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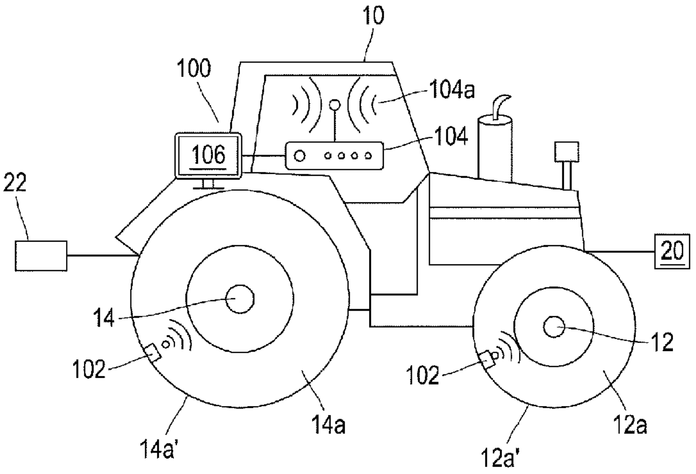
(54) Title: SYSTEM FOR PROVIDING WEIGHT BALANCE BETWEEN FRONT AND REAR AXLES OF AN AGRICULTURAL VEHICLE

[Fig. 1]



(57) **Abstract:** The invention is directed to a system (100) for providing weight balance for an agricultural vehicle (10) having front and rear axles (12, 14) that rotationally support respective front and rear tires (12a, 14a), the system including: - at least one sensor (102) installed along an interior surface of each tire and capable of transmitting data representative of each tire's operational parameters; - at least one receiver (104) receiving the data transmitted by each sensor; and - at least one user interface (106) in communication with the receiver and displaying weight balance information corresponding to signals received from the sensors and treated by the receiver; characterized in that the receiver includes at least one processor in communication with at least one memory configured to permit at least one of selection and adjustment of at least one of a plurality of stored weight balancing options for the agricultural vehicle.

WO 2024/089151 A1

[Continued on next page]

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Description

Title : SYSTEM FOR PROVIDING WEIGHT BALANCE BETWEEN FRONT AND REAR AXLES OF AN AGRICULTURAL VEHICLE

Technical Domain

The disclosed invention is directed to a system for optimizing the weight balance of a vehicle that is employed for agricultural and related applications. In particular, the invention is directed to a system and process implemented by the disclosed system for optimizing the weight balance between front and rear axles of such a vehicle on the basis of acquiring the load applied to one or more tires mounted on the vehicle.

Background

In the agricultural domain, it is well understood that weight balance (or “ballasting”) is critical to the optimization of equipment operation, soil working and cost savings (as used herein, the terms “weight balance” and “ballast” are used interchangeably, and the terms “weight balancing” and “ballasting” are used interchangeably). Adding weight to an agricultural vehicle (for example, a tractor or a polyvalent vehicle also having non-agricultural applications) compensates for horsepower imbalances that affect the vehicle’s capacity to transfer horsepower from the engine to the ground. Because traction capacity is directly related to the vehicle’s weight, weight balancing increase’s the vehicle’s grip, thereby reducing slipping and its associated soil damage. Weight balancing can also be employed to adjust the vehicle’s center of gravity and thereby improve its stability, an attribute that is particularly important on sloping surfaces (e.g., vineyards and other agricultural domains). Accurate weight balancing of an agricultural vehicle, either with or without an attached implement, requires forethought as to the vehicle’s main purpose. For instance, agricultural vehicles such as tractors may be operated alone or in combination with one or more implements for which the operator requires information about weight, center of gravity and their effects on the tractor’s axle load distribution. Examples of commonly employed implements include, but are not limited to, box blades, mowers, front end loaders, rear blades, plows, post hole diggers, back hoes, snow blowers, land planes, rotary tillers, pallet forks and spreaders. Thus, the set-up of both vehicle and implement requires a substantial temporal and fiscal upfront investment that precludes opportunities for later modification.

The control of rear-wheel slip is a common approach to vehicle set-up that attempts to manage tire spin and wear, fuel consumption and ground compaction. While elimination of tire slippage is unlikely, it is well understood that it can be minimized to a recommended slippage rate (for example, 10–15% for two-wheel-drive vehicles and 8–12% for four-wheel-drive vehicles). Considering the importance of transferring horsepower from the engine to the ground, it is also understood that weight balancing become increasingly significant with the introduction of larger tires for agricultural vehicles. Accomplishing such horsepower transfer typically invokes the adjustment of weight on the front and/or rear axle of an agricultural vehicle such as a tractor. Various solutions have been proposed for effecting proper weight balance of a tractor (see, for example, US Patent No. 10,676,141 directed to a method and device for presenting a ballasting proposal for an agricultural tractor having an implement pulled thereby on the basis of an axle load to be maintained on each axle of the tractor and a target tractive force for the implement).

The use of a central tire inflation systems (or “CTIS”) is another common approach to vehicle set-up that enables control of the air pressure in each tire of an agricultural vehicle’s tires. It is well understood that management of tire inflation pressure can attenuate compaction concerns so as to improve vehicle performance on various surfaces (including, but not limited to, soil, rocky terrain, grassy terrain, sandy terrain, road surfaces and other surface types). Such concerns are weighed against the need to minimize wheel slip, particularly in view of the negative impacts of heavy tillage and planting upon the vehicle and any implement pulled thereby. Among the various solutions proposed by the prior art, US Patent No. 9,078,391 is directed to a control system for a tractor. The control system displays an appropriate tire pressure corresponding to the current pull force applied to an implement pulled by the tractor, the current wheel load and the current tractor ground speed. In this manner, the operator is alerted of any recommended weight adjustment relative to the axles of the tractor.

Recent developments in connected tire assemblies that measure their physical quantities by means of embedded sensors, permitting the development of services related to the monitoring of the state of such assemblies. General measured quantities (for example, the inflation pressure of a mounted tire assembly and/or the temperature of this mounted assembly) are not very sensitive to the measurement noises generated by the rotation of the mounted assembly on a randomly rough ground because these general quantities vary little during such rotation. Finer quantities, however, are quite sensitive to the physical phenomena related to the rotation of the mounted assembly. In addition, the mounted assembly is subject to external forces (for example, static load or inflation pressure) that can influence the fine quantities for which a measurement is desired (see, for example, Applicant's pending application no. PCT/FR2022/051540 directed to measurement signals delivered by measurement means on board the mounted assembly of a vehicle during driving in order to determine the static load applied to the mounted assembly).

Thus, the disclosed invention is directed to a system that accesses both "static" and "dynamic" weight balancing data (as used herein, "static" weight balance references the weight of an immobile (e.g., "parked") agricultural vehicle having at least one implement mounted thereon, and "dynamic" weight balance references the weight of an agricultural vehicle in operation having at least one implement mounted thereon). Such data access simplifies the complex determination of weight balancing that often requires extensive operator knowledge of the many parameters influencing vehicle operation.

Summary of the invention

The invention is directed to a system for providing weight balance for an agricultural vehicle having a front axle that rotationally supports at least one front tire and a rear axle that rotationally supports at least one rear tire, with each tire having a respective tread that contacts a ground surface and being in a wheel-mounted state so as to constitute an assembly mounted in a running condition at a rotational speed, the system including:

- at least one sensor installed along an interior surface of each tire so as to be positioned essentially normal with respect to the respective tread with each sensor being capable of transmitting data representative of the operational parameters of the respective tire;
- at least one receiver that receives the data transmitted by each sensor, with each receiver including or being in communication with at least one processor that treats the received data so as to derive a load carried by the tires; and
- at least one user interface in communication with the receiver that displays weight balance information corresponding to the signals received from the sensors and treated by the receiver;

characterized in that the receiver includes at least one processor that is in communication with at least one memory that is configured to permit at least one of selection and adjustment of at least one of a plurality of stored weight balancing options for the agricultural vehicle, the at least one processor including an execution module that is capable of executing programming instructions that are stored in the memory for performing a process for providing weight balance between the front and rear axles of the agricultural vehicle including the following steps:

- a step of performing a process of post treatment of the signal generated by each sensor during which the load applied to each tire is obtained;
- a step of determination of the weight balance between the front axle and the rear axle of the agricultural vehicle, during which step the load borne by each tire that is determined during the process of post treatment is used to compute a ratio in percentage associated with the total load of the agricultural vehicle between its front and rear axles; and
- a final step of displaying the weight balance determined during the step on the user interface.

In certain embodiments of the system of the invention, the ratio in percentage associated with the total load of the agricultural vehicle between its front and rear axles, determined during the step of determination of the weight balance between the front and rear axles of the agricultural vehicle, is determined according to the following formulae representing the front balance and the rear balance :

[Math 4]

$$Balance_{Front}[\%] = \frac{\sum_{i=1}^{N} Z_{front_i}}{\sum_{i=1}^{N} Z_{front_i} + \sum_{i=1}^{N} Z_{rear_i}},$$

where Z_front_i is an estimated load for each individual front tire among N tire(s) operationally supported by front axle and with each front tire being equipped with a sensor; and

[Math 5]

$$Balance_{Rear}[\%] = \frac{\sum_{i=1}^{N} Z_f rear_i}{\sum_{i=1}^{N} Z\_front_i + \sum_{i=1}^{N} Z\_rear_i}$$

where $Z_rear_i$is an estimated load for each individual rear tire among N tire(s) operationally supported by the rear axle and with each rear tire being equipped with a sensor;

and wherein N is equal for the front and rear axles.

In certain embodiments of the system of the invention, the process of post treatment executed by the at least one processor includes the following steps:

- a step of acquisition of a first temporal signal Sig from each sensor, wherein the first signal Sig includes at least the amplitude of at least one output signal during rotation of a corresponding tire;
- a step of determination of at least one reference speed W_{ref} of the corresponding tire

associated with at least a portion of a wheel rotation signal Sig_{TdR} of the corresponding tire;

- a step of normalization of the wheel rotation signal Sig_{TdR} that is obtained from the first signal Sig, during which step at least one part of the wheel speed signal SigTdR is normalized by a quantity that is a function F proportional to the square of the reference speed W_{ref} over a predetermined number of revolutions of the corresponding tire;
- a step of resampling the normalized signal acquired at the output of the step so as to obtain a signal that is angularly periodic per tire revolution.
- a step of identification of a deformation of the corresponding tire under a static load Def%, during which step one or more spectral magnitudes are evaluated from a spectral signal spect(Sig) of the angularly resampled normalized wheel turn signal Sig_{TdR}; and
- a step of definition of a load Z experienced by a mounted assembly incorporating the corresponding tire, during which step the load Z is determined by using a function H including at least as a variable the deformation of the tire envelope Def%.

In certain embodiments of the system of the invention, the step of determination of least one reference speed W_{ref} includes determination of a ratio of an angular variation on a time duration separating two azimuthal positions of the sensor in the corresponding tire around the natural axis of rotation from the first signal Sig or from a signal phased with the first signal Sig, according to the following formula:

[Math 1]

$$W_{ref} = \Delta(\alpha)/\Delta(t)$$

where α is the angular position and t is the time abscissa associated with the angular position.

In certain embodiments of the system of the invention, the process of post treatment executed by the at least one processor includes a step of aggregating the data of the angularly normalized resampled wheel revolution signal Sig_{TdR}, and wherein the data aggregation is performed on a sub-part of the input signal Sig that is a predetermined multiple of wheel revolutions.

In certain embodiments of the system of the invention, the process of post treatment executed by the at least one processor includes a step of performing a correction of the first signal Sig so as to compensate for gravitational effect prior to normalization step.

In certain embodiments of the system of the invention, the receiver performs one or more steps of the process iteratively.

In certain embodiments of the system of the invention, the sensor is an accelerometer that is capable of detecting temperature and/or pressure values in the interior of each tire.

In certain embodiments of the system of the invention, the receiver includes an antenna for receiving radio signals from each sensor.

In certain embodiments of the system of the invention, the receiver includes at least one processor that manages data corresponding to historical information and/or general information regarding the tires.

In certain embodiments of the system of the invention, the stored ballasting options include ballasting options for operation of the agricultural vehicle alone and ballasting options for operation of the agricultural vehicle having with one or more implements coupled therewith.

In certain embodiments of the system of the invention, the user interface includes a graphical user interface (GUI) that communicates the weight balance of the agricultural vehicle to an operator of the agricultural vehicle.

The invention is also directed to an agricultural vehicle that includes:

- a front axle that serves as an axis of rotation supporting a pair of front tires, each front tire having a tread;
- a rear axle that serves as an axis of rotation supporting a pair of rear tires, each rear tire having a tread; and
- the system of the invention.

In certain embodiments of the agricultural vehicle of the invention, the agricultural vehicle further includes at least one of:

- one or more implements attached to the front axle; and
- one or more implements attached to the rear axle.

Other aspects of the invention will become evident in view of the following detailed description.

Brief description of the drawings

The nature and various advantages of the invention will become more apparent from the following detailed description in conjunction with the accompanying drawings, in which the same reference numerals designate identical parts throughout, and in which :

[Fig 1] Figure 1 represents an agricultural vehicle incorporating a system of the invention for providing weight balance between the vehicle’s front and rear axles.

[Fig 2] Figure 2 represents an example of a user interface of the system of the invention as used with the agricultural vehicle of Figure 1.

[Fig 3] Figure 3 represents a flow diagram of a process of providing weight balance between the front and rear axles of the agricultural vehicle of Figure 1 performed by the system of the invention.

Detailed Description

Referring now to the figures, in which the same numbers identify identical elements, an exemplary agricultural vehicle with which the present invention is employed is represented in Figure 1 by a tractor 10. As used herein, the term “tractor” refers to a type of agricultural vehicle, although it is understood that the disclosed invention is suitable for use with equivalent polyvalent vehicles that may not be limited to agricultural applications.

The tractor 10 includes a front axle 12 that serves as an axis of rotation supporting a pair of front tires 12a. The tractor 10 also includes a rear axle 14 that serves as an axis of rotation supporting a pair of rear tires 14a. The tractor 10 may be operated alone or together with one or more attached implements as described hereinabove. Such implements may include one or more implements 20 attached to the front axle 12 and/or one or more implements 22 attached to the rear axle 14.

Each tire 12a, 14a, having a respective tread 12a’, 14a’ that contacts the ground surface, is in a wheel-mounted state so as to constitute an assembly mounted in a running condition at a rotational speed W. As used herein, the terms "radially," "axially," and "circumferentially" mean "in a radial direction," "in the axial direction," and "in a circumferential direction" of the referenced tire, respectively. The terms "radially inward" and "radially outward" respectively mean "closer to”, or “further from”, the axis of rotation of the referenced tire in a radial direction. Thus, the circumferential direction, the axial direction and the radial direction are understood herein to be directions defined with respect to the rotational reference frame of each tire 12a, 14a about its natural axis of rotation. The radial direction is the direction perpendicular to the natural axis of rotation. The axial direction is the direction parallel to the natural axis of rotation. Finally, the circumferential direction forms a direct triad with the predefined radial and axial directions.

The tractor 10 includes an embodiment of a system 100 of the invention incorporating at least one sensor 102 installed in each front tire 12a and in each rear tire 14a. In this configuration, each sensor 102 can transmit data representative of the operational parameters of the respective tire to a receiver 104 of the system in radio communication with each sensor. The sensor 102, which may be selected from one or more commercially available sensors, is installed along an interior surface of each tire 12a, 14a so as to be positioned essentially normal with respect to the respective tread 12a’, 14a’. In embodiments of the system 100, the sensor is an accelerometer that is capable of detecting temperature and/or pressure values in the interior of each tire 12a, 14a.

The system 100 also includes at least one receiver 104 that receives the data transmitted by each sensor 102. In an embodiment of the system 100, the receiver 104 includes at least one antenna 104a that receives radio signals from the sensors 102. While the receiver 104 is represented as being carried on or in the tractor 10, it is understood that the receiver may be integrated in a one or more communication devices (or "devices") that are connected to a communication network that manages data incoming to the system 100 from various sources. Such communication device(s) can include a wearable device(s) such as a mobile network device (e.g., a cell phone, a laptop computer, a network-connected wearable device(s), including "augmented reality" and/or "virtual reality" type devices, and/or any combinations and/or equivalents). The communication network may include wired or wireless connections and may implement any data transfer protocol known to a person skilled in the art. Examples of wireless connections may include, without limitation, radio frequency (RF), satellite, cell phone (analog or digital),Bluetooth®, Wi-Fi, infrared, "ZigBee", local area network (LAN), wireless local area network (WLAN), wide area network (WAN), near field communication (NFC), other wireless communication configurations and standards, their equivalents, and a combination thereof.

The receiver 104 includes (or is in communication with) involves the use of a processor or processors that treat the received data so as to derive a load carried by the corresponding tire 12a, 14a. Each processor is in operational communication with at least one memory that is configured to permit at least one of selection and adjustment of at least one of a plurality of stored weight balancing (or “ballasting”) options for the agricultural vehicle (e.g., the tractor 10). The stored ballasting options include ballasting options for operation of the tractor 10 alone as well as ballasting options for operation of the tractor 10 when it is coupled with one or more implements 20, 22. The at least one processor includes an execution module that is capable of executing programming instructions that are stored in the memory for performing a process 200 of the invention for providing weight balance between the front and rear axles of an agricultural vehicle (described and represented herein with respect to Figure 3). The process 200 of the invention is described herein with respect to the tractor 10, but it is understood that the disclosed process may be used with any agricultural vehicle or its equivalent.

The receiver 104 can include at least one processor that manages data corresponding to historical information and general information regarding the tires 12a, 14a. The term "historical information" (in the singular or plural) is used herein to refer to data corresponding to the historical trips of the tractor 10 having a specified tire 12a, 14a mounted thereon (or a tire that is identical or equivalent to the specified tire 12a, 14a). This data may include, but is not limited to, data corresponding to dates of departure and/or arrival of the tractor 10 at a predetermined location (e.g., a vehicle storage building, a field having specific coordinates, etc.), the routes taken by the tractor 10, general data about the tractor 10 (including, but not limited to, the manufacturer, the model of the tractor and its version, the tractor's identification code, etc.), and histories of the environmental, meteorological, and/or climatic conditions during prior operation of the tractor. The historical information can also include the historical loads observed for the tractor 10 having the tires 12a, 14a mounted thereon and the appropriate weight balances that correspond to such loads under a variety of operating conditions. The historical information can further include any ballast adjustments effected under the variety of operating conditions.

The term "general information" (in the singular or plural) is used herein to refer to the data corresponding to a front tire 12a and/or a rear tire 14a. This data may include, but is not limited to, its size (which may be represented by the type of tire and/or its nomenclature), its construction code (e.g., "R" for radial), its production source (e.g., the name and/or brand of the producer of the tire, its date and place of manufacture, distribution and/or storage), its unique identification number (or "serial number"), its load index, its speed symbol (for example, "A5" representing 25 km/h), and/or its expected mileage. For example, for a 710/70R42 size tire, the number "710" represents the nominal section width of the tire in millimeters, the number "70" represents the aspect ratio of the tire, the letter "R" represents a radial tire, and the number "42" represents the rim diameter in inches.

The term "processor" (or, alternatively, the term "programmable logic circuit") (in the singular or plural) refers to one or more devices capable of processing and analyzing data and including one or more software programs for processing the same (e.g., one or more integrated circuits known to the person skilled in the art as being included in a computer, one or more controllers, one or more microcontrollers, one or more microcomputers, one or more programmable logic controllers (or "PLCs"), one or more application-specific integrated circuits, one or more neural networks, and/or one or more other known equivalent programmable circuits). The processors include software for processing the data captured and transmitted by the sensors 102 as well as software for identifying and locating variances and identifying their sources for correction.

In the system 100, the memory may include both volatile and non-volatile memory devices. Non-volatile memory may include solid state memory, such as NAND flash memory, "keep-alive memory" or "KAM" for saving various operating variables while the processor is powered down, magnetic and optical storage media, or any other suitable data storage device that retains data when the system 100 is powered down or loses power. The volatile memory may include static and dynamic RAM that stores program instructions and data, including a machine learning application.

Still referring to Figure 1, and also referring to Figure 2, the system 100 further includes at least one user interface 106 in communication with the receiver 104. The user interface 106 displays weight balance information corresponding to the signals received from the sensors 102 and treated by the receiver 104. The user interface 106 may incorporate one or several types of interfaces, including, but not limited to, a graphical user interface (or “GUI”), a command-line interface (or “CLI”), a menu-driven interface (or “MDI”), a form-based interface (or “FBI”), and/or a natural language user interface (or “NLI”).

In an embodiment of the user interface 106, the user interface includes a graphical user interface that communicates the weight balance of the tractor 10 to the operator (as determined by the receiver 104 in accordance with a process of the invention described herein). The exemplary user interface 106 that is represented in Figure 2 includes a graphical representation of the weight balance between the front axle and rear axle of the tractor 10 in an image field 106a. The exemplary user interface 106 that is represented in Figure 2 also include along with a text-based representation of the signal data (“Last update”) in a text field 106b. The image field 106a and/or the text field 106b may be updated regularly or intermittently in a manner that communicates whether the detected weight balance falls within predetermined thresholds for operation of the tractor 10 in the current operating conditions. The user interface 106 may incorporate a color index (or other equivalent index) that communicates whether the weight balance falls within predetermined thresholds for operation in the current operating conditions. Using the example of Figure 2, the graphical representation of weight balance shown on user interface 106 indicates a front balance at or above 30% and a rear balance at or above 70%. In this instance the color index may be green to show that no adjustment to the balance is required. In this example, if the front balance is at or below 20%, the color index may be red in order to communicate a need to adjust the ballast. In this example, if the front balance is less than 30% and more than 20%, the color index may be yellow in order to communicate a need for monitoring the ballast. The operator of the tractor 10 can therefore easily adjust the weight balance as needed (for example, by managing the tire inflation pressure of one or more of tires 12a, 14a using a known central tire inflation system (or “CTIS”)). For example, an alert may be communicated in the visual field 106a that includes visual instructions to increase or decrease the load in a particular tire

12, 14. As the balance information is displayed, the sensors 102 detect the revised tire load and generate corresponding signals for transmission to the receiver 104. The receiver 104 awaits the next update of the sensor signal so as to reiterate the computation of the weight balance and communicate the updated computation to the user interface 106.

It is understood that the user interface 106 is not limited to the graphical depiction represented in Figure 2, and that a person of ordinary skill in the art would anticipate the integration of equivalent user interfaces. The user interface 106 may incorporate one or more I/O devices (including but not limited to displays, keyboards, keypads, mice and/or other pointing devices, trackballs, joysticks, haptic feedback devices, motion feedback devices, voice recognition devices, visual recognition devices (including facial recognition devices), digital imprint recognition devices, microphones, speakers, touch screens, touchpads, webcams, one or more cameras, gesture capture and recognition devices, devices incorporating touchless technologies and equivalent and complementary devices that enable operative response to user commands and inputs). It is understood that user input may be received via a computing device coupled to another computing device over a network.

Referring again to Figures 1 and 2, and further to Figure 3, a detailed description is given of exemplary embodiments of a weight balancing process (or “process”) 200 of the invention implemented by the system 100. As used herein, the term “process” may include one or more steps performed by at least one computer system (for example, the receiver 104) having a processor or processors to execute instructions that perform the steps of the process. Unless otherwise noted, any sequence of steps is illustrative and does not limit the described processes to any particular sequence.

Throughout the process 200, the sensors 102 generate and send to the receiver 104 the signals that are required for the calculation of load. It is therefore understood that the process 200 may be performed by the system 100 regardless of whether the tractor 10 is operating alone or operating with at least one implement 20 and/or 22 mounted thereon (see Figure 1).

Upon initiation of the process 200 of the invention, the process includes a step of performing a process of post treatment of the signal generated by each sensor 102. The process of post treatment includes a step 202 of obtaining a first signal Sig. The first signal Sig that is acquired from each sensor 102 is the temporal amplitude of the acceleration of the sensor during the course of rotation of the mounted tire assembly incorporating a corresponding tire 12a, 14a (i.e., the tire mounted on a rim on the tractor 10 with the sensor 102 positioned along an interior surface thereof). Thus, the acquired signal shows the variations in amplitude over a part of the circumference of the tire. These variations may include those associated with the crossing of the contact area by the part of the tire where the sensor 102 is fixed. These variations may also include those associated with other specific zones of the tire circumference (for example, a zone corresponding to the angular sector opposite the contact area) that are sensitive to the counter deflection or that correspond to the angular sectors located at 90 degrees of the contact area in relation to the axis of rotation. In all of these areas, accelerometer-like variations in sensor motion are potentially observable on the output signal depending on the sensitivity of the sensor.

In order to obtain this first signal Sig, different embodiments of the process of post treatment share steps that facilitate acquisition of a scalar representative of the applied load of the finally mounted tire assembly incorporating a tire 12a, 14a. In a first embodiment of the process of post treatment, the step 202 of obtaining the first signal Sig includes a step 204 of determining a reference speed W_{ref} of the corresponding tire 12a, 14a in its mounted assembly configuration. During this step 204, the first signal Sig is already delimited over a predetermined number of revolutions.

The reference speed W_{ref} can be an angular speed linked to the natural rotation of a tire 12a, 14a around its axis of rotation. Using the time signal generated at the output of step 202, this reference speed W_{ref} can also be the linear translation speed of the corresponding tire 12a, 14a according to its direction of movement. The first signal Sig, having been already delimited over a predetermined number of revolutions, is consequently confused with a wheel rotation signal Sig_{TdR}.

While the reference speed W_{ref} can be determined from the wheel rotation signal Sig_{TdR}, it can also be determined from another signal phased in time with the first signal Sig (and thus the wheel rotation signal Sig_{TdR}). In an embodiment of the process 200, the step 204 of determining the reference speed W_{ref} includes a step of determining the ratio of the angular variation to the time duration separating two azimuthal positions of the sensor 102 in a tire 12a, 14a in which the sensor is installed. This ratio of angular variation is determined relative to the natural axis of rotation from the wheel turn signal Sig_{TdR} or from a signal phased with the wheel turn signal Sig_{TdR}, according to the following formula:

[Math 1]

$$W^{reference}=\Delta(\alpha)/\Delta(t)$$

where α is the angular position and t is the time abscissa associated with the angular position.

In the case where the reference speed W_{ref} corresponds to the angular rotation speed of the corresponding tire 12a, 14a, this reference speed is calculated on the basis of an angular variation of the signal between two known positions. This reference speed W_{ref} can be evaluated over a signal duration of less than one wheel revolution. In addition, the precision of the angular resampling of the first signal Sig is improved when the tire 12a, 14a rotates at a variable angular speed, thereby facilitating a more accurate normalization of the signal as well as an increased angular precision on the angular position of the measurement points of the first signal during the angular resampling step.

This first embodiment of the process of post treatment also includes a step 206 of normalization of the wheel rotation signal Sig_{TdR} that is obtained from the first signal Sig. During this step, the first signal Sig is normalized by a function F of the variable W_{ref} (acquired during the previous step 204). This function F is a function that is proportional to the square of the reference speed W_{ref}. At the output of this step 206, a normalized signal of the corresponding tire 12a, 14a over a prescribed time (for example, a predetermined number of rotations) is acquired.

During this step 206, the reference speed W_{ref} is associated with the first acquired signal, which may be identified on this first signal or may come from another source (for example, the output of a system external to the mounted assembly incorporating the corresponding tire 12a, 14a). This reference speed W_{ref} is necessarily associated with the same time frame as the part of the first signal. This reference speed W_{ref} is used to normalize the amplitude of the first signal using the function F. If the dependence of the amplitude of the sensor signal on the reference speed is perceived as a spurious signal of the deformation of the tire, the normalization of the sensor signal is undertaken.

This first embodiment of the process of post treatment further includes a step 208 of resampling the normalized signal (acquired at the output of the previous step 206) in order to recover a signal that is angularly periodic per wheel revolution. Thus, at the end of this step 208, a normalized and angularly resampled signal over several wheel revolutions is acquired.

In an alternative embodiment of the process 200 of the invention, the process of post treatment includes a first step 208 of resampling angularly the first signal Sig (which is also the wheel rotation signal Sig_{TdR}) (this step corresponds to the step 208 of the first embodiment). This step is performed by phasing this first signal Sig, either by using the shape of the first signal Sig or by having another signal temporally phased therewith. During this step, another signal emanates from another sensor 102 or from another channel of the same sensor (such as the circumferential acceleration of a three-dimensional accelerometer). This angular resampling of the first signal Sig generates a periodic signal per wheel revolution at the output of this step 208.

In this alternative embodiment of the process 200 of the invention, and after phasing this angular signal with another time signal, the process of post treatment also includes a subsequent step 204 of determining a reference velocity W_{ref} from another time signal phased with the first signal Sig (this step corresponds to the step 204 of the first embodiment of the process 200). This other time signal can be the same other signal that was used to angularly resample the first signal Sig during the previous step 208. Thus, a reference velocity W_{ref} is identified at the output of this step 204.

In this alternative embodiment of the process 200 of the invention, the process of post treatment further includes a step 206 of using the reference speed W_{ref} to normalize the angularly resampled signal from step 208 (this step corresponds to step 206 of the first embodiment of the process 200). During this step, a function F of the variable W_{ref} is used, resulting in a normalized angularly resampled wheel revolution signal Sig_{TdR} at the output of this step 206.

In both of the aforedescribed embodiments of the process 200 of the invention, the process of post treatment can include an optional step 210 of aggregating the data of the angularly normalized resampled wheel revolution signal Sig_{TdR} (this being acquired at the output of step 208 of the first embodiment of the process or acquired at the output of step 206 of the alternative embodiment of the process). This data aggregation is done on a sub-part of the input signal Sig that is a multiple of wheel revolutions, since the angularly resampled and normalized signal is periodic in nature.

It is therefore understood that, during the process of post treatment, angular resampling of the first signal Sig or the wheel rotation signal Sig_{TdR} may occur before or after a normalization step. This angular resampling transforms the time signal into a spatial signal by phasing the time signal with respect to one or more angular references of the mounted assembly. This angular reference can be obtained from the first signal Sig by a specific response of the sensor 102 to a particular azimuth on the wheel revolution. This angular reference can alternatively be obtained from another signal generated by a sensor that shares a common clock with the first signal Sig. This clock sharing (or “synchronization”) of signals is natural if the two sensors come from the same device or if the signals are communicated to a common device (for example, the receiver 104). This angular resampling enables the generation of a spatially periodic signal per wheel revolution.

In both embodiments of the process 200 of the invention, the process of post treatment can include an optional step (not shown in Figure 3) of performing a correction of the first signal Sig if it is polluted by known physical phenomena (for example, an accelerometer signal influenced by the earth's gravity). By correcting the first signal Sig, the influence of spurious noise generated by these physical phenomena is limited. This correction can be performed at any point between step 202 and step 208. For those embodiments of the invention including the data aggregation step 210, this correction must be performed prior to the data aggregation step. Doing so improves the quality of the deformation signal of the corresponding tire 12a, 14a. It is understood that, if the correction occurs after the normalization step 206, the correction should also be normalized so as not to introduce a correction error.

The process of post treatment further includes a step 212 of identifying the deformation of each corresponding tire 12a, 14a under a static load Def%. This identification step is effected by exploiting one or more spectral magnitudes evaluated from the spectral signal spect(Sig) of the angularly resampled normalized wheel turn signal Sig_{TdR}. The spectral quantity(ies) will feed a linear function that will deliver a vector (preferably a scalar) which is an invariant of the deformation of the tire in a rolling condition and subjected to external forces.

The process of post treatment includes a step 214 of determining a load Z experienced by the mounted assembly incorporating a corresponding tire 12a, 14a. During this step, the load Z is determined by using a function H relating the load Z to the deformation of the tire envelope Def%. The fact that the deformation of the tire envelope is evaluated on the basis of a measurement signal potentially much larger than the simple crossing of the contact area, allows to gain in accuracy on this deformation with a much lower spatial discretization of the wheel turn signal Sig_{TdR}. This is less costly in energy and memory space, which permits determination of the load Z at the level of the sensor 102 embedded in the corresponding tire 12a, 14a.

Depending on whether one wishes to evaluate the load Z applied to the mounted assembly under normal operating conditions or under specified operating conditions, it is appropriate to consider one or other formulae for the function H. In the known field of use of a tire in application of the rules of the ETRTO (European Tyres and Rim Technical Organization), a simple affine function correctly describes the evolution of the load Z as a function of the deformation of the pneumatic envelope Def%:

[Math 2]

$$H = A * Def_{\%} + B$$

where (A, B) are parameters linked to the mounted assembly.

Therefore, the knowledge of the mounted assembly (and in particular the corresponding tire 12a, 14a) allows to identify with certainty the load Z applied to the mounted assembly.

If one wishes, however to extend the area of modeling the load as a function of the deformation of the pneumatic envelope for specific uses (for example, for very low or very high Z loads), a power type representation is better suited:

[Math 3]

$$H = X * (Def_{\%})^{Y}$$

where (X, Y) are parameters linked to the mounted assembly.

In the common area of use, both functions give very close results and are sufficient for the desired accuracy (being less than 10%, and preferably less than 5%).

The majority of tires are mounted on wheels and then inflated to an inflation pressure P that varies according to the type of tire. This inflation pressure P influences the mechanical behavior of the mounted assembly and that of the tire. Consequently, with the mounted assembly (and particularly the corresponding tire 12a, 14a) being inflated to a predetermined inflation pressure, the parameters B or Y (and thus the deformation of the corresponding tire 12a, 14a) are at least dependent on this inflation pressure P. The dependence on the inflation pressure P of these second parameters B or Y of the function H is similar to an evolution of the slope of the function H as a function of the deformation of the tire Def%. This evolution with the inflation pressure P of these second parameters B or Y reinforces the precision of the estimation of the load Z applied to the mounted assembly and thus to the tire.

The process 200 of the invention includes an additional step 216 of determination of the load carried by each axle of the tractor 10. During this step, the load borne by each tire 12a, 14a (that which is determined during the process of post treatment) is used to compute a ratio in percentage associated with the total load of the tractor 10 between its front and rear axles. This ratio, which represents the weight balance (or "ballast") of the tractor 10, is computed by the receiver 104 according to the following formulae representing the front balance and the rear balance :

[Math 4]

$$Balance_{Front}[\%] = \frac{\sum_{i=1}^{N} Z_{front_i}}{\sum_{i=1}^{N} Z_{front_i} + \sum_{i=1}^{N} Z_{rear_i}},$$

where Z_front_i is the estimated load for each individual front tire 12a among N tire(s) operationally supported by front axle and with each front tire 12a being equipped with a sensor 102; and

[Math 5]

$$Balance_{Rear}[\%] = \frac{\sum_{i=1}^{N} Z_f rear_i}{\sum_{i=1}^{N} Z\_front_i + \sum_{i=1}^{N} Z\_rear_i}$$

where Z_rear_i is the estimated load for each individual rear tire 14a among N tire(s) operationally supported by the rear axle and with each rear tire 14a being equipped with a sensor 102.

It is understood that N must be equal for the front and rear axles. It is also understood that the weight balance can be determined even if only one tire is equipped on the front axle and/or the rear axle of the tractor 10.

The process 200 of the invention includes a final step 218 of displaying the weight balance between the front axle and the rear axle (determined during the previous step 214) on the user interface 106. During this step, the user interface 106 can be configured to display one or more indices that communicate an action item to the operator (for example, a visual alert in the image field 106a and/or a text alert in the text field 106b).

It is understood that the one or more steps of the process 200, as well as the process itself, may be performed iteratively.

The present invention facilitates optimal weight distribution between the front and rear axles of an agricultural vehicle so as to ensure that the slip rates are maintained in the appropriate range for the vehicle's operation in the selected conditions.

The terms "at least one" and "one or more" are used interchangeably. Ranges that are shown as being "between a and b" include both "a" and "b" values.

Although particular embodiments of the disclosed apparatus have been illustrated and described, it will be understood that various changes, additions, and modifications may be practiced without departing from the spirit and scope of this disclosure. Accordingly, no limitations should be imposed on the scope of the described invention except those set forth in the appended claims.

Claims

1. A system (100) for providing weight balance for an agricultural vehicle (10) having a front axle (12) that rotationally supports at least one front tire (12a) and a rear axle (14) that rotationally supports at least one rear tire (14a), with each tire (12a, 14a) having a respective tread (12a', 14a') that contacts a ground surface and being in a wheel-mounted state so as to constitute an assembly mounted in a running condition at a rotational speed (W), the system (100) including:

- at least one sensor (102) installed along an interior surface of each tire (12a, 14a) so as to be positioned essentially normal with respect to the respective tread (12a', 14a') with each sensor being capable of transmitting data representative of the operational parameters of the respective tire;
- at least one receiver (104) that receives the data transmitted by each sensor (102), with each receiver (104) including or being in communication with at least one processor that treats the received data so as to derive a load carried by the tires (12a, 14a); and
- at least one user interface (106) in communication with the receiver (104) that displays weight balance information corresponding to the signals received from the sensors (102) and treated by the receiver (104);

characterized in that the receiver (104) includes at least one processor that is in communication with at least one memory that is configured to permit at least one of selection and adjustment of at least one of a plurality of stored weight balancing options for the agricultural vehicle (10), the at least one processor including an execution module that is capable of executing programming instructions that are stored in the memory for performing a process (200) for providing weight balance between the front and rear axles (12, 14) of the agricultural vehicle including the following steps:

- a step of performing a process of post treatment of the signal generated by each sensor (102) during which the load applied to each tire (12a, 14a) is obtained, the process of post-treatment including a step (214) of determining a load Z undergone by the mounted assembly incorporating a corresponding tire (12a, 14a);
- a step (216) of determination of the weight balance between the front axle (12) and the rear axle (14) of the agricultural vehicle (10), during which step the load borne by each tire (12a, 14a) that is determined during the process of post treatment is used to compute a ratio in percentage associated with the total load of the agricultural vehicle (10) between its front and rear axles; and

- a final step (218) of displaying the weight balance determined during the step (214) on the user interface 106.

2. The system (100) of claim 1, wherein the ratio in percentage associated with the total load of the agricultural vehicle (10) between its front and rear axles, determined during the step (216), is determined according to the following formulae representing the front balance and the rear balance :

[Math 4]

$$Balance_{Front}[\%] = \frac{\sum_{i=1}^{N} Z_{front_i}}{\sum_{i=1}^{N} Z_{front_i} + \sum_{i=1}^{N} Z_{rear_i}},$$

where Z_front_i is an estimated load for each individual front tire (12a) among N tire(s) operationally supported by front axle and with each front tire (12a) being equipped with a sensor 102; and

[Math 5]

$$Balance_{Rear}[\%] = \frac{\sum_{i=1}^{N} Z_f rear_i}{\sum_{i=1}^{N} Z\_front_i + \sum_{i=1}^{N} Z\_rear_i}$$

where $Z_rear_i$is an estimated load for each individual rear tire (14a) among N tire(s) operationally supported by the rear axle and with each rear tire 14a being equipped with a sensor (102);

and wherein N is equal for the front and rear axles.

3. The system (100) of claim 2, wherein the process of post treatment executed by the at least one processor comprises the following steps:

- a step (202) of acquisition of a first temporal signal Sig from each sensor (102), wherein the first signal Sig comprises at least the amplitude of at least one output signal during rotation of a corresponding tire (12a, 14a) ;
- a step (204) of determination of at least one reference speed W_{ref} of the corresponding tire (12a, 14a) associated with at least a portion of a wheel rotation signal Sig_{TdR} of the corresponding tire;
- a step (206) of normalization of the wheel rotation signal Sig_{TdR} that is obtained from the first signal Sig, during which step at least one part of the wheel speed signal SigTdR is normalized by a quantity that is a function F proportional to the square of the reference speed

W_{ref} over a predetermined number of revolutions of the corresponding tire (12a, 14a);

- a step (208) of resampling the normalized signal acquired at the output of the step (206) so as to obtain a signal that is angularly periodic per tire revolution;
- a step (212) of identification of a deformation of the corresponding tire (12a, 14a) under a static load Def%, during which step one or more spectral magnitudes are evaluated from a spectral signal spect(Sig) of the angularly resampled normalized wheel turn signal Sig_{TdR}; and
- the step (214) of definition of a load Z, during which step the load Z is determined by using a function H comprising at least as a variable the deformation of the tire envelope Def%.

4. The system (100) of claim 3, wherein the step (204) of determination of least one reference speed W_{ref} comprises determination of a ratio of an angular variation on a time duration separating two azimuthal positions of the sensor (102) in the corresponding tire (12a, 14a) around the natural axis of rotation from the first signal Sig or from a signal phased with the first signal Sig, according to the following formula:

[Math 1]

$$W_{ref} = \Delta(\alpha)/\Delta(t)$$

where α is the angular position and t is the time abscissa associated with the angular position.

5. The system (100) of claim 3 or claim 4, wherein the process of post treatment executed by the at least one processor comprises a step (210) of aggregating the data of the angularly normalized resampled wheel revolution signal Sig_{TdR}, and wherein the data aggregation is performed on a sub-part of the input signal Sig that is a predetermined multiple of wheel revolutions.

6. The system (100) of any of claims 3 to 5, wherein the process of post treatment executed by the at least one processor comprises a step of performing a correction of the first signal Sig so as to compensate for gravitational effect prior to normalization step (206).

7. The system (100) of any of claims 1 to 6, the receiver (104) performs one or more steps of the process (200) iteratively.

8. The system (100) of any one of claims 1 to 7, wherein the sensor (102) comprises an

accelerometer that is capable of detecting temperature and/or pressure values in the interior of each tire (12a, 14a).

9. The system (100) of any one of claims 1 to 8, wherein the receiver (104) comprises an antenna (104a) for receiving radio signals from each sensor (102).

10. The system (100) of any one of claims 1 to 9, wherein the receiver (104) includes at least one processor that manages data corresponding to historical information and/or general information regarding the tires (12a, 14a).

11. The system (100) of any one of claims 1 to 10, wherein the stored ballasting options include ballasting options for operation of the agricultural vehicle (10) alone and ballasting options for operation of the agricultural vehicle (10) having with one or more implements (20, 22) coupled therewith.

12. The system (100) of any one of claims 1 to 11, wherein the user interface (106) comprises a graphical user interface (GUI) that communicates the weight balance of the agricultural vehicle (10) to an operator of the agricultural vehicle.

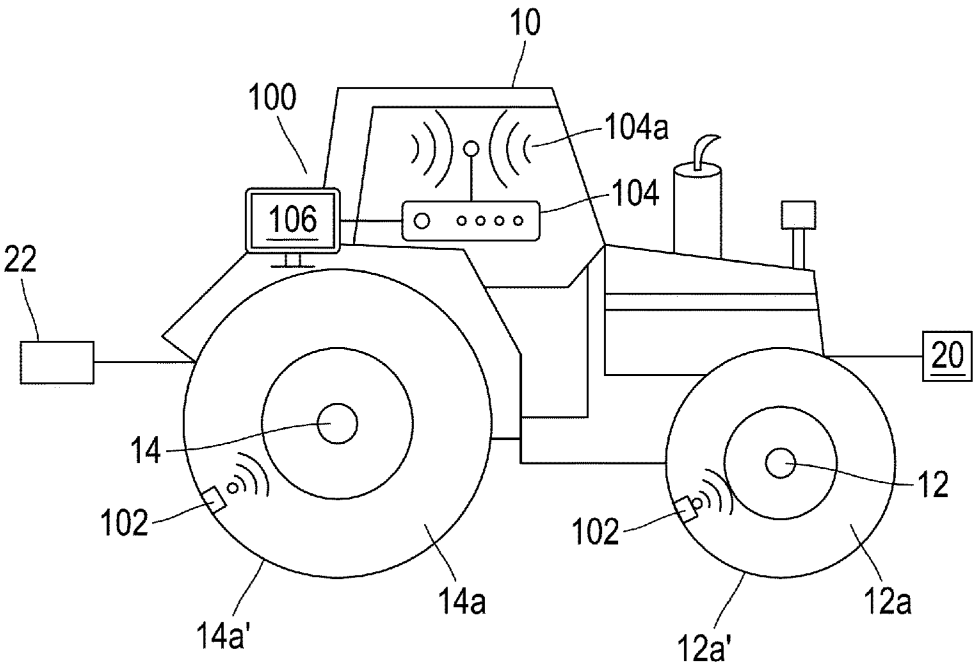
13. An agricultural vehicle (10) comprising:

- a front axle (12) that serves as an axis of rotation supporting a pair of front tires (12a), each front tire having a tread (12a');
- a rear axle (14) that serves as an axis of rotation supporting a pair of rear tires (14a), each rear tire having a tread (14a'); and
- the system of one of claims 1 to 12.

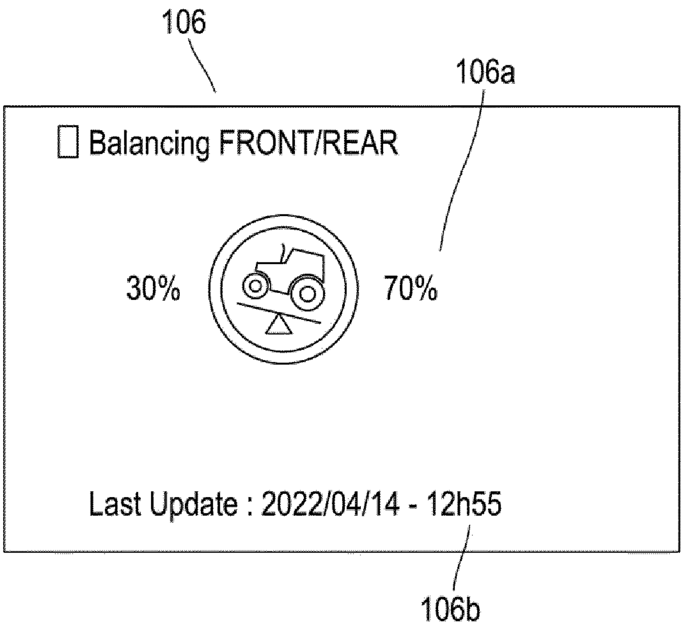
14. The agricultural vehicle (10) of claim 13, further comprising at least one of:

- one or more implements (20) attached to the front axle (12); and
- one or more implements (22) attached to the rear axle (14).

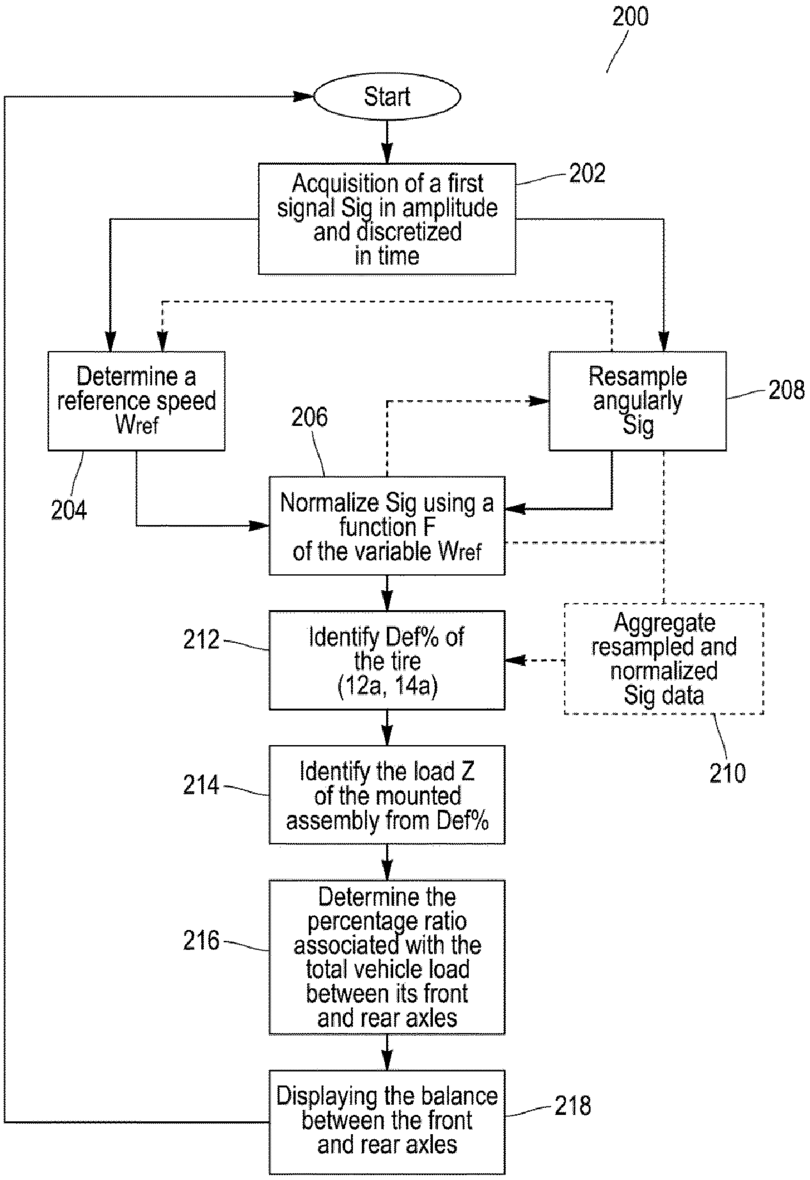
[Fig. 1]


10
100
104a
104
106
22
20
14
12
102
102
14a
14a'
12a
12a'

[Fig. 2]


106
106a
☐ Balancing FRONT/REAR
30%
70%
Last Update : 2022/04/14 - 12h55
106b

[Fig. 3]


200
Start
Acquisition of a first signal Sig in amplitude and discretized in time
202
Determine a reference speed Wref
204
Resample angularly Sig
208
206
Normalize Sig using a function F of the variable Wref
Aggregate resampled and normalized Sig data
210
212
Identify Def% of the tire (12a, 14a)
214
Identify the load Z of the mounted assembly from Def%
216
Determine the percentage ratio associated with the total vehicle load between its front and rear axles
Displaying the balance between the front and rear axles
218

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/079882

A. CLASSIFICATION OF SUBJECT MATTER
INV. A01B63/00 B60W40/13
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)
A01B B60W G01M G01G B60C

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 9 078 391 B2 (PICHLMAIER BENNO [DE]; AGCO INT GMBH [CH]) 14 July 2015 (2015-07-14) cited in the application	1,2,7, 10-14
Y	column 1, line 3 - column 11, line 9	8,9
A	figures 1-8 -----	3-6
Y	US 2022/283016 A1 (BUNNER JOHN EVAN [US] ET AL) 8 September 2022 (2022-09-08) paragraphs [0005] - [0042] figures 1-11 -----	8,9
A	DE 20 2019 102183 U1 (LUGE KRISTIAN [DE]) 29 May 2019 (2019-05-29) paragraphs [0001] - [0205] figures 1-17 ----- -/--	1-14

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 January 2024	22/01/2024

Name and mailing address of the ISA/	Authorized officer
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1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PRANAV P K ET AL: "Computer simulation of ballast management for agricultural tractors", JOURNAL OF TERRAMECHANICS, ELSEVIER, AMSTERDAM, NL, vol. 45, no. 6, 29 January 2009 (2009-01-29), pages 185-192, XP025967304, ISSN: 0022-4898, DOI: 10.1016/J.JTERRA.2008.12.002 [retrieved on 2009-01-29] pages 185-191 -----	1-14

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/079882

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