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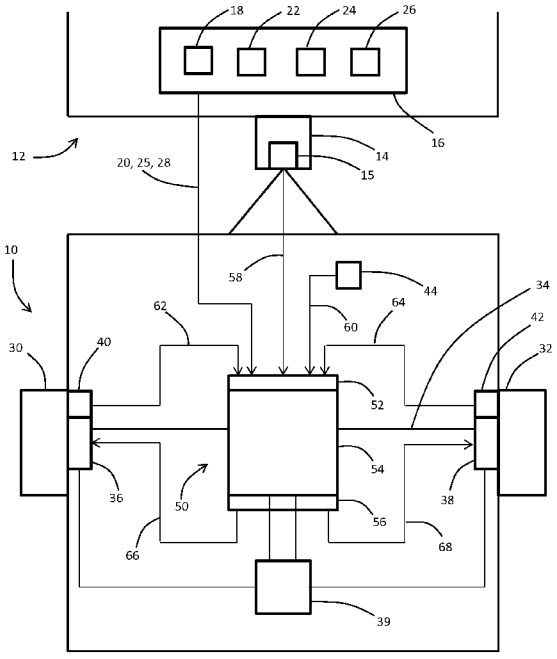


Figure 1

(57) Abstract: The present invention provides a system for use in a trailer towable by a vehicle. The trailer comprises an axle having two wheels and at least one electric motor coupled thereto and a coupling sensor configured to measure a coupling force exerted on the trailer by the vehicle. The system comprises receiving means configured to receive a vehicle braking signal, from at least one subsystem of the vehicle, indicative of a braking force to be applied to one or more wheels of the vehicle, and to receive coupling sensor output data from the coupling sensor. The system also includes processing means configured to determine, for each wheel of the at least one axle of the trailer, a trailer wheel brake force value based on the received vehicle braking signal and the received coupling sensor output data. The system also comprises control means configured to cause the at least one electric motor to apply a force to the wheel to which it is coupled in dependence on the determined trailer wheel brake force value.

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SYSTEM AND METHOD FOR A TRAILER TOWABLE BY A VEHICLE

TECHNICAL FIELD

The present disclosure relates to a system and method for a trailer towable by a vehicle. Aspects of the invention relate to a system, to a method, and to a trailer.

BACKGROUND

It is common for a vehicle having motive power means, such as an internal combustion engine, that provides motive power to its wheels to also provide motive power to the wheels of a trailer. This may be in the context of a car towing a caravan or horse box, for example.

Trailers may be provided with a mechanical over-run sensor that applies mechanically-coupled friction brakes of the trailer in response to braking, or a decrease in acceleration, of the vehicle. This assists the vehicle with reducing the speed of the trailer as appropriate. Such a mechanical over-run sensor operates only when the vehicle and trailer are moving in a forward direction. This means that a vehicle that is reversing, particularly downhill, or at rest on an uphill gradient, will receive no braking assistance from a trailer with a mechanical over-run sensor.

As the nature of the braking is mechanical as determined by the over-run trailer compared with the tow vehicle of the sensor, then the trailer will apply a destabilising force to the vehicle under braking. This can also result in swaying of the trailer behind the vehicle.

Also, as vehicles become lighter, with increasing numbers of vehicles being provided with motive power at least partially by means of a battery or other energy storage means, it may be the case that such vehicles lack sufficient power or traction to tow a trailer.

It is an aim of the present invention to address one or more disadvantages associated with the prior art.

SUMMARY OF THE INVENTION

According to an aspect of the present invention there is provided a system for use in a trailer towable by a vehicle. The trailer comprises an axle (44) having two wheels and at least one electric motor attached thereto, and a coupling sensor configured to measure a coupling force exerted on the trailer by the vehicle. The system comprises receiving means configured to receive a vehicle braking signal, from at least one subsystem of the vehicle, indicative of a braking force to be applied to one or more wheels of the vehicle, and to receive coupling sensor output data from the coupling sensor. The system also comprises processing means configured to determine, for each wheel of the at least one axle of the trailer, a trailer wheel brake force value based on the received vehicle braking signal and the received coupling sensor output data. The system also comprises control means configured to cause the at least one electric motor to apply a force to the or each wheel to which it is coupled in dependence on the determined trailer wheel brake force value.

The present invention is advantageous in that the determined trailer wheel brake force value is based on signals both from systems of the tow vehicle and from the coupling sensor. This means that the system is operable to control the electric motors in response to receiving the signal that the vehicle is braking, but the particular manner in which the system controls the electric motors, i.e. the level of force that the electric motors are commanded to apply to the trailer wheels, is calibrated or adjusted in dependence on the coupling sensor output. For example, for a given level of braking of the vehicle wheels as communicated to the trailer via the vehicle braking signal, the corresponding level of braking to be applied to the trailer wheels may differ in dependence on certain conditions, such as relative weights of the vehicle and trailer, the particulars of the terrain over which the vehicle and trailer are travelling, weather conditions, etc. Expressed differently, the coupling sensor output data is used to calibrate the proportionality of the force to be applied to the trailer wheels with respect to the received braking signal.

The processing means may comprise an electronic processor and the receiving means may be an electrical input of the electronic processor, the electrical input being for

receiving the vehicle braking signal and the coupling sensor output data. The system may comprise an electronic memory device electrically coupled to the electronic processor and having instructions stored therein, the processor being configured to access the memory device and execute the instructions stored therein such that it is operable to determine, for each wheel of the at least one axle of the trailer, a trailer wheel brake force value based on the received vehicle braking signal and the received coupling sensor output data.

The trailer may be coupled to the vehicle by means of a mechanical hitch joint, the coupling force being a force at the mechanical hitch joint.

The coupling force may include a magnitude component and a direction component.

The determined trailer wheel brake force value may be such that the force applied by the at least one electric motor is a tractive force.

The processing means may be configured to determine a force applied to the wheels of the vehicle per unit mass of the vehicle based on the received vehicle braking signal and/or the received coupling sensor output data.

The processing means may be configured to determine the trailer wheel brake force value based on the force applied to the wheels of the vehicle per unit mass of the vehicle.

The determined trailer wheel brake force value may be such that the force applied by the at least one electric motor to the wheels of the trailer per unit mass of the trailer is different from the force applied to the wheels of the vehicle per unit mass of the vehicle.

The force applied by the at least one electric motor to the wheels of the trailer per unit mass of the trailer may have a magnitude that is greater than the force applied to the wheels of the vehicle per unit mass of the vehicle.

The force applied to the vehicle may comprise the force applied to one or more wheels of the vehicle.

The at least one subsystem of the vehicle may include a vehicle braking system having a braking controller configured to cause operation of the brake means of the vehicle, and the receiving means nay be configured to receive the vehicle braking signal from the braking controller.

The at least one subsystem of the vehicle may include a vehicle stability control system having a stability controller and the receiving means may be configured to receive the vehicle braking signal from the stability controller.

The vehicle may include a vehicle steering system having a steering controller configured to steer one or more wheels of the vehicle, the receiving means may be configured to receive a vehicle steering signal from the steering controller, and the processing means may be configured to determine the trailer wheel brake force value based on the received vehicle steering signal.

The trailer may comprise a yaw sensor configured to measure a level of yaw of the trailer, the receiving means may be configured to receive yaw sensor output data from the yaw sensor, and the processing means may be configured to determine the trailer wheel brake force value based on the received yaw sensor output data. Alternatively, or in addition, the receiving means may be configured to receive yaw data from the vehicle, and the processing means may be configured to determine the trailer wheel brake force value based on the received yaw data from the vehicle.

The yaw sensor may be an accelerometer.

Each wheel of the at least one axle of the trailer may have an associated trailer wheel speed sensor configured to measure a wheel speed of the associated wheel, the receiving means may be configured to receive trailer wheel speed sensor output data from each of the trailer wheel speed sensors, and the processing means may be configured to determine the trailer wheel brake force value based on the received trailer wheel speed sensor output data.

If the wheel speed associated with the trailer wheel speed sensor output data of a first one of the trailer wheel speed sensors is less than the wheel speed associated with the trailer wheel speed sensor output data of a second one of the trailer wheel speed sensors by at least a predetermined value, then the control means may be configured

such that the force applied by the at least one electric motor coupled to the wheel associated with the first trailer wheel speed sensor is smaller than the force applied by the at least one electric motor coupled to the wheel associated with the second trailer wheel speed sensor.

The receiving means may be configured to receive a terrain signal indicative of at least one terrain feature of the terrain in the vicinity of the vehicle and/or trailer, and the processing means may be configured to determine the trailer wheel brake force value based on the received terrain signal.

The terrain signal may include an indication of a type of terrain in the vicinity of the vehicle and/or trailer.

The terrain signal may include a signal from a terrain adjustment subsystem of the vehicle, in which the setup of various components of the vehicle may be adjusted in dependence on the type of terrain over which the vehicle is travelling. For example, this may be a Terrain Response® subsystem.

The at least one terrain feature may include a level of friction of the terrain.

The processing means may be configured to determine the trailer wheel brake force value based on the received terrain signal only if the level of friction of the terrain is less than a predetermined friction threshold value.

The receiving means may be configured to receive a gradient signal indicative of a gradient of a surface in the vicinity of the vehicle and/or trailer, and the processing means may be configured to determine the trailer wheel brake force value based on the received gradient signal.

The processing means may be configured to determine the trailer wheel brake force value based on the received gradient signal only if the gradient of the surface is greater than a predetermined gradient threshold value.

The control means may be configured to cause the at least one electric motor to apply a first force to a first one of the wheels a second force to a second one of the wheels, the first force being different from the second force.

The first force may be a tractive force, and the second force may be a braking force.

The system may comprise the at least one electric motor coupled to the wheels of the axle of the trailer.

The system may comprise a first electric motor coupled to a first one of the wheels and a second electric motor coupled to a second one of the wheels.

The system may comprise energy storage means configured to supply electric power to the at least one electric motor.

The at least one electric motor may be configured to act as a generator to charge the energy storage means when the force applied to the respective wheel is a braking force.

According to another aspect of the present invention there is provided a system for use in a trailer towed by a vehicle. The trailer comprises an axle having two wheels and at least one electric motor coupled thereto, and a yaw sensor configured to measure a level of yaw of the trailer. The system comprises receiving means configured to receive yaw sensor output data from the yaw sensor. The system also comprises processing means configured to determine, for each wheel of the at least one axle of the trailer, a trailer wheel brake force value based on the yaw sensor output data. The system also comprises control means configured to cause the at least one electric motor to apply a force to the wheel to which it is coupled in dependence on the determined trailer wheel brake force value.

The trailer may comprise a coupling sensor configured to measure a coupling force exerted on the trailer by the vehicle, the receiving means may be configured to receive coupling sensor output data from the coupling sensor, and the processing means may be configured to determine the trailer wheel brake force value based on the received coupling sensor output data.

The control means may be configured to cause the at least one electric motor to apply a force to the wheel to which it is coupled in dependence on the determined trailer

wheel brake force value only if the received yaw sensor output data is indicative of the level of yaw of the trailer being greater than a predetermined level of yaw.

According to another aspect of the present invention there is provided a method for use in a trailer towed by a vehicle. The trailer comprises an axle having two wheels and at least one electric motor coupled thereto, and a coupling sensor configured to measure a coupling force exerted on the trailer by the vehicle. The method comprises receiving a vehicle braking signal, from at least one subsystem of the vehicle, indicative of a braking force to be applied to one or more wheels of the vehicle, and receiving coupling sensor output data from the coupling sensor. The method also comprises determining, for each wheel of the at least one axle of the trailer, a trailer wheel brake force value based on the received vehicle braking signal and the received coupling sensor output data. The method also comprises causing the at least one electric motor to apply a force to the wheel to which it is coupled in dependence on the determined trailer wheel brake force value.

According to another aspect of the present invention there is provided a trailer including an axle having two wheels and at least one electric motor coupled thereto, and the trailer comprises a system as described above.

According to another aspect of the present invention there is provided a non-transitory, computer-readable storage medium storing instructions thereon that when executed by one or more processors causes the one or more processors to carry out the method as described above.

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. 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 1 is a schematic plan view of a trailer towed by a vehicle, the trailer having a system according to an embodiment of an aspect of the invention, together with the inputs to, and outputs from, the system;

Figure 2 shows the steps carried out by the system of Figure 1 in a method according to an embodiment of an aspect of the invention; and,

Figures 3a to 3c show plots of yaw against time for both a vehicle and a trailer towed by the vehicle when an instability develops in three different cases, in particular: Figure 3a shows the trailer yaw and vehicle yaw in the case when no intervention is applied to the trailer to correct for the instability; Figure 3b shows the trailer yaw and vehicle yaw in the case when a so-called 'common brake application' is applied to the trailer; and, Figure 3c shows the trailer yaw and vehicle yaw for the trailer and vehicle of Figure 1, where the system of Figure 1 causes application of torque to wheels of the trailer via electric machines attached to the trailer wheels.

DETAILED DESCRIPTION

The present invention provides a system for a trailer towable by a vehicle via a hitch. Each of at least two wheels of the trailer has an electric motor attached thereto. The system is arranged to receive a braking signal from a subsystem of the vehicle, such as a vehicle braking subsystem, and a sensor measuring a force at the hitch. The system determines a braking force that should be applied to each wheel of the trailer in dependence on the received signals, and the system then commands each electric motor to apply the respective braking force to each respective wheel of the trailer.

Figure 1 shows a schematic plan view of a trailer 10 towed by a vehicle 12. The trailer 10 is connected to the vehicle 12 by means of a hitch coupling 14. The hitch coupling 14 is in the form of a mechanical hitch joint. The hitch 14 comprises a hitch or coupling

sensor 15 configured to measure a coupling force exerted on the trailer 10 by the vehicle 12. In particular, the coupling sensor 15 is arranged to measure both over-run and under-run of the trailer 10 on the tow vehicle 12. Over-run occurs when the trailer 10 applies a force in the forward direction to the vehicle 12, for example when the driver of the vehicle 12 applies the vehicle brakes when the trailer 10 and vehicle 12 are travelling in a forwards direction. Under-run occurs when the trailer 10 applies a force in the backward direction to the vehicle 12, for example when the driver of the vehicle 12 applies the vehicle brakes when the trailer 10 and vehicle 12 are reversing.

In the described embodiment, the vehicle 12 is a car having a plurality of on-board vehicle control subsystems 16. For example, the control subsystems 16 include a vehicle braking control system 18. The vehicle 12 may be fitted with a hydraulic brake circuit as is known in the art, whereby application of a brake pedal (not shown) of the vehicle 12 by the driver causes application of the vehicle's wheel brakes. The wheel brakes (not shown) can be drum brakes or disc brakes, for example. Application of the brakes may be controlled by a controller of the braking system 18. The vehicle braking control system 18 senses when the vehicle brake pedal is depressed by the driver and generates a vehicle braking signal 20 to be sent to the trailer 10, as will be described in greater detail below.

The vehicle control subsystems 16 also include an electronic stability control system (SCS) or anti-lock braking system 22. The SCS 22 monitors the rotational speed of each of the wheels of the vehicle 12 via individual wheel speed sensors. If the speed of one of the wheels is significantly less than the other wheels under braking of the vehicle 12 then the SCS 22, by means of a controller of the SCS 22, acts to reduce the braking pressure applied to that wheel so as to guard against locking of the vehicle wheels, which can result in skidding and a loss of control of the vehicle 12. The SCS 22 can modify or correct the vehicle braking signal 20 generated by the vehicle braking control system 18. This may correct the signal 20 to include information that the vehicle 12 is not slowing as much as demanded by the vehicle braking control system 18, for example when the vehicle is travelling on a relatively slippery surface. This could provide a useful explanation of there is a disparity between the demanded brake torque from the vehicle braking control system and the force sensed at the coupling sensor 15.

The vehicle control subsystems 16 also include a vehicle steering control system 24. The steering system 24 has a controller that takes inputs from a steering wheel (not shown) of the vehicle 12 and causes appropriate application of a steering angle for the vehicle 12. The steering system 24 can also generate a vehicle steering signal 25 and send the signal 25 to the trailer 10 when the steering controller causes a change of steering of the vehicle wheels.

The vehicle control subsystems 16 also include a vehicle Terrain Response® (TR) system 26. The TR system 26 has a controller operable to adjust the settings of various components and subsystems of the vehicle 12 in dependence on the type of terrain over which the vehicle 12 is travelling. These components and subsystems may include the vehicle suspension, vehicle ride height, anti-lock braking response time, transmission shift schedule, throttle response etc. The driver may input the type of terrain over which the vehicle 12 is travelling into the TR system 26, or the TR system 26 may determine the type of terrain automatically. The type of terrain over which the vehicle 12 is travelling may be communicated to the trailer 10 via a terrain signal 28. The types of terrain may include standard tarmac, mud-ruts, grass-gravel-snow, rock crawl and sand.

In the described embodiment, the trailer 10 has two wheels 30, 32, one on each side of the trailer 10, and connected by an axle 34. Each of the trailer wheels 30, 32 has an electric motor/generator or machines 36, 38 attached thereto. The electric machines 36, 38 are connected to the axle 34; however, they may be connected to the trailer 10 differently in different embodiments, for example via trailer wheel hub or frame connections. The electric machines 36, 38 are connected to, and powered by, a high-power, low-capacity battery 39 of the trailer 10. The electric machines 36, 38 may be used to apply regenerative braking or tractive torque to the wheels 30, 32 of the trailer 10. In the described embodiment, the electric machines are configured to freewheel during normal driving of the trailer 10 and vehicle 12. The battery 39 is a lithium-titanate rechargeable battery: this type of battery is advantageous because of its fast charging time compared with other types of lithium-ion batteries.

Each of the trailer wheels 30, 32 also has a wheel speed sensor 40, 42 which measures the rotational speed of the respective wheel 30, 32. The trailer also includes a yaw sensor 44 in the form of an accelerometer that is configured to detect the yaw, i.e. the angular velocity about a vertical axis, of the trailer 10.

The trailer 10 includes an electronic control unit or system (ECU) 50 configured to control the operation of the electric machines 36, 38. In particular, the ECU 50 comprises a receiver or receiving means 52, a processor or processing means 54, and a controller or control means 56.

The receiver 52 is configured to receive electronic signals from components and subsystems of both the trailer 10 and vehicle 12. Specifically, the receiver 52 is configured to receive the vehicle braking signal 20 and the vehicle terrain signal 28 from the vehicle 12. Also, the receiver 52 is configured to receive a coupling signal 58 from the coupling sensor 15 indicative of a force exerted on the trailer 12 by the vehicle 10. In addition, the receiver 52 is configured to receive a trailer yaw signal 60 from the trailer yaw sensor 44 indicative of a current level of yaw of the trailer 10. Furthermore, the receiver 52 is configured to receive trailer wheel speed sensor output data 62, 64 from the trailer wheel speed sensors 40, 42.

The processor 54 is configured to calculate a level of braking that is needed at each trailer wheel 30, 32 in dependence on the received signals 20, 28, 58, 60, 62, 64. In particular, the level of braking needed at each wheel 30, 32 is calculated so as to guard against instabilities developing in the trailer 10.

The controller 56 is configured to send control signals 66, 68 to the respective electric machines 36, 38 in the form of a level of force to be applied to the trailer wheels 30, 32 by means of the electric machines 36, 38 based on the determined level of braking that is needed.

Figure 2 shows a flow diagram outlining the steps of a method 70 undertaken by the processor 54. At step 72, the ECU 50 receives the braking signal 20. As mentioned above, when the driver of the vehicle 12 depresses the vehicle brake pedal the vehicle braking signal 20 is generated and sent to the trailer 10, the braking signal 20 being

received by the receiver 52 of the ECU 50. The braking signal 20 can be a binary signal, i.e. the braking signal 20 includes only information as to whether the vehicle pedal is being applied or not. Alternatively, the braking signal 20 can contain information about the degree to which the vehicle pedal is being applied.

The braking signal 20 may be based only on depression of the vehicle brake pedal. When the braking signal 20 is received, at step 74 the receiver 52 is configured to receive the coupling signal 58 from the coupling sensor 15. The coupling signal 58 includes information about the force exerted by the vehicle 12 on the trailer 10 not only in a forwards and backwards (longitudinal) direction, but also in a left and right direction, or sideways, (transverse) direction. In other words, the coupling signal 58 includes both magnitude and directional information.

At step 76 the processor 54 determines, for each of the electric machines 36, 38, a trailer wheel brake force value based on the received vehicle braking signal 20 and the received coupling sensor output data 58. The determined trailer wheel brake force value is indicative of the level of force that is to be applied by the electric machines 36, 38 to the respective trailer wheels 30, 32. In particular, the coupling signal 58 is used to calibrate the proportionality of the calculated trailer wheel brake force value with respect to the braking signal 20. In a normal braking scenario, the aim is that the electric machines 36, 38 will cause the trailer 10 to brake slightly harder than the vehicle 12. This ensures that the tow coupling at the hitch 14 will remain in tension, which in turn guards against a destabilising force being applied to the vehicle 12 by the trailer 10. Expressed differently, the braking response commanded by the ECU 50 will be proportional to the deceleration demand of the vehicle 12 derived from the vehicle braking signal 20, but with the proportionality constant slightly greater than one to cause the trailer 10 to brake slightly harder than the vehicle 12, thus maintaining tension at the hitch 14 and maintaining stability.

As the coupling signal 58 also includes information regarding transverse force at the hitch 14, the determined trailer wheel brake force value for one of the electric machines 36 may be different from the determined trailer wheel brake force value for one of the other electric machine 38. Note that the determined trailer wheel brake force values may indicate that both electric machines 36, 38 are to apply a braking force to

their respective wheels 30, 32, which can be of the same or different magnitude, or that one of the electric machines 36, 38 is to apply a braking force while the other electric machine 36, 38 is to apply a tractive force. The latter may be useful when the vehicle 12 and trailer 10 are going round a corner, in which case cornering can be enhanced by braking the inside trailer wheel 30, 32 and accelerating the outside trailer wheel 30, 32. Note that the vehicle steering signal 25 can also be used to determine the difference in force to be applied to the trailer wheels 30, 32 via the electric machines 36, 38.

The determined trailer wheel brake force values take into account the masses of the trailer 10 and vehicle 12, and particularly the difference between them. The masses of the trailer 10 and vehicle 12 may be predetermined, constant values, or the ECU 50 may receive information during a vehicle journey regarding these masses. The trailer wheel brake forces are calculated such that the overall braking force per unit mass of the trailer 10 is slightly greater than the overall braking force per unit mass of the vehicle 12, for the reasons given above.

The determined trailer wheel brake force values may also depend on the received yaw signal 60, which is received at step 78. The ECU 50 is arranged to detect instability in yaw based on the yaw signal 60: the trailer wheel brake force values are then calculated so that a correcting torque may be applied by one or both of the electric machines 36, 38 to the trailer wheels 30, 32. In particular, this is a scenario in which a differential force will be applied between the first and second electric machines 36, 38. Note that the ECU 50 can additionally receive a signal from the vehicle 12 indicative of a level of yaw of the vehicle 12, which can then be compared against the yaw signal 60 (which is indicative of trailer yaw) so as to determine whether the trailer 10 is developing an instability.

The determined trailer wheel brake force values may also depend on the received wheel speed signals 62, 64, which are received at step 80. The ECU 50 is arranged to detect when the trailer 10 is undergoing a slip event by monitoring the relative speeds of the wheels 30, 32. The ECU 50 also monitors the speeds of the trailer wheels 30, 32 relative to the speed of the vehicle wheels in case each of the trailer wheels 30, 32 are slipping. The trailer wheel brake force values are then calculated so that a correcting

torque may be applied by one or both of the electric machines 36, 38 to the trailer wheels 30, 32. Note that the braking signal 20 may also include information relating to intervention by the SCS 22 of the vehicle 12, and this can also be used to determine the force to be applied by one or both of the electric machines 36, 38 so as to correct for a slip event. In this way, the ECU 50 includes trailer wheel 30, 32 anti-lock functionality.

When correcting for trailer instability, it is likely that one of the electric machines 36, 38 will be commanded to apply a tractive (positive) torque, while the other of the electric machines 36, 38 will be commanded to apply a braking (negative) torque. This combination means that the electric motors 36, 38 will not dissipate significant amounts of energy, which in turn means that they may be operated indefinitely without being at risk of overheating.

The determined trailer wheel brake force values may also depend on the received TR signal 28, which is received at step 82. The type of terrain over which the vehicle 12 and trailer 10 are travelling may influence the magnitude of the force to be applied to the trailer wheels 30, 32, and so the trailer wheel brake force values are calculated accordingly. For example, if the vehicle 12 and trailer 10 are travelling over a low-friction surface then it may be preferable to reduce the magnitude of the force that is applied by the electric motors 36, 38 so as to reduce the chance of causing slip between the wheels 30, 32 and the terrain surface.

As mentioned above, the determined trailer wheel brake force values are indicative of the force that is to be applied to the trailer wheels 30, 32 by the electric machines 36, 38. At step 84 the controller 56 is configured to cause each electric motor 36, 38 to apply a force to the wheel 30, 32 to which it is attached in dependence on the respective determined trailer wheel brake force value. This is achieved via control signals 66, 68 sent by the controller 56 to the electric machines 36, 38.

The effectiveness of utilising the electric motors 36, 38 to correct for an unstable trailer is highlighted with reference to Figures 3a to 3c. Figure 3a shows a plot of yaw against time for both the vehicle 12 and the trailer 10 when there is no intervention on the path of the trailer 10. In particular, it is seen that the magnitude of the trailer yaw 90 is

slightly greater than the magnitude of the vehicle yaw 92, and also that the peaks of the trailer and vehicle yaw 90, 92 are out of phase, with the peaks of the trailer yaw 90 being slightly delayed with those of the vehicle 12. It is also apparent that the magnitude of the trailer and vehicle yaw 90, 92 increases over time, and so the trailer 10 and vehicle 12 become more unstable over time.

Figure 3b shows a plot of yaw against time for both the vehicle 12 and the trailer 10, this time in the case of a so-called 'common brake application'. In this case, the trailer braking consists of a mechanical over-run sensor which drives mechanically coupled friction brakes. The nature of the braking is purely mechanical and determined by the over-run of the sensor. This means that the trailer will always apply a destabilising force to the tow vehicle under braking. As a purely mechanical system, the common brake application cannot include anti-lock functionality. The common brake application system used to provide the data shown in Figure 3b includes some degree of stability control. In particular, weaving and snaking is monitored to detect instability, and the brakes are applied intermittently to straighten the combination of the vehicle and trailer and reducing the speed below a critical value. However, this system can only be effective against short-term perturbations because of heat build-up in the brakes. Also, it will not correct for significant instability. With reference to Figure 3b, it is seen that the peaks of the trailer and vehicle yaw 90, 92 are out of phase, albeit to a lesser extent than in the case shown in Figure 3a. In addition, the magnitude of the trailer yaw 90 first increases to significantly beyond that of the vehicle before being reduced by the common brake application.

Figure 3c shows a plot of yaw against time for both the vehicle 12 and the trailer 10 when the electric motors 36, 38 are used to correct for trailer instability in accordance with the differential application of the presently described embodiment. In particular, it is seen that the peaks of the trailer yaw 90 are out of phase with the peaks of the vehicle yaw 92 to a far lesser extent than in the cases shown in Figures 3a and 3b. In addition, increases in the magnitude of the peaks of the trailer yaw 90 are suppressed to a far greater extent compared with the cases shown in Figures 3a and 3b. Also, stability control in this case is achieved by applying a positive torque to the electric motor 36, 38 on one side of the trailer 10 and a negative torque to the electric motor

36, 38 on the other side of the trailer 10. This means that, unlike for the system of Figure 3b, this system can be operated continuously without overheating.

Note that the present embodiment in which the electric motors 36, 38 are used to provide braking torque to the trailer wheels 30, 32 to provide braking assistance and increased stability to the combination of the trailer 10 and vehicle 12 can be used in conjunction with operating the electric motors 36, 38 to provide drive torque to the trailer wheels 30, 32 to provide pull away assist to the vehicle 12. In such a case, utilising the electric motors 36, 38 to provide drive torque will deplete the stored charge of the battery 39, while utilising the electric motors 36, 38 to provide regenerative braking to the trailer wheels 30, 32 will replenish the stored charge of the battery 39.

Many modifications may be made to the above examples without departing from the scope of the present invention as defined in the accompanying claims.

In the described embodiment, the trailer 10 has a single axle 34; however, in different embodiments the trailer 10 may have a plurality of axles connecting pairs of trailer wheels.

In the described embodiment, the electric machines 36, 38 are powered by the battery 39; however, other energy storage means, such as one or many capacitors, supercapacitor or ultracapacitors, may be used in combination with or instead of the battery.

In the described embodiment, the ECU 50 is operable to cause the electric machines 36, 38 to apply a force to the trailer wheels 30, 32 in response to the vehicle braking signal 20; however, in different embodiments this need not be the case. For example, the ECU 50 may be operable to cause the electric machines 36, 38 to apply a force to the trailer wheels 30, 32 in response to the trailer yaw signal 60. In particular, if the trailer yaw signal 60 indicates that the current level of yaw of the trailer 10 is greater than a predetermined level of yaw then the processor 54 may be operable to determine the trailer wheel brake force value for each trailer wheel 30, 32 based on the trailer yaw signal 60 only. Alternatively, the coupling signal 58 may also be taken into account in the determination of the trailer wheel brake force values. Further

alternatively, other signals such as the TR signal 28 and wheel speed signals 62, 64. In each of these cases, the trailer wheel brake force values are determined so as to correct for the development of trailer instability in yaw and, specifically, differential forces can be applied by the electric machines 36, 38 to the trailer wheels 30, 32 so as to dampen the instability.

CLAIMS

1. A system for use in a trailer towable by a vehicle, the trailer comprising an axle having two wheels and at least one electric motor coupled thereto, and a coupling sensor configured to measure a coupling force exerted on the trailer by the vehicle, the system comprising:

receiving means configured to receive a vehicle braking signal, from at least one subsystem of the vehicle, indicative of a braking force to be applied to the vehicle, and to receive coupling sensor output data from the coupling sensor;

processing means configured to determine, for each wheel of the axle of the trailer, a trailer wheel brake force value based on the received vehicle braking signal and the received coupling sensor output data; and,

control means configured to cause the at least one electric motor to apply a force to the or each wheel to which it is coupled in dependence on the determined trailer wheel brake force value.

2. A system according to Claim 1, the trailer being coupled to the vehicle by means of a mechanical hitch joint, the coupling force being a force at the mechanical hitch joint.

3. A system according to Claim 1 or Claim 2, the coupling force including a magnitude component and a direction component.

4. A system according to any previous claim, the determined trailer wheel brake force value being such that the force applied by the at least one electric motor to the or each wheel is a tractive force.

5. A system according to any previous claim, the processing means being configured to determine a force applied to the vehicle per unit mass of the vehicle based on the received vehicle braking signal and/or the received coupling sensor output data.

6. A system according to Claim 5, the processing means being configured to determine the trailer wheel brake force value based on the force applied to the vehicle per unit mass of the vehicle.

7. A system according to Claim 6, the determined trailer wheel brake force value being such that the force applied by the at least one electric motor to the or each wheel of the trailer per unit mass of the trailer is different from the force applied to the vehicle per unit mass of the vehicle.

8. A system according to Claim 7, the force applied by the at least one electric motor to the wheels of the trailer per unit mass of the trailer having a magnitude that is greater than the force applied to the vehicle per unit mass of the vehicle.

9. A system according to any of Claims 5 to 8, wherein the force applied to the vehicle comprises the force applied to one or more wheels of the vehicle.

10. A system according to any previous claim, the at least one subsystem of the vehicle including a vehicle braking system having a braking controller configured to cause operation of a brake means of the vehicle, and the receiving means being configured to receive the vehicle braking signal from the braking controller.

11. A system according to any previous claim, the at least one subsystem of the vehicle including a vehicle stability control system having a stability controller and the receiving means being configured to receive the vehicle braking signal from the stability controller.

12. A system according to any previous claim, the vehicle including a vehicle steering system having a steering controller configured to steer one or more wheels of the vehicle, the receiving means being configured to receive a vehicle steering signal from the steering controller, and the processing means being configured to determine the trailer wheel brake force value based on the received vehicle steering signal.

13. A system according to any previous claim, the trailer comprising a yaw sensor configured to measure a level of yaw of the trailer, the receiving means being configured to receive yaw sensor output data from the yaw sensor, and the processing means being configured to determine the trailer wheel brake force value in dependence on the received yaw sensor output data.

14. A system according to Claim 13, the determined trailer wheel brake force value being such that the force applied by the at least one electric motor to the or each wheel causes a reduction in the level of yaw of the trailer.

15. A system according to Claim 13 or Claim 14, wherein the yaw sensor is an accelerometer.

16. A system according to any previous claim, each wheel of the axle of the trailer having an associated trailer wheel speed sensor configured to measure a wheel speed of the associated wheel, the receiving means being configured to receive trailer wheel speed sensor output data from each of the trailer wheel speed sensors, and the processing means being configured to determine the trailer wheel brake force value based on the received trailer wheel speed sensor output data.

17. A system according to Claim 16, wherein if the wheel speed associated with the trailer wheel speed sensor output data of a first one of the trailer wheel speed sensors is less than the wheel speed associated with the trailer wheel speed sensor output data of a second one of the trailer wheel speed sensors by at least a predetermined value, then the control means is configured such that the force applied by the electric motor to the wheel associated with the first trailer wheel speed sensor is smaller than the force applied by the electric motor to the wheel associated with the second trailer wheel speed sensor.

18. A system according to Claim 16 or Claim 17, the receiving means being configured to receive a vehicle speed signal indicative of a speed of the vehicle, and the processing means being configured to determine the trailer

wheel brake force value based on a comparison between the received trailer wheel speed sensor output data and the received vehicle speed signal.

19. A system according to any previous claim, the receiving means being configured to receive a terrain signal indicative of at least one terrain feature of the terrain in the vicinity of the vehicle and/or trailer, the processing means being configured to determine the trailer wheel brake force value based on the received terrain signal.

20. A system according to Claim 19, the terrain signal including an indication of a type of terrain in the vicinity of the vehicle and/or trailer.

21. A system according to Claim 20, the terrain signal including a signal from a terrain adjustment subsystem of the vehicle, optionally a Terrain Response® subsystem.

22. A system according to any of Claims 19 to 21, the at least one terrain feature including a level of friction of the terrain.

23. A system according to Claim 22, the processing means being configured to determine the trailer wheel brake force value based on the received terrain signal only if the level of friction of the terrain is less than a predetermined friction threshold value.

24. A system according to any previous claim, the receiving means being configured to receive a gradient signal indicative of a gradient of a surface in the vicinity of the vehicle and/or trailer, the processing means being configured to determine the trailer wheel brake force value based on the received gradient signal.

25. A system according to Claim 24, the processing means being configured to determine the trailer wheel brake force value based on the received gradient signal only if the gradient of the surface is greater than a predetermined gradient threshold value.

26. A system according to any previous claim, the control means being configured to cause the at least one electric motor to apply a first force to a first one of the wheels and a second force to a second one of the wheels, the first force being different from the second force.

27. A system according to Claim 26, the first force being a tractive force, and the second force being a braking force.

28. A system according to any previous claim, the system comprising the at least one electric motor coupled to the wheels of the axle of the trailer.

29. A system according to Claim 28, the system comprising a first electric motor coupled to a first one of the wheels and a second electric motor coupled to a second one of the wheels.

30. A system according to any previous claim, comprising energy storage means configured to supply electric power to the electric motors.

31. A system according to Claim 30 when dependent on Claim 28, the at least one electric motor being configured to act as a generator to charge the energy storage means when the force applied to the respective wheel is a braking force.

32. A system for use in a trailer towable by a vehicle, the trailer comprising an axle having two wheels and at least one electric motor coupled thereto, the system comprising:

receiving means configured to receive yaw sensor output data from a yaw sensor of the trailer or the vehicle configured to measure a level of yaw of the trailer or the vehicle, respectively;

processing means configured to determine, for each wheel of the axle of the trailer, a trailer wheel brake force value based on the yaw sensor output data; and,

control means configured to cause each of the electric motors to apply a force to the wheel to which it is coupled in dependence on the determined trailer wheel brake force value.

33. A system according to Claim 32, the trailer comprising a coupling sensor configured to measure a coupling force exerted on the trailer by the vehicle, the receiving means being configured to receive coupling sensor output data from the coupling sensor, and the processing means being configured to determine the trailer wheel brake force value based on the received coupling sensor output data.

34. A system according to Claim 32 or Claim 33, the control means being configured to cause the at least one electric motor to apply a force to the wheel to which it is coupled in dependence on the determined trailer wheel brake force value only if the received yaw sensor output data is indicative of a level of yaw of the trailer being greater than a predetermined level of yaw.

35. A method for use in a trailer towable by a vehicle, the trailer comprising an axle having two wheels and at least one electric motor attached thereto, and the trailer comprising a coupling sensor configured to measure a coupling force exerted on the trailer by the vehicle, the method comprising:

receiving a vehicle braking signal, from at least one subsystem of the vehicle, indicative of a braking force to be applied to one or more wheels of the vehicle, and receiving coupling sensor output data from the coupling sensor;

determining, for each wheel of the axle of the trailer, a trailer wheel brake force value based on the received vehicle braking signal and the received coupling sensor output data; and,

causing each of the electric motors to apply a force to the wheel to which it is coupled in dependence on the determined trailer wheel brake force value.

36. A trailer for being towed by a vehicle, the trailer having an axle having two wheels and at least one electric motor coupled thereto, and the trailer comprising a system according to any of Claims 1 to 34.

37. A trailer according to Claim 36, the trailer having a first electric motor coupled to a first one of the wheels and a second electric motor coupled to a second one of the wheels.

38. A trailer according to Claim 36 or Claim 37, the trailer having a further axle having two further wheels and at least one further electric motor coupled thereto.

39. A non-transitory, computer-readable storage medium storing instructions thereon that when executed by one or more processors causes the one or more processors to carry out the method of Claim 35.

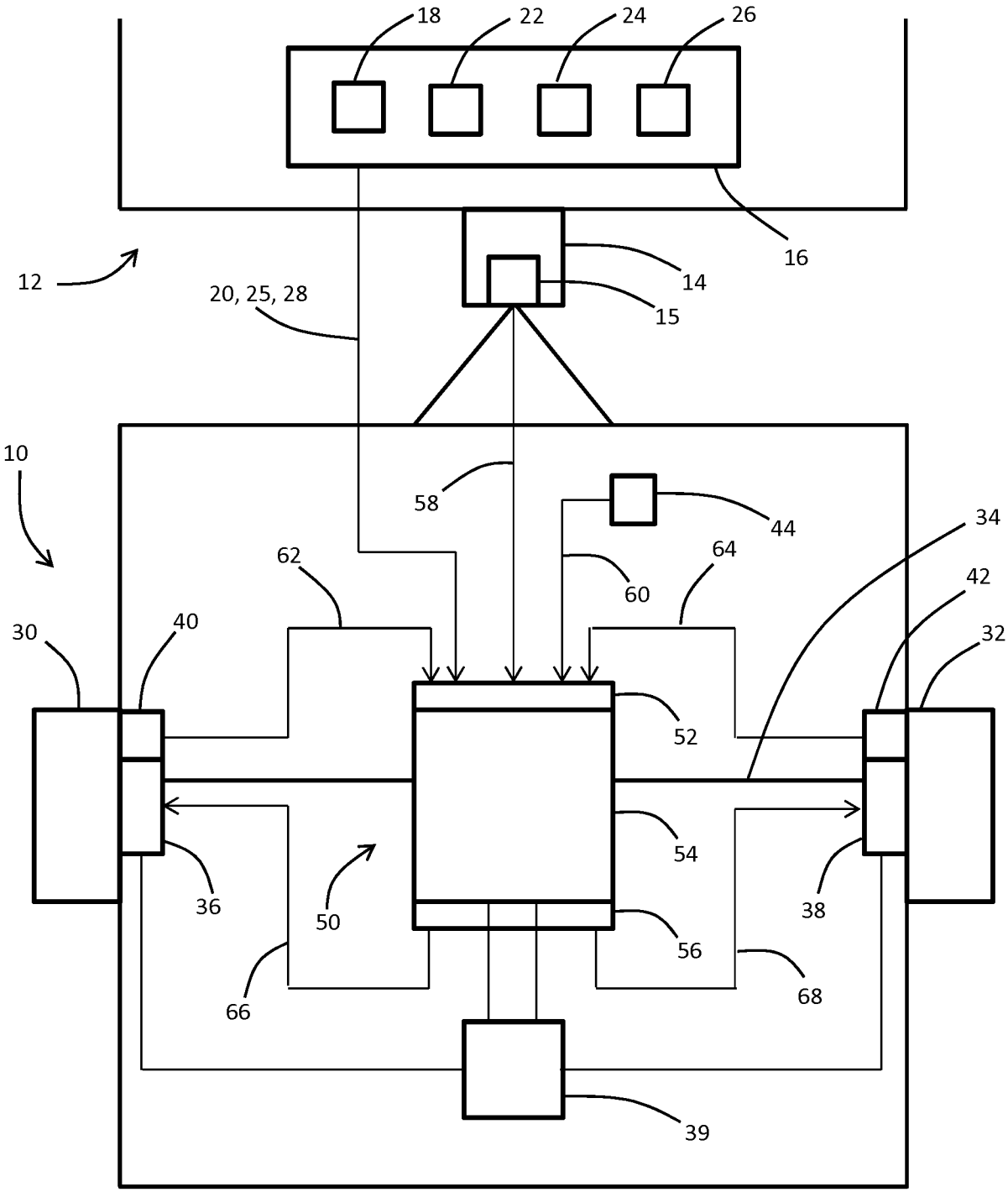

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66
68
39

Figure 1

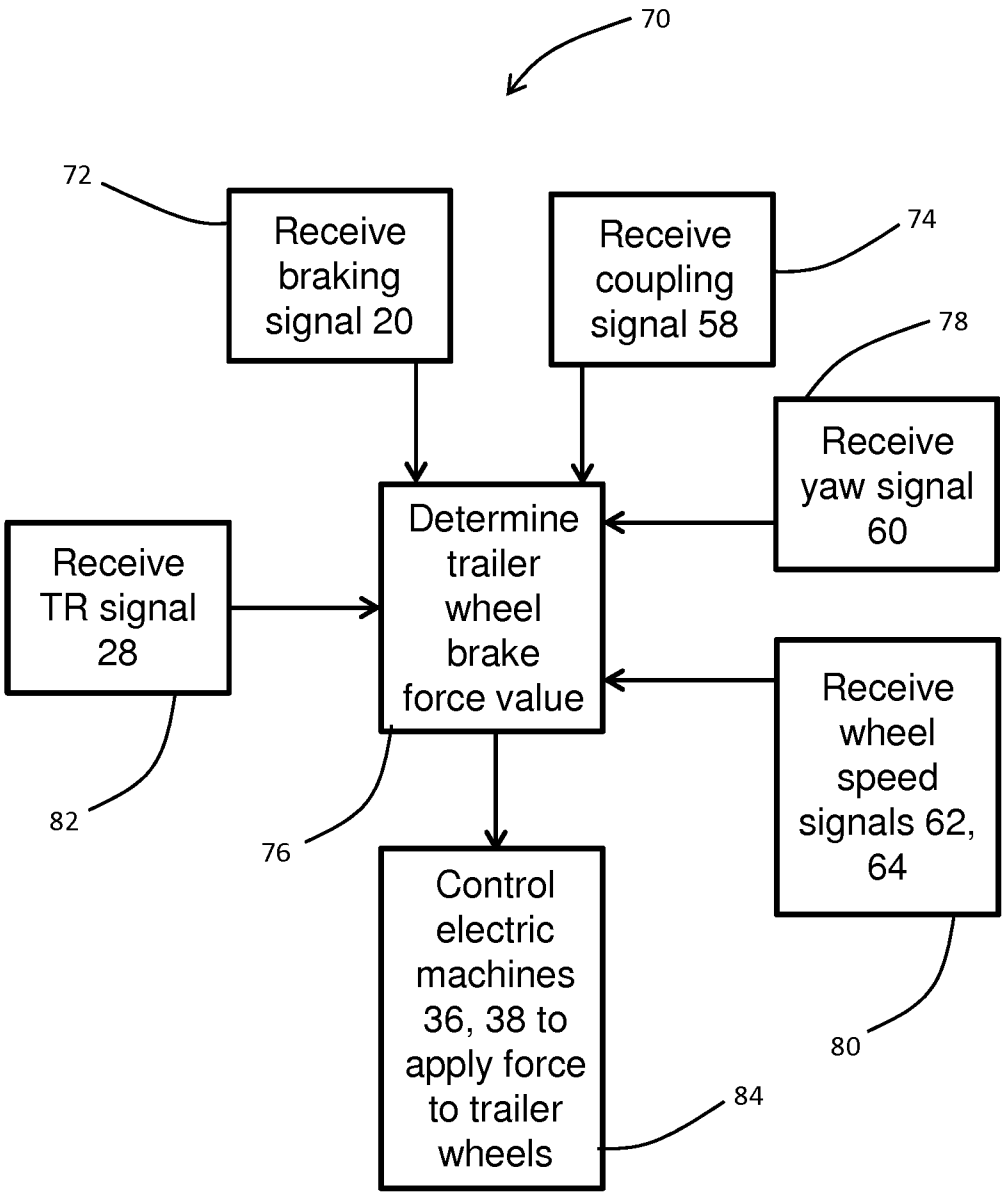

70
72
Receive braking signal 20
Receive coupling signal 58
74
78
Receive yaw signal 60
Determine trailer wheel brake force value
Receive TR signal 28
82
76
Receive wheel speed signals 62, 64
80
Control electric machines 36, 38 to apply force to trailer wheels
84

Figure 2

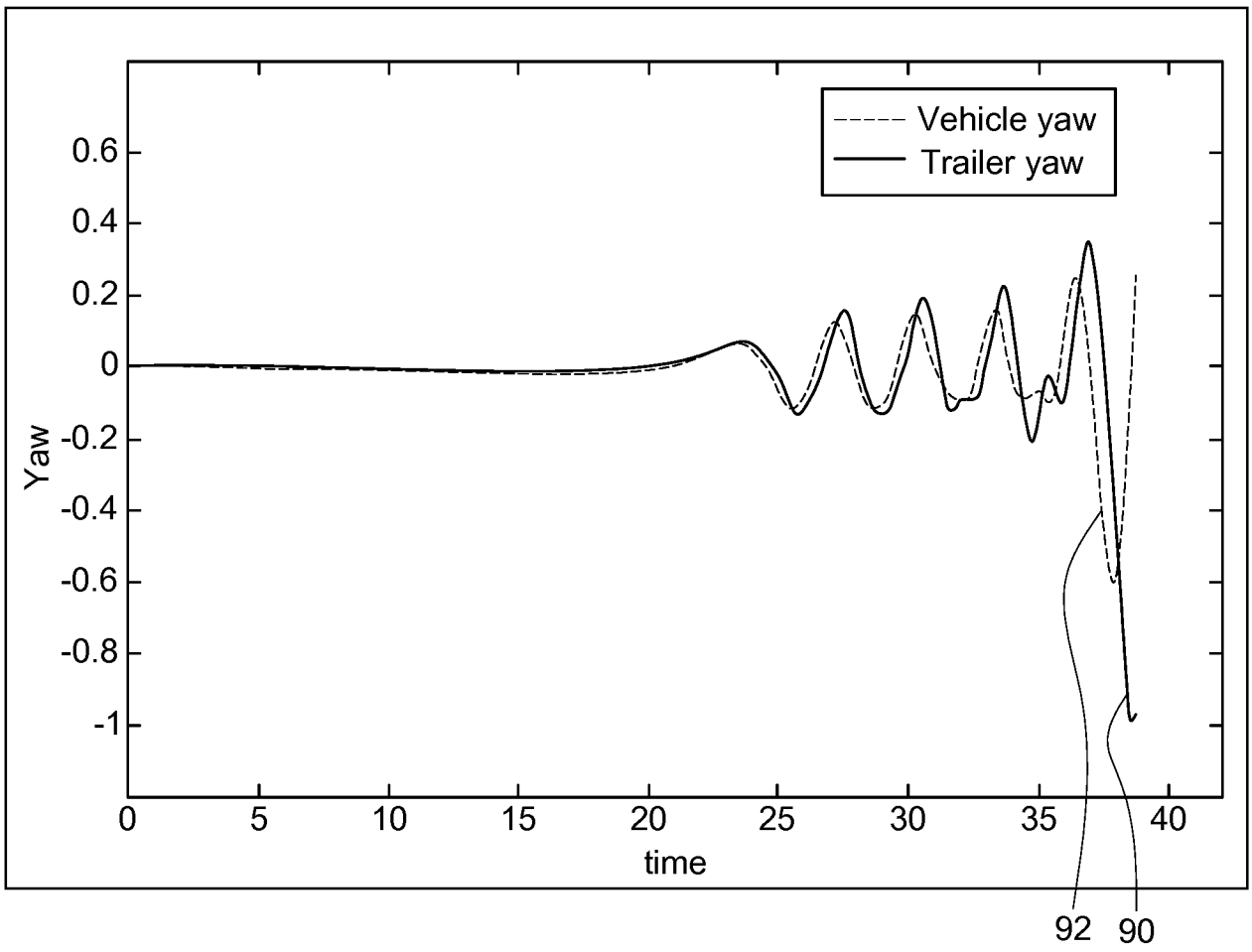

Vehicle yaw
Trailer yaw
Yaw
time
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
5
10
15
20
25
30
35
40
92
90

FIG. 3a

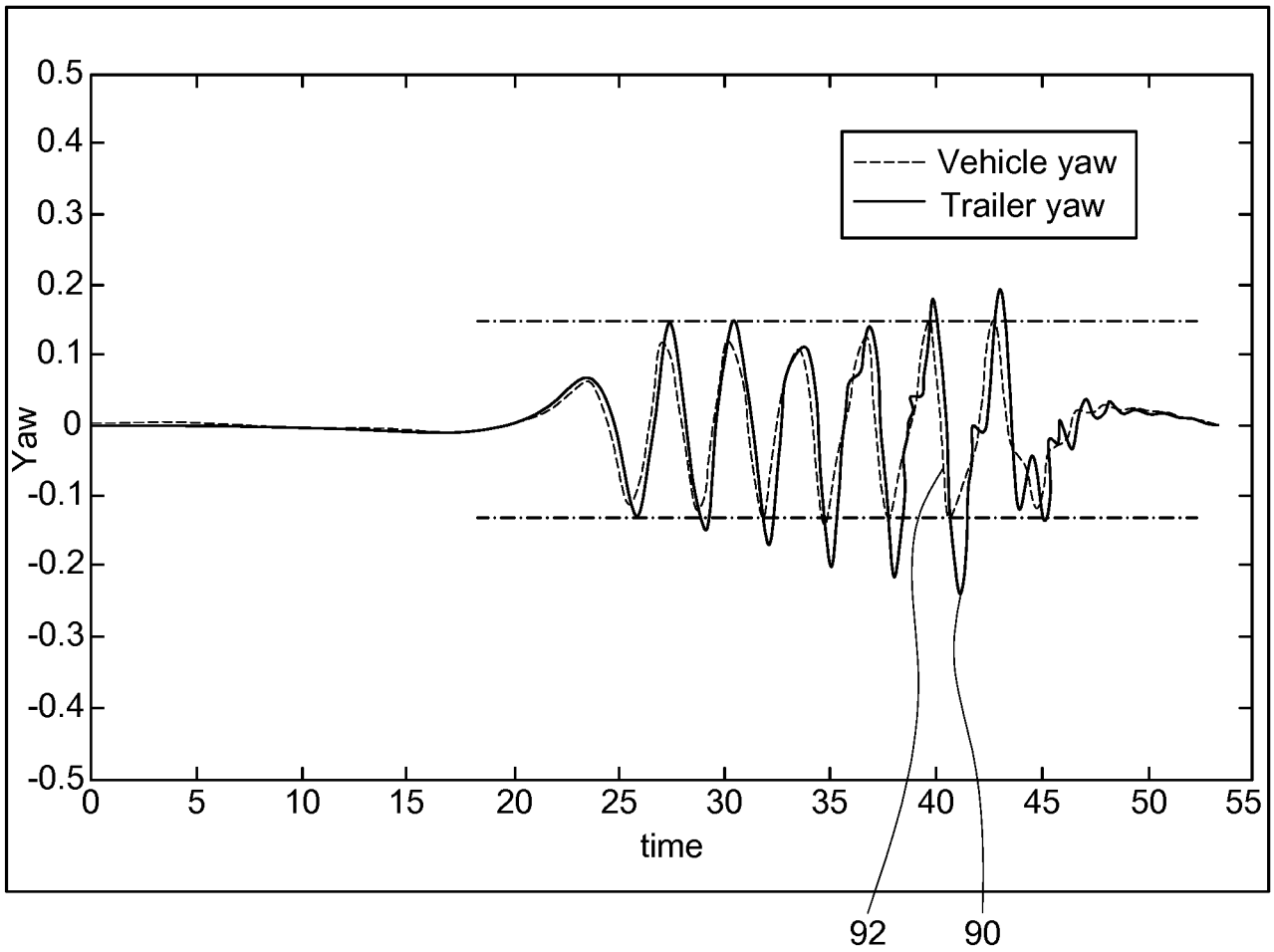

0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Yaw
0
5
10
15
20
25
30
35
40
45
50
55
time
Vehicle yaw
Trailer yaw
92
90

FIG. 3b

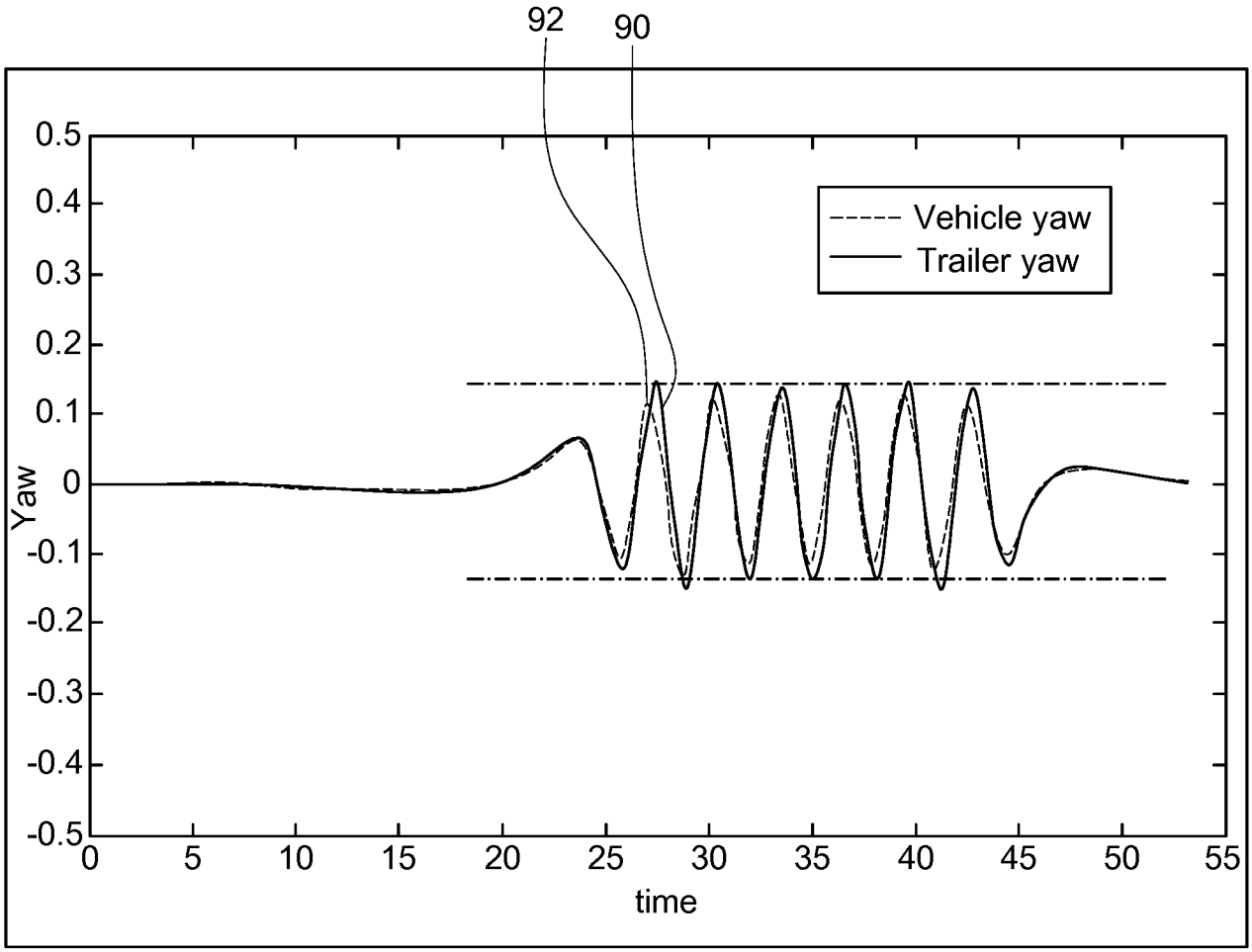

92
90
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Yaw
0
5
10
15
20
25
30
35
40
45
50
55
time
Vehicle yaw
Trailer yaw

FIG. 3c

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/074507

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60W10/18 B62D59/04 B60L7/10 B60T8/00 B60W10/26
B60W20/00 B60W30/18
ADD.
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)
B60W B62D B60L B60T

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)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/193795 A1 (FORSYTH JOHN R [US]) 23 August 2007 (2007-08-23)	1-4, 10-18, 24-32, 35-37
Y	paragraphs [0009], [0010], [0019] - [0027], [0031]; claims 1-8; figures 1,2	5-9, 19-23, 33,34,38

X	US 8 365 849 B2 (BARTEL BRIAN DANIEL [US]) 5 February 2013 (2013-02-05)	1-4, 10-18, 26-37
Y	column 2, line 57 - column 4, line 6; claim 1 column 5, line 19 - column 7, line 12 column 8, line 4 - column 8, line 46	5-9, 19-23

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"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	Date of mailing of the international search report
5 November 2018	16/11/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Vena, Gianpiero

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/074507

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008/174174 A1 (BURNS JAMES S [US] ET AL) 24 July 2008 (2008-07-24) paragraphs [0031] - [0033], [0055]; claims 1-8; figures 1,2	5-9,33, 34,38
Y	US 2008/169144 A1 (DEGRAVE KEN [US] ET AL) 17 July 2008 (2008-07-17) paragraphs [0032] - [0034]	19-23
A	DE 10 2010 062979 A1 (BOSCH GMBH ROBERT [DE]) 14 June 2012 (2012-06-14) the whole document	1-39

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2018/074507

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007193795 A1	23-08-2007	NONE	
US 8365849 B2	05-02-2013	NONE	
US 2008174174 A1	24-07-2008	NONE	
US 2008169144 A1	17-07-2008	US 2008169144 A1	17-07-2008
		WO 2008086087 A2	17-07-2008
DE 102010062979 A1	14-06-2012	NONE	