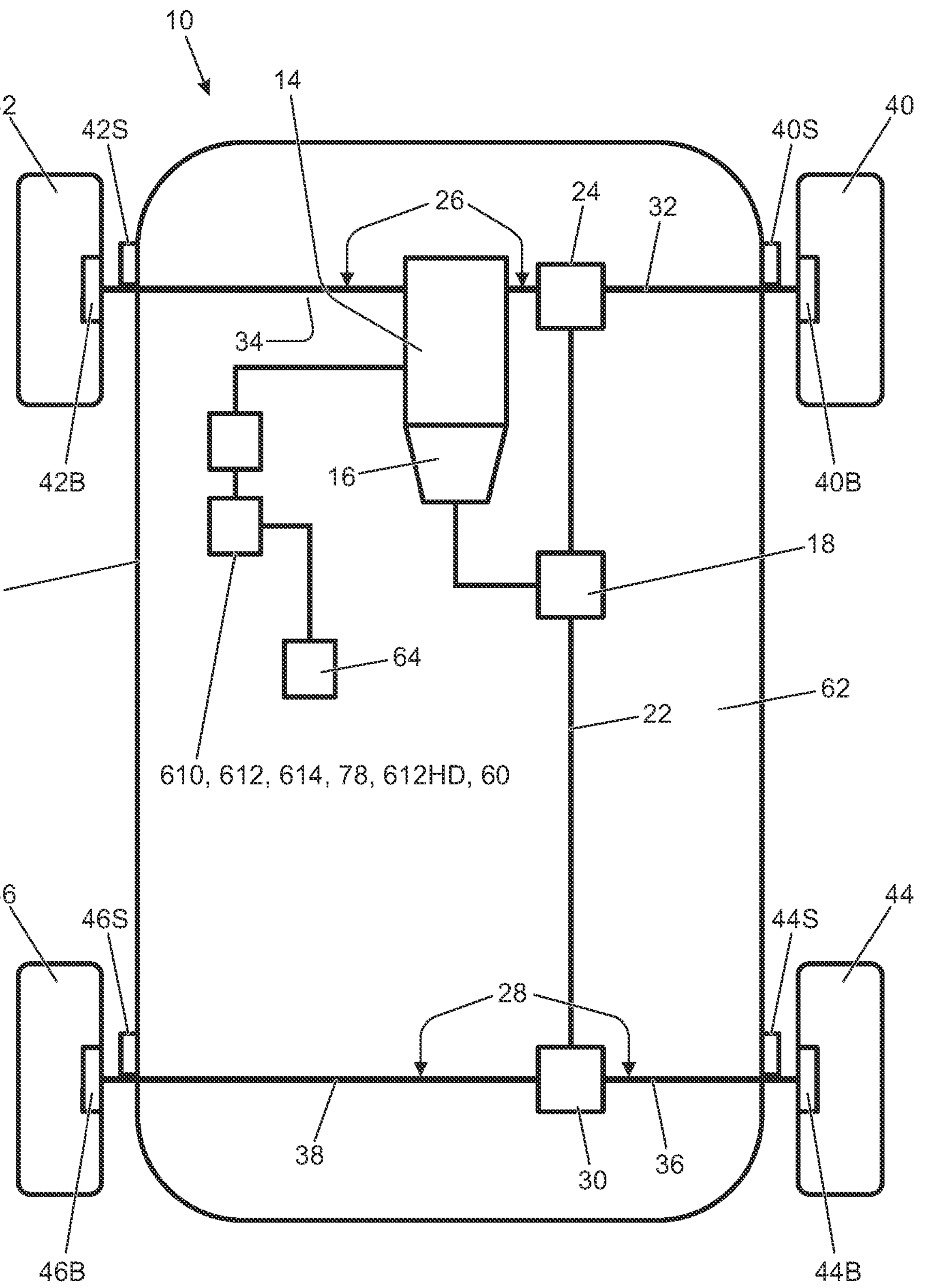

Figure 1A

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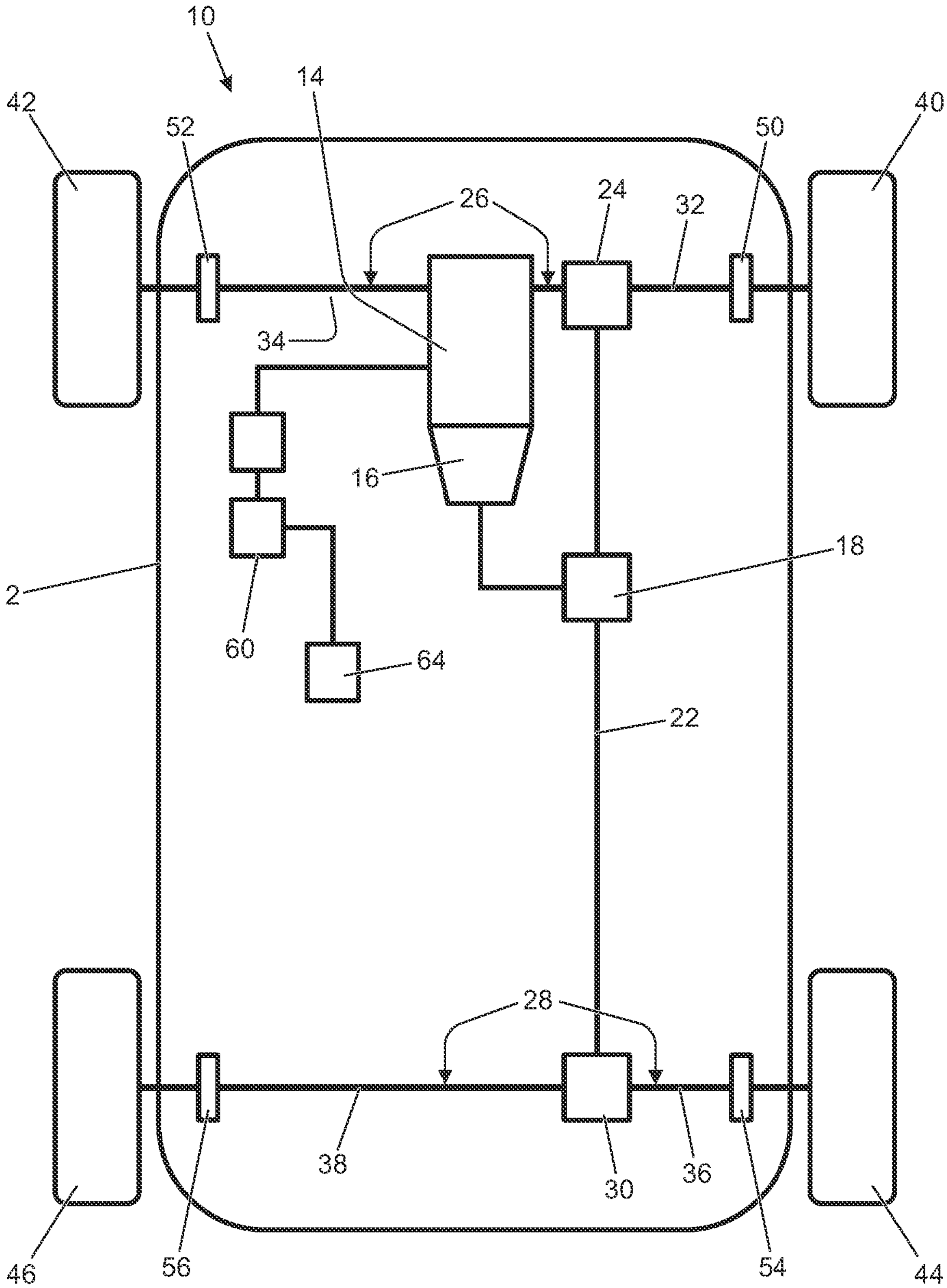

Figure 1B

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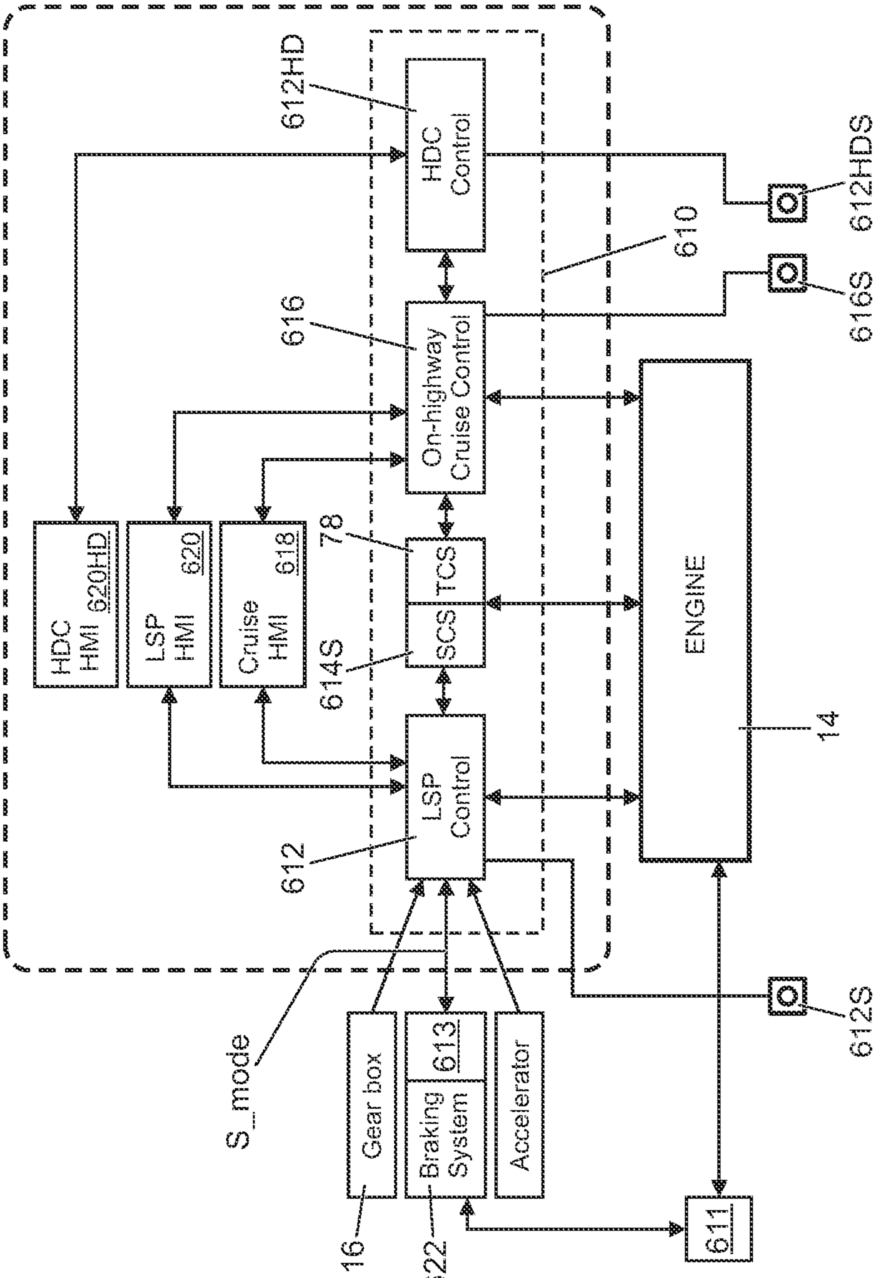

FIGURE 1C

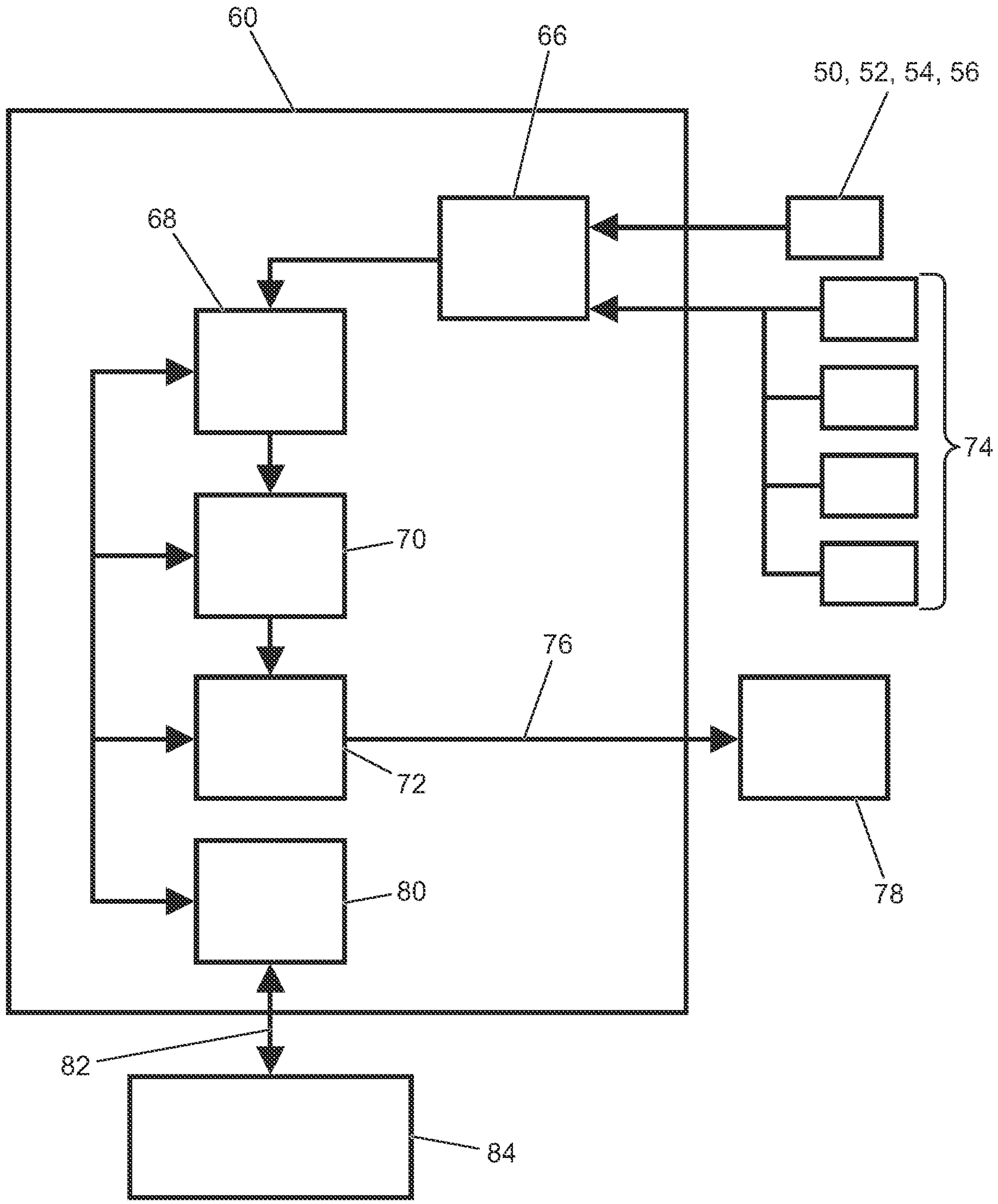

Figure 2

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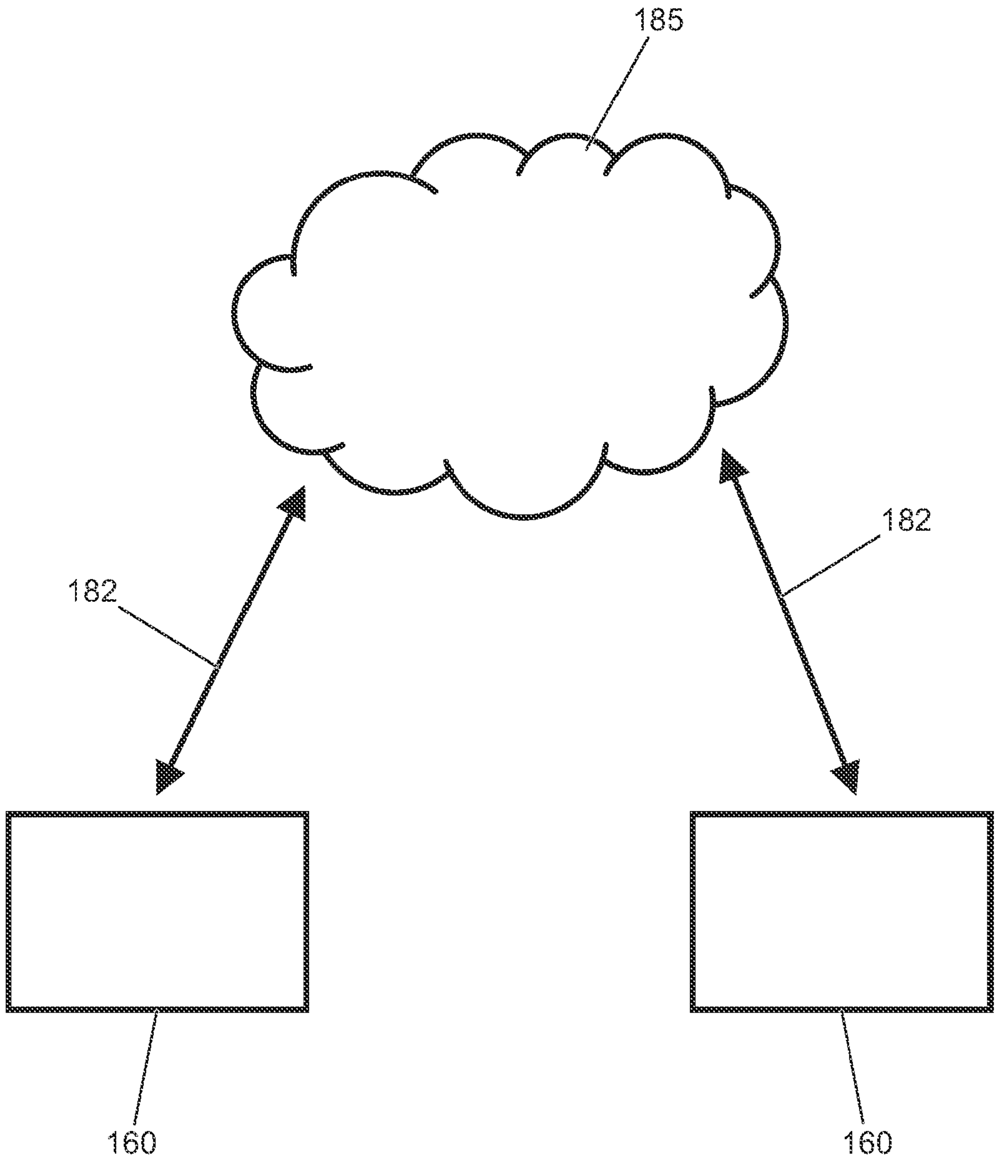

Figure 3

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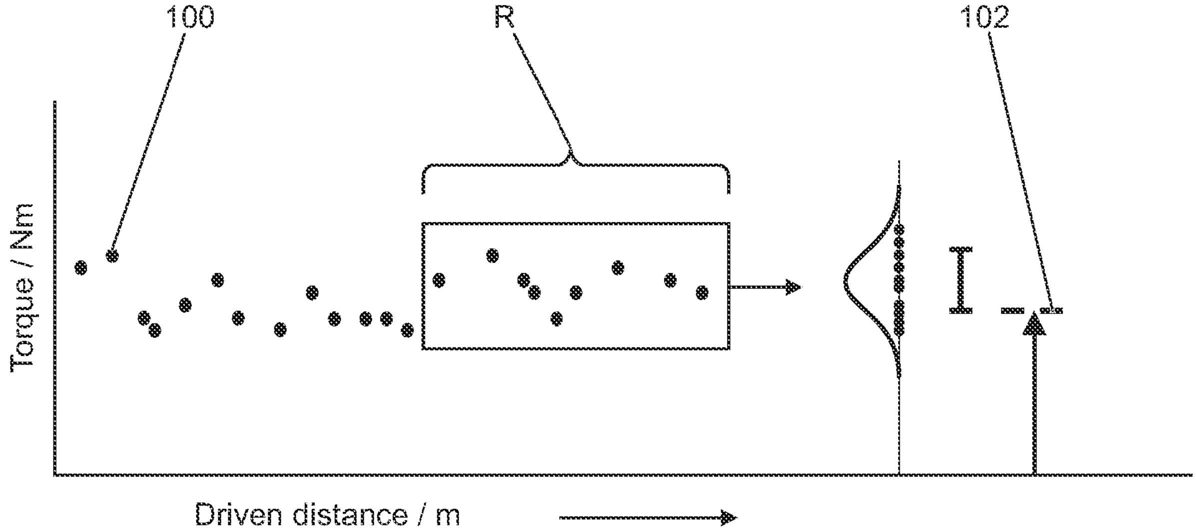

Figure 4

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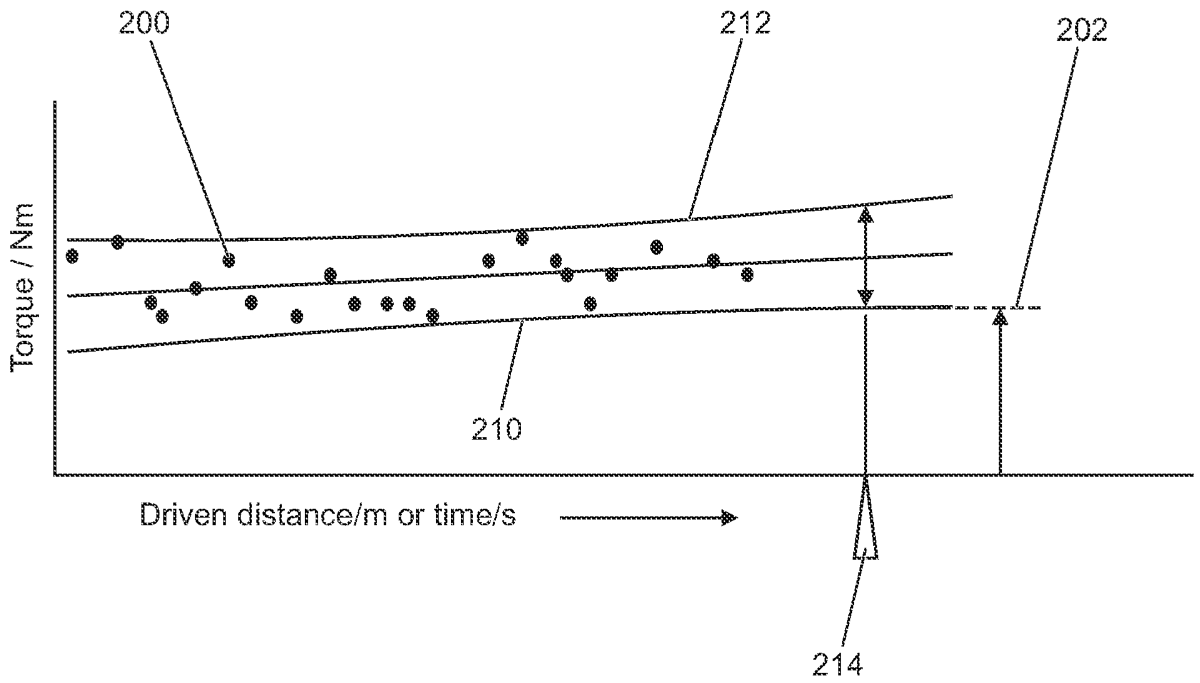

Figure 5

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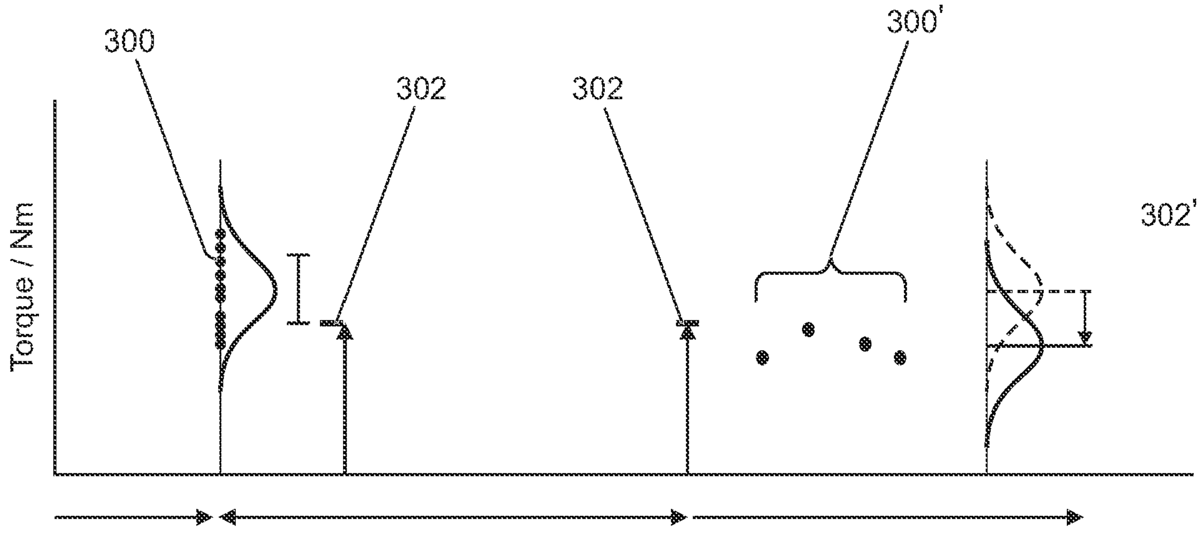

Figure 6

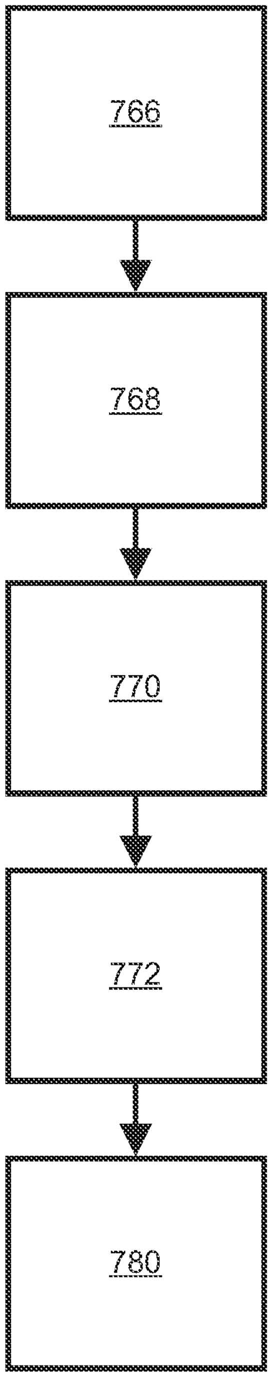

Figure 7

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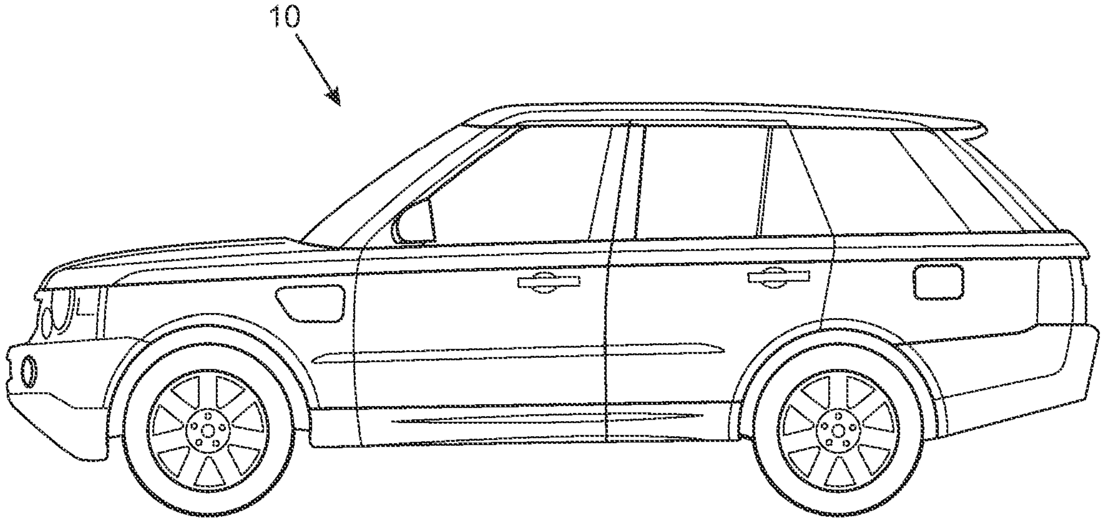

Figure 8

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A CONTROLLER FOR A VEHICLE SYSTEM

TECHNICAL FIELD

The present disclosure relates to a controller for a vehicle system and a method of operating the same particularly, but not exclusively a controller and method for estimating traction of a vehicle. Another aspect of the invention relates to a vehicle including the controller and methods.

BACKGROUND

A vehicle includes an engine coupled to a transmission system which in turn is coupled to two or four ‘driven’ wheels by a drive shaft. Power and torque from the engine is transmitted through the transmission system and the drive shaft to each of the ‘driven’ wheels. In the case of electric vehicle (EV), motors are located at the wheels for propulsion.

Depending on the terrain a vehicle is on, high torque levels of the ‘driven’ wheels may be more than the surface can tolerate. In such cases, the ‘driven’ wheels will slip on the surface. A particular problem occurs on low friction surfaces, such as wet grass, where a wheel slip can cause damage to the surface and the wheel loses traction.

In general a vehicle reacts when the wheel slips are detected by implementing one or more strategies such as applying braking force, retarding the throttle or changing the engine response profile. These control responses are reactive and applied for a limited duration of time. These responses may need to be applied repeatedly. The repetition of wheel slips and vehicle response pattern does not provide satisfactory results, as further wheel slips and damages to the surface on which the vehicle is driven are unavoidable.

It is an object of the present invention to further improve on this prior art.

SUMMARY OF THE INVENTION

According to one aspect of the present invention there is provided a controller for estimating traction of a vehicle, comprising a monitoring module that monitors wheel torque values; a determining module to determine maximum torque values by obtaining and storing empirical data while driving on a surface, the maximum torque values being the wheel torque values immediately prior to wheel slip; a predicting module that predicts a traction threshold based on the maximum torque values; and a control module that outputs a signal indicative of the traction threshold.

In this way, the vehicle is able to detect an imminent wheel slip by monitoring the maximum torque values gathered on a surface whilst driving on a surface and predicting traction threshold and provide a signal indicative of traction control before wheel slip so that traction and/or torque are communicated accordingly rather than communicating request of traction and/or torque after the occurrence of wheel slip. This prevention of a wheel slip provides a better solution than a reactive approach after a wheel slip event so the surface upon which the vehicle is operable is prevented from degradation which is likely to be the case if wheel slip had already occurred. A fully intact driving surface would mean that further wheel slips are less likely to occur, thus degradation of the surface and preventing a vehicle becoming encumbered in more extreme conditions.

The predicting module predicting the traction threshold may comprise calculating the probability of wheel slip using a parametric model of said empirical data. In this way, historical data and past record of detecting and monitoring of the torque value are taken into consideration for a better accuracy. Also probabilistic model may use parameters in dependence on available data, making the model more robust.

The control module may output a signal indicative of traction demand in response to a current torque value exceeding the traction threshold. In this way, the vehicle is able to detect an imminent wheel slip by monitoring whether the current torque value is exceeding a predicted traction threshold and request traction and/or torque accordingly rather than requesting traction and/or torque after the occurrence of wheel slip. This prevention of a wheel slip provides a better solution than a reactive approach after a wheel slip event so the surface upon which the vehicle is operable is prevented from degradation which is likely to be the case if wheel slip had already occurred. A fully intact driving surface would mean that further wheel slips are less likely to occur, thus preventing degradation of the surface and a vehicle becoming encumbered in more extreme conditions.

The traction demand may be output to a Traction Control System (TCS).

The controller may comprise a vehicle display.

The vehicle display allows a driver of the vehicle to receive an indication that the predicted traction threshold has been exceeded so that he may react to excessive torque of the vehicle and prevent wheel slips occurring.

The monitoring module may monitor one or more vehicle conditions. The determining module may determine one or more maximum torque values associated with the or each vehicle condition.

The vehicle condition may be selected from the list of time, date, weather, distance the vehicle has travelled, position of the vehicle, dynamic or static state of the vehicle, altitude of the vehicle, vehicle speed, and duration of the vehicle being in a current position. The vehicle condition may be a configuration of the vehicle such as current set-up of the vehicle, state of the vehicle or any factors that could affect the configuration and/or state of the vehicle such as environmental conditions.

The vehicle itself and also the surface upon which the vehicle is operable may change according to any of the aforementioned conditions. For example, the surface upon which the vehicle is operable will change according to the position of the vehicle. The vehicle may be on a different terrain having different surface types in one position then in another position. For example, a vehicle may be on a grass in one position then moved onto tarmac (road) in another. Terrain may be identified as grass, gravel, snow, ice, sand, rock, mud and rut. The vehicle may be on the same terrain but at positions which have different degrees of slipperiness. In another example, the time of day, the date or the weather may affect the surface upon which the vehicle is operable hence change the vehicle condition. By predicting the traction threshold for a particular condition, the vehicle may be configured to reduce or prevent wheel slip from occurring. In this way, wheel slip is less likely to occur than a case where one traction threshold was applied for all vehicle conditions.

The predicting module may predict the traction threshold based on one or more maximum torque values corresponding to a predetermined range of the or each vehicle condition. For instance, where the vehicle condition relates to position, the traction threshold will be based on one or more maximum torque values corresponding to a predetermined range of positions.

The predetermined range of the or each vehicle condition may be determined based on the or each current vehicle condition.

Basing the traction threshold on a range of a vehicle condition based on the current vehicle condition is more advantageous than a case where the traction threshold is based on every possible vehicle condition including anomalies, such as extreme conditions, which could distort the traction threshold. Determining the traction threshold in this way further improves the reliability of the system to prevent wheel slips. For example, where the vehicle condition is distance the vehicle has travelled or time leading up to the current vehicle position, having a range of the traction threshold eliminate or minimise anomalies resulted from distance-based surface change.

The predicting module may be update the traction threshold in response to monitoring maximum torque values of the system, in-use.

Updating the traction threshold while the system is in use provides a degree of feedback in order to optimise the traction threshold generated by the system, thus making the traction demand more reliable.

The traction threshold may be based on a stochastic model of the maximum torque values.

The traction threshold may be less than or equal to a predetermined percentage of maximum torque values.

Setting the transaction threshold to less than or equal to a predetermined percentage a vehicle of maximum torque values allows the system to filter out anomalies. These anomalies may be created by one or more sensors being used while they operate. The predetermined percentage can be set according to any desired confidence level which the designer of the vehicle desires. A higher percentage results in increased confidence that no wheel slip will occur.

The predetermined percentage of maximum torque values may be 95%.

The predetermined percentage of maximum torque values being 95% means all but the most extreme anomalies have been taken into account when predicting the traction threshold.

The predicting module may be generate a prediction band based on a regression model. The prediction band may have a minimum prediction value and a maximum prediction value for each condition. The traction threshold may be less than or equal to the minimum threshold value.

The traction threshold being less than the minimum threshold value results in a specifically chosen degree of certainty that wheel slip will not occur based on those instances of wheel slip which have occurred in the past.

The regression model may be arranged to extrapolate the prediction band to conditions outside of the range of recorded conditions.

Extrapolating the prediction bands means that the model can be used for vehicle conditions outside of the range of conditions in which the vehicle has been operated in the past. For example, maximum torque values of a vehicle being operated in relatively light rainfall at the occurrence of a wheel slip event can be used to predict the traction threshold for more severe rainfall of the same position.

The signal indicative of the traction threshold may be transmitted to a Human Machine Interface (HMI) and the feedback comprises one or more of: visual output, audible output and/or haptic output. In this way, the vehicle provides feedback to its operator, a driver, so that the driver can make an informed decision on how to operate the vehicle to avoid wheel slip and drive the vehicle smoothly.

The signal indicative of the traction threshold may be transmitted to a vehicle control unit and the feedback comprises reduction in engine power and/or modification in the throttle pedal mapping. In this way, the signal indicative of traction threshold and/or traction demand may be directly communicated to the relevant vehicle system/subsystems, causing the vehicle to change its set up automatically.

The controller may send and/or receive data; the data may be selected from the list of torque, maximum torque value, and vehicle condition.

By virtue of the communications module, the controller may receive data from other places, such as a central repository, or transmit data to other places in order to build a more robust model. The communications module may be arranged to send and/or receive data to/from other vehicles and/or a repository.

In the case where data is sent and received from other vehicles, such an arrangement provides for better modelling since vehicles can learn from the data received and analysed by the controllers of a fleet of vehicles. Alternatively, the repository may be beneficial depending on the hardware available and communication protocol used by the controller and/or the communications module.

According to a further aspect of the present invention there is provided a vehicle comprising the controller of any preceding claim.

According to a further aspect of the present invention there is provided a method of estimating traction of a vehicle, comprising: monitoring torque values; determining a maximum torque values by obtaining and storing empirical data while driving on a surface, the maximum torque values being the wheel torque values immediately prior to wheel slip; predicting a traction threshold based on the maximum torque value; and outputting a signal indicative of the traction threshold.

The method may comprise predicting the traction threshold comprising calculating the probability of wheel slip using a parametric model of said empirical data.

The method may comprise outputting a signal indicative of traction demand in response to a current torque value exceeding the traction threshold.

The method may comprise monitoring one or more vehicle conditions and determining one or more maximum torque value associated with the or each vehicle condition.

The vehicle condition may be selected from the list of time, date, weather, distance the vehicle has travelled, position of the vehicle, dynamic or static state of the vehicle, altitude of the vehicle, vehicle speed, and duration of vehicle in current position.

The method may comprise predicting the traction threshold based on one or more maximum torque values corresponding to a predetermined range of the or each vehicle condition.

The predetermined range of the or each vehicle condition may be determined based on the or each current vehicle condition.

The method may comprise updating the traction threshold in response to monitoring maximum torque values of the system, in-use.

Predicting the traction threshold may include calculating the traction threshold so as to be less than or equal to a predetermined percentage of maximum torque values.

The predetermined percentage may be adjustable. The predetermined percentage may be 95%.

The method may comprise generating a prediction band based on a regression model, the prediction band having a minimum prediction value and a maximum prediction value for each condition; and determining the traction threshold to be less than or equal to the minimum threshold value.

The method may comprise extrapolating the prediction band to conditions outside of the range of conditions used to construct the regression model.

The method may comprise sending and/or receiving data to/from another vehicle and/or a repository. The data may be selected from the list of torque, maximum torque value, and vehicle condition.

According to a further aspect of the present invention there is provided a controller for as described above, wherein: said means for receiving one or more signals each indicative of a value of wheel torque comprises an electronic processor having an electrical input for receiving said one or more signals each indicative of a value of wheel torque; and an electronic memory device electrically coupled to the electronic processor and having instructions stored therein, said means to determine that the vehicle is in a state immediately prior to wheel slip based on the value(s) of wheel torque, and said and means to estimate traction by monitoring wheel torque values; determining maximum torque values by obtaining and storing empirical data while driving on a surface, the maximum torque values being the wheel torque values immediately prior to wheel slip; and predicting a traction threshold based on the maximum torque values comprises the processor being configured to access the memory device and execute the instructions stored therein such that it is operable to detect that the vehicle is in a state immediately prior to wheel slip based on the value(s) of wheel torque; and command output of a signal indicative of the traction threshold.

According to a further aspect of the present invention there is provided a non-transitory computer-readable medium tangibly embodying computer-executable instructions for operating a controller of a motor vehicle, the instructions being executable by a vehicle processor to provide operations comprising: monitoring torque values; determining a maximum torque values by obtaining and storing empirical data while driving on a surface, the maximum torque values being the wheel torque values immediately prior to wheel slip; predicting a traction threshold based on the maximum torque value; and outputting a signal indicative of the traction threshold.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. Features described in connection with one embodiment are applicable to all embodiments, unless such features are incompatible. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1A shows a schematic of a vehicle including a controller according to an embodiment of the present invention;

Figure 1B shows a schematic of a vehicle including a controller according to another embodiment of the invention;

Figure 1C is a high level schematic diagram of a speed control system of the vehicle of Figure 1A;

Figure 2 shows a block diagram of the controller from Figure 1A and/or Figure 1B;

Figure 3 shows a block diagram of an alternative embodiment of the system from Figure 2;

Figure 4 shows a graph representation of a method of predicting a transaction threshold using the controller from Figure 2;

Figure 5 shows a graph representation of an alternative method of determining the transaction threshold using the controller from Figure 2;

Figure 6 shows a graph representation of a method of updating the transaction threshold from Figure 4 while the controller is in use;

Figure 7 shows a flow diagram of a method being utilised by the controller of Figures 1A and 1B; and

Figure 8 shows a graphical representation of a vehicle which comprises the controller of Figures 1A or 1B.

DETAILED DESCRIPTION

With reference to Figure 1A a vehicle 10 includes a chassis 12 for supporting various components. The vehicle 10 is intended to be suitable for off-road use, that is for use on terrains other than regular tarmac road, as well as on-road. The various components mounted to the chassis 12 include an engine 14, a transmission 16, a transfer box 18, a propshaft 22, a Front Drive Unit (FDU) 24, a front drive shaft 26, a Rear Drive Unit (RDU) 30, and a rear drive shaft 28. The front drive shaft 26 and the rear drive shaft 28 are divided into a front off-side drive shaft 32, a front near-side drive shaft 34, rear off-side drive shaft 36, and a rear near-side drive shaft 38. Each of the aforementioned drive shafts 32, 34, 36, 38 is connected to a wheel. Accordingly, there are four wheels namely, a front off-side wheel 40, a front near-side wheel 42, a rear off-side wheel 44, and a rear near-side wheel 46.

The wheels 40, 42, 44, 46 each have a respective brake 40B, 42B, 44B, 46B. Respective speed sensors 40S, 42S, 44S, 46S are associated with each wheel 40, 42, 44, 46 of the vehicle 10. The sensors 40S, 42S, 44S, 46S are mounted to a chassis 12 of the vehicle 10 and arranged to measure a speed of the corresponding wheel.

A control system for the vehicle comprises a central controller 610 (FIG. 1B), referred to as a vehicle control unit (VCU) 610, the powertrain controller 611 and a brake controller 613 (FIG 1C). The brake controller is an anti-lock braking system (ABS) controller 613 and forms part of a braking system 622 (FIG. 1B). The VCU 610 receives and outputs a plurality of signals to and from various sensors and subsystems (not shown) provided on the vehicle 10. The VCU 610 includes a low-speed progress (LSP) control system 612 shown in FIG. 1C, a stability control system (SCS) 614S, a traction control system (TCS) 78, a cruise control system 616 and a Hill Descent Control (HDC) system 612HD. The SCS 614S improves stability of the vehicle 10 by detecting and managing loss of traction. If excessive wheel spin is detected, the TCS 78 is configured to reduce wheel spin by application of brake force in combination with a reduction in powertrain drive torque. In the embodiment shown the SCS 614S and TCS 78 are implemented by the VCU 610. In some alternative embodiments the SCS 614S and/or TCS 78 may be implemented by the brake controller 613. Further alternatively, the SCS 614S and/or TCS 78 may be implemented by separate controllers.

With reference to Figure 2, the controller for estimating traction 60 includes a monitoring module 66, a determining module 68, a predicting module 70, and a control module 72 all provided as electronic data on a non-transitory memory component of a computer unit. The computer unit also includes a processor for executing each of the aforementioned modules, 66, 68, 70, 72. In an embodiment, these modules are provided in series such that the monitoring module 66 is linked to the determining module 68, which is linked to the predicting module 70 which is linked to the control module 72.

The SCS 614S, TCS 78, ABS controller 613 and HDC system 612HD provide outputs indicative of, for example, SCS activity, TCS activity, ABS activity, brake interventions on individual wheels and engine torque requests from the VCU 610 to the engine 14 in the event a wheel slip event occurs. Each of the aforementioned events indicates that a wheel slip event has occurred. Other vehicle sub-systems such as a roll stability control system or the like may also be present.

In the present embodiment, the wheel speed signals are generated by wheel speed sensors 40S, 42S, 44S, 46S associated with respective wheels of the vehicle 10. The wheel speed signals received by the ABS controller 613 are compared with a vehicle reference speed value corresponding to an actual speed of the vehicle 10 over ground. Thus, defining the amount of slip of a given road wheel as the difference between the speed of a given wheel 40, 42, 44, 46 and vehicle reference speed value. The ABS controller 613 is configured to estimate the value of surface friction based at least in part on measurements of wheel slip for a given amount of torque applied to a wheel.

In response to receipt of the signal surface friction, the engine controller is configured to determine the amount of torque that may be applied to a driving wheel of the vehicle 10 before the amount of slip of the driving wheel will exceed a prescribed slip value. In the present embodiment the prescribed slip value is determined taking into account vehicle reference speed value. That is, the prescribed slip value is dependent on vehicle speed, typically increasing with vehicle speed although other arrangements are also useful.

The amount of torque is determined by the engine controller referencing to a look-up table (LUT) that provides torque values of in view of the prescribed slip. In some embodiments, the engine controller obtains the prescribed slip value also taking into account the driving mode in which the vehicle 10 is operating, driving mode. In some driving modes larger amounts of slip are allowed for a given vehicle speed compared with other driving modes, and the controller is configured to take this into account in determining the prescribed slip value. In some embodiments the engine controller also takes into account an amount of weight that is acting on each driving wheel, or on each axle that is delivering drive torque to drive the vehicle 10, in calculating the amount of torque that is required to be applied to a given wheel or axle 26, 28 in order to cause the prescribed amount of slip for that wheel or axle. This is because the amount of torque that may be applied to a wheel typically increases with increasing weight on a wheel for a given value of surface mu. The weight acting on each wheel or axle 26, 28 may be determined by reference to information indicative of a distribution of weight between forward and rear axles 26, 28. After determining an estimated value of the amount of torque that would be required to cause a given driving wheel 40, 42, 44, 46 to exhibit slip of the prescribed amount, the engine controller calculates a specific amount of torque that the engine 14 is required to develop in order to deliver the calculated amount of torque at a given driving wheel 40, 42, 44, 46 or axle 26, 28, under the instant configuration of the driveline. Therefore the amount of torque at a given driving wheel is calculated by engine controller, or by a brake controller such as ABS controller.

In another embodiment, the transmission can obtain accurate torque prediction for internal components by taking the predicted engine torque input and then taking into account the gear ratio and transmission loss to predict transmission output. It is possible to calculate torque at the wheel by using this output and differential ratio.

In yet another embodiment, each of the front off-side, front near-side, rear off-side, and rear near-side drive shafts 32, 34, 36, 38, includes a torque sensor as shown in Figure 1B. Specifically, there is a front off-side torque sensor 50, a front near-side torque sensor 52, a rear off-side torque sensor 54, and a rear near-side torque sensor 56. Each of the torque sensors 50, 52, 54, and 56 is connected to a control unit in the form of a controller for estimating traction 60. The controller 60 is connected, via a network such as CAN or Flexray, to a human machine interface (HMI) 64 which includes a display. The HMI 64 is installed on a dashboard (not shown) of the vehicle 10. These torque sensors 50, 52, 54, 56 measure the amount of torque at each wheel 40, 42, 44, 46 respectively.

The monitoring module 66 includes an input function so as to receive signals from engine controller and/or brakes controller such as ABS controller 613. In another embodiment the monitoring module 66 receives signals from the torque sensor(s) 50, 52, 54, 56. In this way, the monitoring module 66 is arranged to monitor torque values, specifically, torque values associated with the each wheels 40, 42, 44, 46.

The input function of the monitoring module 66 is also arranged to receive inputs from other sensors 74 and modules relating to various vehicle conditions. Said vehicle conditions include time, date, weather, distance the vehicle travelled, position of the vehicle, dynamic or static state of the vehicle, altitude of the vehicle, vehicle speed, and time of vehicle in current position. The monitoring module 66 is thus arranged to monitor one or more of these vehicle conditions.

The functionality of the determining module 68, the predicting module 70 and the control module 72 are described in more detail below. However, in summary, the determining module 68 is arranged to determine a 'maximum torque value'. The maximum torque value is equivalent to the torque value calculated for each wheel immediately prior to occurrence of a wheel slip. In another embodiment the maximum torque value is equivalent to the torque value detected at a given torque sensor 50, 52, 54, 56 immediately prior to wheel slip. It is the torque value immediately prior to wheel slip which is taken as the 'maximum torque value' since there is an inherent reduction in torque when wheel slip has occurred.

The predicting module 70 is then arranged to predict a 'traction threshold' based on the 'maximum torque value'. The traction threshold comprises calculating the probability of wheel slip using a parametric model of said empirical data. The 'traction threshold' is a torque value below which there is an inherent degree of confidence that a wheel slip will not occur.

In statistics, a parametric model is a family of distributions that can be described using a finite number of parameters. These parameters are usually collected together to form a single k-dimensional parameter vector θ = (θ1, θ2, ..., θk). The 'traction threshold' could be based on the maximum value collected in such a parametric model array.

The control module 72 then outputs a signal indicative of the traction threshold and/or a signal indicative of 'traction demand' 76 in responses to a current torque value, estimated by engine controller and/or brakes controller such as ABS controller 613. In another embodiment the current torque value is sensed by a sensor 50, 52, 54, 56 exceeding the 'traction threshold'. The signal indicative of 'traction demand' 76 is output to a communication network, such as CAN or Flexray of a vehicle.

The traction control system 78 is not within the definition of the traction system 60 but rather a different system within the same vehicle 10. This invention is a part of VCU 610 and could be separate from or part of VCU's subsystems. For example, the controller 60 can be part of TCS 78 or ABS 613 or SCS 614S.

The signal indicative of traction demand is sent to a respective system within a vehicle to provide a direct feedback to a driver. This can take a form of haptic, audio or visual feedback. For example, there may be at least one of: an audible sound, a visual indication on a HMI 64 display, haptic feedback through a pedal or a steering wheel. This is not an exhaustive list and there may be different type or combination of feedback provided to the driver.

In an embodiment the HMI 64 is arranged to display a warning to the driver with a visual cue stating to “reduce acceleration” or “reduce speed” derived from the signal indicative of the traction demand. A driver can thus take action to avoid wheel slip, for instance, by reducing a throttle level, when the “reduce acceleration” or “reduce speed” warning appears.

Alternatively, or additionally the signal indicative of traction demand is sent to a system which could provide the driver with more sensitive control. For example, a throttle map can be modified such that the pedal feed would be softer when the driver’s input needs to be less aggressive in order to avoid breaking the surface.

In an embodiment, the controller 60 also includes a communications module 80 which also transmits and receives data to a destination external to the vehicle 10 via a telematics unit within the vehicle. The transceiver can transmit and receive data to the external destination over an electromagnetic medium 82 such as 3G, 4G, or even Wi-Fi.

In an alternative embodiment, the controller 60 also includes a communications module 80, wherein the communications module 80 is a hardware component in the form of a transceiver arranged to transmit and receive data to a destination external to the vehicle 10. The transceiver can transmit and receive data to the external destination over an electromagnetic medium 82 such as 3G, 4G, or even Wi-Fi.

The communications module 80 is also connected to each of the determining module 68, the predicting module 70, and the control module 72. The communication between the communications module 80 and each of these other respective modules 68, 70, 72 is two-way communication. Any data which the communications module 80 receives from an external destination is thus delivered directly to each module 68, 70, 72. Similarly, any outputs from these three respective modules 68, 70, 72 can be detected by the communications module 80 and sent to the external destination.

Data may comprise torque, maximum torque value, direction where the vehicle moves into, vehicle condition, vehicle location data and other factors which may inform the surface conditions

In this embodiment, the communications module 80 communicates with a central repository 84, at an external destination to the vehicle 10. The repository 84 includes one or more databases for storing data including torque, maximum torque value, direction where the vehicle moves into, vehicle condition, vehicle location data and other factors which may inform the surface conditions. In this way, these parameters can be sent from the vehicle 10 to the repository 84 directly since the communications module 80 can read the outputs from each module 68, 70, 72. Other vehicles can then use this raw data stored at the repository 84 to share information and build a more accurate model for predicting the 'traction threshold' and subsequent traction demand 76. In addition to different controllers 60 sharing data, data such as current weather conditions can be uploaded from other sources to the vehicle's repository by a central operator. A fleet of vehicles can thus indirectly communicate with each other, via the central repository 84, to share information to build more accurate models of maximum torque values and traction thresholds.

An alternative embodiment is shown in Figure 3. Those features in common with the first embodiment are labeled 100 greater. Not all features in common with both embodiments are shown nor described for brevity.

With reference to Figure 3, the controller 160 does not communicate with a central repository 84 (Figure 2). Instead, the controller 160 is arranged to communicate directly with other controllers 160 located on other vehicles by communicating over a cloud server 185.

Either of the first or the second embodiments can operate in the same way to determine a 'maximum torque value', and generate signals indicative of the 'traction threshold' and the 'traction demand'. The main difference between the first and second embodiments is the way in which data is shared between a plurality of the controllers 60, 160. Accordingly, the following descriptions of operating methods are applicable to both embodiments but will be described only with reference to the first embodiment for brevity.

One method of operating the controller 60, 160 for estimating traction for a vehicle 60 is best described with reference to Figure 4. Torque values are monitored by the monitoring module 766 (Figure 7). When wheel slip is detected, ie sudden loss of torque at a wheel, the torque value immediately preceding wheel slip is recorded as a maximum torque value 100. The maximum torque value 100 is recorded for a specific vehicle condition. The vehicle condition is also being continuously monitored by the monitoring module 66. The vehicle condition in this case is distance as plotted on the X axis. Distance is equivalent to the distance from a starting position of the vehicle and the distance may be substituted for current vehicle position provided as GPS co-ordinates. In this way, the maximum torque value for a vehicle condition, namely position, is determined. It is possible to record another vehicle condition, such as weather type, time of day, or vehicle speed associated with the maximum torque value. A more exhaustive list of potential vehicle conditions includes time, date, weather, position of the vehicle, dynamic (i.e. the vehicle is travelling/moving) or static (i.e. the vehicle is stationary) state of the vehicle, distance travelled, altitude of the vehicle, vehicle speed, and time of vehicle in current position. However, for illustrative purposes, this method of operating the controller 60, 160 is only described with reference to vehicle position.

Next, the 'traction threshold' is predicted. In determining the 'traction threshold' 768, first an array of maximum torque values needs to be recorded for a wide range of positions. The controller 60, 160 obtains and stores empirical data of these maximum torque values while driving on a surface, these maximum torque values being the wheel torque values immediately prior to wheel slip. These maximum torque values 100 are then filtered to obtain a range, R, of maximum torque values 100. The filtering process looks at the current vehicle position and then selects those maximum torque values 100 which are representative of the current position. For instance, maximum torque values for vehicle positions within $\pm$20m of the current position are considered within the range, R. Those maximum torque values 100 outside of the $\pm$20m range, R, are ignored. In this way, predicting the 'traction threshold' 770 is based on maximum torque values corresponding to a predetermined range of vehicle positions, where the range of vehicle positions is based on the current vehicle position.

Instantaneous axle torque values may be calculated by taking real time engine torque output supplied by the engine controller (accurate mapped estimates), multiplied by the transmission ratio and differential ratios to predict axle torques.

Torque split across axles may be assumed to be equal for a normal open differential, therefore axle torque could be divided by 2 to predict wheel torque, which is the empirical data which may be collected for the maximum torque 100 as an example. Other methods of wheel torque calculation may be used.

The maximum empirical torque values 100 would be collected and associated with a given vehicle position, which the controller could use to set the traction threshold for that position, if the vehicle was in that same position again.

Next, the maximum torque values 100 within the range, R, are assigned to a distribution curve. In this way, the 'traction threshold' is based on a stochastic model of the maximum torque values 100. The predicting module 70 predicts a traction threshold comprising calculating the probability of wheel slip using a parametric model of the obtained empirical data. The 'traction threshold' 102 is calculated as being less than a predetermined percentage of the maximum torque values 100 within the range, R. The predetermined percentage is known as a confidence band. A confidence band of 95% would yield a high confidence level that a future wheel slip would not occur since 95% of the previous maximum torque values for similar vehicle positions are higher in magnitude than the current torque value. The control module 72 may output the signal indicative of 'traction threshold'. This may be for further processing by the controller 60, 160 or by any other subsystem of the vehicle 10. In this way, the 'traction demand' is based on the 'maximum torque value' monitored by the monitoring module 68 (Figure 2).

When the vehicle 10 is being driven, the monitoring module 66 (Figure 2) continues to monitor torque values of each wheel from engine controller and/or brakes controller such as ABS controller 613. In another embodiment, the torque values from each of the torque sensors 50, 52, 54, 56 are monitored. The control module 72 includes a comparator which compares the current torque values to the 'traction threshold'. When the current torque value is greater than or equal to the 'traction threshold' the control module 72 outputs the signal indicative of the 'traction demand' 76 to a communication network such as CAN or Flexray or to a communication module.

The output signal will then be transmitted to High Level Display Front (HLDF) unit and the HLDF unit will signal the HMI 64 to display the 'traction demand' as a warning, for instance, "stop accelerating". Alternatively, the warning may be warning of approaching wheel slip limit or that it has exceeded. The warning may be one or more of: visual, audible or haptic feedback. In this way, a driver will understand that there is a potential issue and reduce the accelerator demand. In this way, wheel slip is likely to be prevented whilst the driver is in charge of operating the vehicle in response to the received controller output signal. Preventing a wheel slip occurring is better than responding to a wheel slip occurrence because the ground beneath the vehicle will not have been damaged.

In another embodiment the output signal will be transmitted to the vehicle control unit (VCU) such that the throttle pedal mapping may be modified to provide increased sensitivity. The driver then can use the throttle pedal in the normal manner, whilst the vehicle caters for the difference in the traction demand. This avoids the breaking of the ground beneath the vehicle whilst the driver does not need to be operating in a different manner to cater for the wheel slip event.

In yet another embodiment the output signal will be transmitted to the vehicle control unit (VCU) and to the engine controller and power train controller, such that the engine power is reduced and/or the transmission caters for the required difference gear is changed so that the breaking of the surface of the ground is prevented.

An alternative method of operating the controller 60, 160 is best described with reference to Figure 5. Torque values are monitored by the monitoring module 766 (Figure 7). When wheel slip is detected, ie sudden loss of torque at a wheel, the torque value immediately preceding the wheel slip is recorded as a maximum torque value 200. The maximum torque value 200 is recorded for a specific vehicle condition, also being continuously monitored by the monitoring module 66 (Figure 2). The vehicle condition in this case is distance as plotted on the X axis. Distance is the distance from a starting position of the vehicle and the distance may be substituted for current vehicle position provided as GPS co-ordinates. In this way, the maximum torque value for a vehicle condition, namely position, is determined. It is possible to record another vehicle condition, such as weather type, time of day, or vehicle speed associated with the maximum torque value. A more exhaustive list of potential vehicle conditions includes time, date, weather, position of the vehicle, dynamic or static state of the vehicle (moving or stationary), altitude of the vehicle, vehicle speed, and time of vehicle in current position. However, for illustrative purposes, this method of operating the vehicle condition is only described with reference to vehicle position.

Next, the ‘traction threshold’ is predicted. In determining the ‘traction threshold’, first an array of maximum torque values needs to be recorded for a wide range of positions. A regression model is then implemented to create a minimum prediction value 210 and a maximum prediction value 212. The difference in torque between the minimum prediction value 210 and the maximum prediction value 212 is a prediction band. The minimum and maximum prediction values 210, 212 of the prediction band are extrapolated to distances less than and greater than those positions which have been monitored previously. The ‘traction threshold’ 202 is then calculated so as to be lower than the minimum prediction value 212. The minimum prediction value 212 is not constant over a full range of position values since the maximum torque value 200 is sensitive to the distance. This is because the terrain type at one position will be different to the terrain type at another position. Terrain type impacts on the maximum torque value 200 since wheel slip will occur more easily on one terrain type than another.

When the vehicle 10 is being driven, the monitoring module 66 (Figure 2) continues to monitor torque values of each wheel from engine controller and/or brakes controller such as ABS controller 613. In another embodiment, monitored torque values are from each of the torque sensors 50, 52, 54, 56. The control module 72 (Figure 2) includes a comparator which compares the current torque value to the ‘traction threshold’. The current torque value is compared to the ‘traction threshold’ at the current position 214 of the vehicle. For a current torque value being greater than or equal to the ‘traction threshold’ the control module 72 outputs the signal indicative of the ‘traction demand’ 76 to a network such as CAN or Flexray or the communication module 80. The output signal will then be transmitted to HLDF unit. HLDF unit will signal to the HMI 64 to display the ‘traction demand’ as a warning, for instance, “stop accelerating”. In this way, a driver will understand that there is a potential issue and reduce the accelerator demand. In this way, wheel slip is likely to be prevented. Preventing a wheel slip occurring is better than responding to a wheel slip occurrence because the ground beneath the vehicle will not have been damaged.

A further alternative method of operating the controller 60 is best described with reference to Figure 6. This further alternative method builds upon either the first method of Figure 4 or the second method of Figure 5. In particular, the ‘traction threshold' 302 has already been predicted based on an array of maximum torque values 300.

Next, the vehicle 10 is operated as usual. The monitoring module 66 (Figure 2) continues to monitor further maximum torque values 300' experienced by the controller 60 in-use. Since the 'traction threshold' 302 is predicted so as to be less than the majority of maximum torque values 300, further maximum torque values 300' will only usually be recorded where other conditions, such as weather state, impact on the terrain at a given position. One scenario where a further maximum torque value 300' occurs would be where a vehicle comes to rest at a particular position. The vehicle is then left static for a period of time. The vehicle is then driven off from the rest at which point other conditions may have changed such as heavy rainfall while the vehicle was at rest. These further recorded maximum torque values 300' are used by the predicting module 70 (Figure 2) to update the 'traction threshold' 302'.

Further alternative methods and modifications to the system are considered to fall within the scope of the present invention without departing from the scope of protection as outlined by the subsequent claims.

CLAIMS

1. A controller for estimating traction of a vehicle, comprising;

a monitoring module that monitors wheel torque values;
a determining module to determine maximum torque values by obtaining and storing empirical data while driving on a surface, the maximum torque values being the wheel torque values immediately prior to wheel slip;
a predicting module that predicts a traction threshold based on the maximum torque values; and
a control module that outputs a signal indicative of the traction threshold.

2. A controller for a vehicle according to claim 1 wherein the predicting module predicting the traction threshold comprises calculating the probability of wheel slip using a parametric model of said empirical data.

3. A controller for a vehicle according to claim 1 or claim 2 wherein the control module outputs a signal indicative of traction demand in response to a current torque value exceeding the traction threshold.

4. A controller of any preceding claim wherein the monitoring module monitors one or more vehicle conditions, and the determining module determines one or more maximum torque values associated with the or each vehicle condition.

5. A controller of claim 4 wherein the vehicle condition is selected from the list of time, date, weather, distance the vehicle has travelled, position of the vehicle, dynamic or static state of the vehicle, altitude of the vehicle, vehicle speed, and duration of the vehicle being in a current position.

6. A controller of claim 4 or claim 5 wherein the predicting module predicts the traction threshold based on one or more maximum torque values corresponding to a predetermined range of the or each vehicle condition.

7. A controller of claim 6 wherein the predetermined range of the or each vehicle condition is determined based on the or each current vehicle condition.

8. A controller of any preceding claim wherein the predicting module updates the traction threshold in response to monitoring maximum torque values of the system, in-use.

9. A controller of any preceding claim wherein the traction threshold is based on a stochastic model of the maximum torque values.

10. A controller of claim 9 wherein the traction threshold is less than or equal to a predetermined percentage of maximum torque values.

11. A controller of any of claims 4 to 8 wherein the predicting module generates a prediction band based on a regression model, the prediction band having a minimum prediction value and a maximum prediction value for each condition, the traction threshold is arranged to be less than or equal to the minimum threshold value.

12. A controller of claim 11 wherein the regression model is arranged to extrapolate the prediction band to conditions outside of the range of conditions used to construct the regression model.

13. A controller of any preceding claim wherein the signal indicative of the traction threshold is transmitted to a Human Machine Interface and the feedback comprises one or more of: visual output, audible output and/or haptic output.

14. A controller of any preceding claim wherein the signal indicative of the traction threshold is transmitted to a vehicle control unit and the feedback comprises reduction in engine power and/or modification in the throttle pedal mapping.

15. A controller of any preceding claim wherein the controller transmits and/or receives data to and from other vehicles and/or a repository, the data

being selected from the list of torque, maximum torque value, and vehicle condition

16. A vehicle comprising the controller of any preceding claim.

17. A method of estimating traction of a vehicle, comprising:

monitoring torque values;

determining a maximum torque values by obtaining and storing empirical data while driving on a surface, the maximum torque values being the wheel torque values immediately prior to wheel slip;

predicting a traction threshold based on the maximum torque value; and

outputting a signal indicative of the traction threshold.

18. The method of claim 17 comprising:

predicting the traction threshold comprising calculating the probability of wheel slip using a parametric model of said empirical data.

19. The method of claim 17 or claim 18 comprising:

outputting a signal indicative of traction demand in response to a current torque value exceeding the traction threshold.

20. The method of any preceding claim comprising:

monitoring one or more vehicle conditions; and

determining one or more maximum torque values associated with the or each vehicle condition.

21. The method of any preceding claim comprising:

predicting the traction threshold based on one or more maximum torque values corresponding to a predetermined range of the or each vehicle condition.

22. The method of claim 21 wherein the predetermined range of the or each vehicle condition is determined based on the or each current vehicle condition.

23. The method of any of claims 17 to 22 comprising:

updating the traction threshold in response to monitoring maximum torque values of the system, in-use.

24. The method of any of claims 17 to 23 wherein predicting the traction threshold comprises calculating the traction threshold so as to be less than or equal to a predetermined percentage of maximum torque values.

25. The method of any of claims 17 to 24 comprising:

generating a prediction band based on a regression model, the prediction band having a minimum prediction value and a maximum prediction value for each condition; and

determining the traction threshold to be less than or equal to the minimum threshold value.

26. The method of claim 25 comprising:

extrapolating the prediction band to conditions outside of the range of conditions used to construct the regression model.

27. The method of any of claims 17 to 26 comprising sending and/or receiving data to/from another vehicle and/or a repository.

28. A controller as described substantially herein with reference to the accompanying figures.

29. A vehicle as described substantially herein with reference to the accompanying figures.

30. A method of estimating traction of a vehicle as described substantially herein with reference to the accompanying figures.

Application No:	GB1611808.5	**Examiner:**	Mr Kevin Hewitt
Claims searched:	1 to 30	**Date of search:**	8 January 2017

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	JP 2001355478 A (NISSAN MOTOR) See especially the WPI Abstract Accession Number 2001-111178; and all Figures.
A	-	US 2009/0076699 A1 (OSAKI et al.) See especially the Abstract; Figures 3 & 4; and all Claims.
A	-	EP 0434059 A1 (JAPAN ELECTRONIC CONTROL SYSTEMS) See especially the Abstract; and all Figures.
A	-	US 2016/0107634 A1 (HYUNDAI MOTOR) See especially the Abstract; and all Figures.

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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

B60T; B60W

The following online and other databases have been used in the preparation of this search report

WPI; EPODOC

International Classification:

Subclass	Subgroup	Valid From
B60W	0030/18	01/01/2012
B60W	0010/184	01/01/2012
B60W	0050/14	01/01/2012