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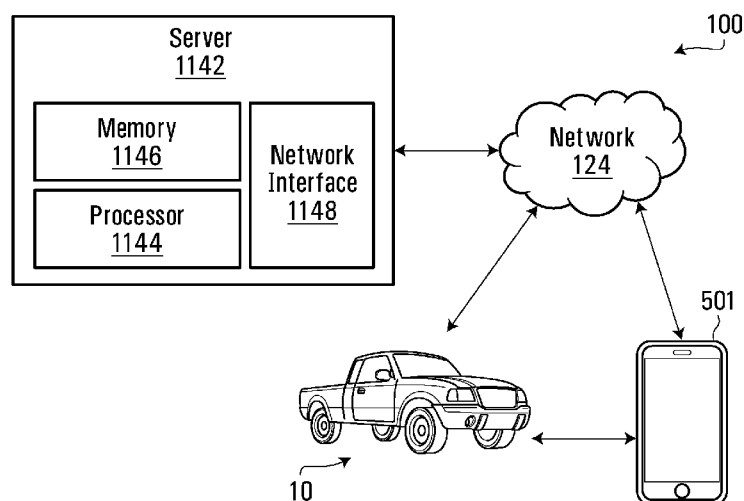


FIG. 5

(57) Abstract: A vehicle comprising wheels having tires can be monitored to obtain information regarding the vehicle, including information regarding the wheels, such as an indication of a physical state of a tire and/or other component of the wheel based on at least 3D recognition and/or 2D recognition of image data of the tire and/or other wheel component.



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SYSTEMS AND METHODS FOR MONITORING VEHICLES WITH TIRES

FIELD

This disclosure relates to tires, including pneumatic and non-pneumatic tires (NPTs), for
5 vehicles, including road vehicles and off-road vehicles and, more particularly, to
monitoring wheels comprising tires of such vehicles.

BACKGROUND

Wheels for vehicles comprise tires, which may be pneumatic tires or non-pneumatic
tires. Tires are subject to various forces and environments that cause them to wear and
10 sometimes fail. Road vehicles and off-road vehicles equipped with tires are used on
soft, slippery and/or irregular grounds (e.g., soil, mud, sand, ice, snow, etc.) for work
and/or other purposes. In some cases, off-road vehicles may also be operable on paved
roads.

Numerous factors affect performance of road vehicles and off-road vehicles, including
15 their components (e.g., tires) and their environments (e.g., grounds on which they
operate). While some of these factors may be managed by users (e.g., operator) of the
vehicles, this may lead to suboptimal work (e.g., construction work), greater wear or
other deterioration of components of the vehicles, and/or other issues in some cases.

Similar issues may arise because of wear or other deterioration of a wheel (e.g., the
20 outer rim) around which a tire is disposed. For these and other reasons, there is a need
to improve monitoring tires of road vehicles and off-road vehicles.

SUMMARY

In accordance with various aspects of this disclosure, a vehicle (e.g., a road vehicle or
an off-road vehicle) comprising wheels can be monitored to obtain information regarding
25 the vehicle, including information regarding a given one of the wheels, such as an
indication of deterioration of a tire and/or another component of the given one of the
wheels (e.g., an indication of a level of wear, a rupture like a break, a puncture,

chunking, de-bonding, etc. of the tire and/or other component of that wheel), an identifier of the tire and/or another component of the given one of the wheels, and/or other parameters of the tire and/or another component of the given one of the wheels, which can be used for various purposes, such as, for example, to: convey the information to a user (e.g., an operator of the vehicle); control the vehicle (e.g., a speed of the vehicle); transmit the information to a remote party (e.g., a provider such as a manufacturer or distributor of the tire and/or another component of the given one of the wheels, and/or of the vehicle; etc.).

In accordance with an aspect, this disclosure relates to a system for monitoring a tire for traction of a vehicle. The system comprises an interface configured to receive data regarding at least one image of the tire. The system also comprises a processor configured to process the data regarding the at least one image of the tire to obtain an indication of a physical state of the tire, and to generate a signal based on the indication of the physical state of the tire.

In accordance with another aspect, this disclosure relates to a method of monitoring a tire for traction of a vehicle. The method comprises receiving data regarding at least one image of the tire. The method also comprises processing the data regarding the at least one image of the tire to obtain an indication of a physical state of the tire. The method also comprises generating a signal based on the indication of the physical state of the tire.

In accordance with yet another aspect, this disclosure relates to a wheel monitoring system. The system comprises an image data capture device configured to capture image data relating to a wheel component (e.g. tire, rim, etc.). The system also comprises an image processing device, in data communication with the image capture device. The image processing device is configured to receive captured image data from the image data capture device and process the captured image data to determine at least one physical characteristic of the wheel component.

In accordance with yet another aspect, this disclosure relates to wheel monitoring system. The system comprises a 3D scanning device configured to generate a 3D scan

relating to a wheel component. The system also comprises a processing device, in data communication with the 3D scanning device. The processing device is configured to receive the 3D scan from the 3D scanning device and process the 3D scan to determine at least one physical characteristic of the wheel component.

5

BRIEF DESCRIPTION OF THE DRAWINGS

A detailed description of embodiments is provided below, by way of example only, with reference to accompanying drawings, in which:

10 Figure 1 shows an example of an embodiment of a vehicle comprising a wheel including a pneumatic tire in accordance with an embodiment;

Figure 2 shows a perspective view of a pneumatic tire in accordance with an embodiment;

Figure 3 shows a cutaway view of the pneumatic tire of Figure 2;

15 Figure 4 shows a diagram of an image processing system according to one embodiment;

Figure 5 shows a schematic network diagram of a system for monitoring road vehicles and off road vehicles, according to one embodiment;

Figure 6 shows a diagram of a computer of a vehicle according to one embodiment;

20 Figure 7 shows a schematic network diagram of a system for monitoring road vehicles and off road vehicles, according to another embodiment;

Figure 8 A to C illustrate representations of different databases according to various embodiments;

25 Figures 9 to 15 show flowcharts of the use of a monitoring system, according to various embodiments;

Figures 16 to 19 show data capture for a system according to various embodiments;

Figure 20 shows the communication of a result in a system according to one embodiment;

Figure 21 shows scheduling of maintenance according to one embodiment;

5 Figure 22 shows a system capable of facilitating the purchase of parts according to one embodiment;

Figure 23 shows a system able schedule a maintenance request according to one embodiment;

10 Figure 24 shows a system able to connect two electronic devices, according to one embodiment;

Figures 25 to 27 show a system that can determine that the vehicle has a critical malfunction according to various embodiments;

Figure 28 shows an example of a camera station for inspecting tires;

Figure 29 shows an example of a laser line scanner station for inspecting tires;

15 Figure 30 shows an embodiment of a drone device for inspecting the tire;

Figure 31 shows the drone device for inspecting the tire;

Figure 32 shows an example of a vehicle-mounted inspection device for inspecting tires;

Figure 33 shows an example of an embodiment of a computing apparatus;

20 Figure 34 shows an example 3D tire model generated using the system described herein;

Figures 35 to 38 show example 3D tire models of used and/or damaged tires generated using the system described herein, overlaid by 3D tire models of unused and/or undamaged tires;

Figures 39 and 40 show examples of wear/damage being detected and characterized using 2D recognition techniques; and

Figures 41 to 43 shows flowcharts of the use of a monitoring system, according to various embodiments.

5 DETAILED DESCRIPTION OF EMBODIMENTS

Figure 1 shows an example of an embodiment of a vehicle 10 comprising wheels 20₁-20₄ on a ground surface 11. Each of the wheels 20₁-20₄ comprises a tire 34 for contacting the ground surface 11.

As further discussed later, in this embodiment, the vehicle 10, including the wheels 20₁-20₄, can be monitored (e.g., during operation of the vehicle 10) to obtain information regarding the vehicle 10, including information regarding the wheels 20₁-20₄, such as an indication of deterioration of the tire 34 and/or another component of a given one of the wheels 20₁-20₄ (e.g., an indication of a level of wear, a rupture like a break, a puncture, chunking, de-bonding, etc. of the tire 34 and/or other component of that wheel), an identifier of the tire 34 and/or another component of the given one of the wheels 20₁-20₄, and/or other parameters of the tire 34 and/or another component of the given one of the wheels 20₁-20₄, which can be used for various purposes, such as, for example, to: convey the information to a user (e.g., an operator of the vehicle 10); control the vehicle 10 (e.g., a speed of the vehicle 10); transmit the information to a remote party (e.g., a provider such as a manufacturer or distributor of the tire 34 and/or another component of the given one of the wheels 20₁-20₄, and/or of the vehicle 10; etc.); etc. This may be useful, for example, to gain knowledge about the vehicle 10, including the wheels 20₁-20₄, to enhance efficiency of the vehicle 10, help prevent rapid wear or other deterioration of the wheels 20₁-20₄, facilitate maintenance (e.g., replacement or repair) of the tire 34 and/or another component of each of the wheels 20₁-20₄, and/or for various other reasons.

In this embodiment, the ground surface 11 is a road and the vehicle 10 is a road vehicle that is designed to legally carry people or cargo on the road 11, which is part of a public

road infrastructure (e.g., public streets, highways, etc.). More particularly, in this embodiment, the road vehicle 10 is a truck. In this example, the vehicle 10 is a light truck for cargo transportation (e.g., having a gross vehicle weight rating (GVWR) greater than 6,001 lbs or 2,722 kg, such as in class 2 or higher according to the U.S. Department of Transportation's Federal Highway Administration (FHWA)). As will be appreciated, other examples can relate to trucks of any class or size, as well as any other vehicle requiring tires.

In addition to the wheels 20₁-20₄, in this embodiment, the vehicle 10 comprises a frame, a powertrain, a steering system, a suspension, a cabin, and a control system. The vehicle 10 has a longitudinal direction, a widthwise direction, and a heightwise direction.

The powertrain is configured to generate power for the vehicle 10, including motive power for respective ones of the wheels 20₁-20₄ to propel the vehicle 10 on the ground surface 11. To that end, the powertrain comprises a power source (e.g., a primer mover) that includes one or more motors. For example, in some embodiments, the power source may comprise an internal combustion engine, an electric motor (e.g., powered by a battery), or a combination of different types of motor (e.g., an internal combustion engine and an electric motor). The powertrain can transmit power from the power source to one or more of the wheels 20₁-20₄ in any suitable way (e.g., via a transmission, a differential, a shaft engaging (i.e., directly connecting) a motor and a given one of the wheels 20₁-20₄, etc.).

The steering system is configured to steer the vehicle 10 on the ground surface 11. In this embodiment, the steering system is configured to turn front ones of the wheels 20₁-20₄ to change their orientation relative to the frame of the vehicle 10 in order to cause the vehicle 10 to move in a desired direction.

The suspension is connected between the frame and the wheels 20₁-20₄ to allow relative motion between the frame and the wheels 20₁-20₄ as the vehicle 10 travels on the ground surface 11. For example, the suspension may enhance handling of the vehicle 10 on the ground surface 11 by absorbing shocks and helping to maintain traction between the wheels 20₁-20₄ and the ground surface 11. The suspension may

comprise an arrangement of springs and dampers. A spring may be a coil spring, a leaf spring, a gas spring (e.g., an air spring), or any other elastic object used to store mechanical energy. A damper (also sometimes referred to as a “shock absorber”) may be a fluidic damper (e.g., a pneumatic damper, a hydraulic damper, etc.), a magnetic
5 damper, or any other object which absorbs or dissipates kinetic energy to decrease oscillations. In some cases, a single device may itself constitute both a spring and a damper (e.g., a hydropneumatic device).

The cabin is configured to be occupied by one or more occupants of the vehicle 10. In this embodiment, the cabin comprises a user interface configured to interact with one or
10 more occupants of the vehicle 10, including, in this example, the operator (e.g., a driver) of the vehicle 10. The user interface comprises an input portion including one or more input devices (e.g., a set of buttons, levers, dials, etc., a touchscreen, a microphone, etc.) allowing an occupant of the vehicle 10 to input commands and/or other information into the vehicle 10 and an output portion including one or more output devices (e.g., a
15 display, a speaker, etc.) to provide information to an occupant of the vehicle 10. The output portion of the user interface which may comprise an instrument panel (e.g., a dashboard) which provides indicators (e.g., a speedometer indicator, a tachometer indicator, etc.) related to operation of the vehicle 10.

The wheels 20_1 - 20_4 engage the ground surface 11 for traction of the vehicle 10. Each
20 wheel 20_i comprises its tire 34 for contacting the ground surface 11 and a hub 32 for connecting the wheel 20_i to an axle.

With additional reference to Figures 2 and 3, the wheel 20_i has an axis of rotation 35, which defines an axial direction (also referred to as a “Y” direction) parallel to the axis of rotation 35 of the wheel 20_i , a vertical direction (also referred to as a “Z” direction) that is
25 normal to the axis of rotation 35 of the wheel 20_i , and a horizontal direction (also referred to as a “X” direction) that is normal to the axis of rotation 35 of the wheel 20_i and the vertical direction and can be viewed as corresponding to a heading direction of the wheel 20_i . The axial direction of the wheel 20_i can also be referred to as a lateral or widthwise direction of the wheel 20_i , while each of the vertical direction and the

horizontal direction of the wheel 20_i can also be referred to as radial direction of the wheel 20_i (also referred to as a “R” direction). The wheel 20_i also has a circumferential direction (also referred to as a “C” direction). The wheel 20_i has an outer diameter D_W and a width W_W. It comprises an inboard lateral side 47 for facing towards a center of the vehicle 10 in the widthwise direction of the vehicle 10 and an outboard lateral side 49 opposite its inboard lateral side 47.

Similarly, the tire 34 has an axial direction, a vertical direction and a horizontal direction that each are a radial direction, and a circumferential direction, which respectively correspond to the axial direction, the vertical direction and the horizontal direction that each are the radial direction, and the circumferential direction of the wheel 20_i, has an inner diameter D_{TI}, an outer diameter D_T, and a width W_T, and comprises an inboard lateral side 53 and an outboard lateral side 57, which are respectively part of the inboard lateral side 47 and the outboard lateral side 49 of the wheel 20_i.

When it is in contact with the ground surface 11, the tire 34 has an area of contact with the ground surface 11, which may be referred to as a “contact patch” of the tire 34 with the ground surface 11.

In this embodiment, the tire 34 is a pneumatic tire, which comprises a body 40 to define a cavity 42 containing pressurized gas (e.g., air) to support loading on the tire 34 and allow the tire 34 to be resiliently deformable (i.e., changeable in configuration) as it contacts the ground surface 11. The tire 34 is configured to be mounted to a rim 44 of the hub 32 to form the cavity 42 containing the pressurized gas. Inflation pressure of the tire 34 is suitable for use of the vehicle 10.

More particularly, in this embodiment, the tire 34 comprises a tread 50, a shoulder 52, a sidewall 54, and a bead 56. The tread 50 is configured to contact the ground surface 11 and enhance traction. The tread 50 may comprise a plurality of tread recesses 23₁-23_R and a plurality of tread projections 27₁-27_P such that each of the tread recesses 23₁-23_R is disposed between adjacent ones of the tread projections 27₁-27_P. The tread 50 may be implemented in any suitable way in other embodiments (e.g., may have a smooth outer surface without tread recesses or projections). The bead 56 is configured to

engage the rim 44. The sidewall 54 extends between the tread 50 and the bead 56 and contains the pressurized gas within the cavity 42. The shoulder 52 is a transition between the tread 50 and the sidewall 54.

5 The tire 34 comprises elastomeric material 45 to allow the tire 34 to be resiliently deformable. The elastomeric material 45 can include any polymeric material with suitable elasticity. In this embodiment, the elastomeric material 45 includes rubber. Various rubber compounds may be used and, in some cases, different rubber compounds may be present in different areas of the tire 34. In other embodiments, the elastomeric material 45 may include another elastomer in addition to or instead of
10 rubber (e.g., polyurethane elastomer).

Also, the tire 34 comprises reinforcement 40 disposed within (e.g., embedded in) the elastomeric material 45 to reinforce the tire 34. In this embodiment, the reinforcement 40 comprises a plurality of reinforcing members 46₁-46_R each of which can be stiffer and stronger than the elastomeric material 45 to reinforce the tire 34 in one or more
15 directions. For example, a given one of the reinforcement members 46₁-46_R may be metallic in that it is at least mainly (i.e., mainly or entirely) made of metal. As another example, a given one of the reinforcing members 46₁-46_R may be polymeric but non-elastomeric in that it is at least mainly made of polymeric but non-elastomeric material (e.g., nylon, polyester, aramid, etc.).

20 More particularly, in this embodiment, each of the reinforcing members 46₁, 46₂ is a belt running in the circumferential direction of the tire 34. In this example, each of the belts 46₁, 46₂ comprises a layer of reinforcing cables 37₁-37_M that extend generally parallel to one another. In this example, the reinforcing cables 37₁-37_M of the belt 46₂ extend diagonally to the circumferential direction tire, and in the general direction of outboard
25 lateral side 49 of the tire 34 to reinforce the tire 34 in that direction, whereas the reinforcing cables 37₁-37_M of the belt 46₁ extend diagonally to the circumferential direction tire, and in the general direction of the inboard lateral side 47 of tire 34 to reinforce the tire 34 in that direction. In other examples, the reinforcing cables 37₁-37_M of the belt 46₁ extend in the circumferential direction of the tire 34 to reinforce the tire 34

in that direction, whereas the reinforcing cables 37₁-37_M of the belt 46₂ extend transversally to the circumferential direction of the tire 34 to reinforce the tire 34 in that direction. In this embodiment, each of the reinforcing cables 37₁-37_M of the each of belts 46₁, 46₂ is a cord including a plurality of strands (e.g., metallic fibers or wires).
5 Specifically, in this embodiment, each of the reinforcing members 46₁, 46₂ is a metallic (e.g., steel) belt in which the reinforcing cables 37₁-37_M are metallic.

In some embodiments, the belts 46₁, 46₂ are separated by belt edge wedges 55₁ and 55₂ extending circumferentially around the tire 34 between the edges of the belts 46₁, 46₂. The belt edge wedges 55₁ and 55₂ are configured to suppress the formation of
10 cracks at the edges of the belts 46₁, 46₂.

Also, in this embodiment, each of the reinforcing members 46₃, 46₄ is a layer of reinforcing fabric. Each of the layers of reinforcing fabric 46₃, 46₄ comprises thin pliable material made usually by weaving, felting, knitting, interlacing, or otherwise crossing natural or synthetic elongated fabric elements, such as fibers, filaments, strands and/or
15 others, such that some elongated fabric elements extend transversally others. For instance, each of the layers of reinforcing fabric 46₃, 46₄ may comprise a ply of reinforcing woven fibers (e.g., nylon, polyester, aramid, and/or other synthetic fibers).

Figure 4 shows a schematic block diagram of an image processing system 500 for use
20 with a system 100 for monitoring road vehicles and off-road vehicles such as one or more vehicles like the vehicle 10. In some embodiments, one or more images captured by an electronic device 501 can be processed using the image processing system 500. For example, in some embodiments, the electronic device 501 may transmit image information relating to a tire 34 of a vehicle, such as the tires 34₁ to 34₄ of the vehicle
25 10, through a communication network 502, to an image processing entity 505 over a communication link, which may be implemented over a cellular network, a WiFi network or other wireless LAN, a WiMAX network or other wireless WAN, etc.

In some examples, the electronic device 501 can be a smartphone, a tablet, a smartwatch, a computer, etc., of a user, who may be the operator of the vehicle or

another person having access to the vehicle. In other examples, the electronic device 501 may be integrated with the vehicle.

In some embodiments, the image processing entity 505 can be an application running on a server. In other embodiments, the image processing entity 505 can be a dedicated
5 network appliance. In yet other embodiments, the image processing entity 505 may be an application running on the electronic device 501. In the embodiment of Figure 4, the image processing entity 505 comprises a memory 506 for storing image information and instructions for processing images, a processor 507 implementing a plurality of
10 computing modules 508_x (for example, Artificial Intelligence, or “AI”, modules) for performing image recognition, pattern recognition and 3D model matching in order to assess a level and nature of wear, degradation and/or other deterioration of the tire 34. In some embodiments, the computing modules 508_x can be implemented using a processor 507. In some embodiments, the computing modules 508_x may be implemented by way of an Application Program Interface (API) that results in the
15 computing modules 508_x being implemented on a separate device or system.

Computing modules 508_x may for example be implemented using known computer vision products, such as, AutoML Vision™ and/or Vision API™, each provided by Google™. In other embodiments, computing modules 508_x may comprise standalone AI or machine-learning solutions forming part of image processing entity 505. As herein
20 defined, AI refers to some implementation of artificial intelligence and/or machine learning (e.g., heuristics, support vector machines, artificial neural networks, convolutional neural networks, any types of deep neural networks, etc.) in software, hardware or some combination of both.

In some embodiments, complex algorithms, like artificial intelligence, are used to
25 categorize what may be considered uncategorizable data. For example, the system 100 can be configured for generating conclusions about a physical state of a tire based on one or more images of the tire itself. This analysis can include whether or not there is a defect in the tire, according to some embodiments. In some embodiments, this can include indications as to the physical state of the tire and/or useful life remaining. As will

be described below, a machine learning algorithm may be trained to identify a defect or other characteristic in a tire by way of image analysis.

In some embodiments, computing modules 508_x are first taught how to identify parameters in a training mode (sometimes referred to as supervised learning mode).

5 This is done by analyzing a given set of values, making quantitative comparisons, and cross-referencing conclusions with known results. Iterative refinement of these analyses and comparisons allows an algorithm to achieve greater predictive certainty. This process is continued iteratively until the solution converges or reaches a desired accuracy.

10 In this embodiment, computing modules 508_x can compare image data for a given tire to a previously-analyzed mass of known data. When placed in a supervised learning mode, information can be generated from already populated tire data provided to the computing modules 508_x. For example, this data could contain images of tires, along with determinations of the remaining life of the tires. In other words, in the supervised
15 learning mode, both the inputs and the outputs are provided to the system 100. The system 100 can process the given inputs and compare the calculated outputs according to its algorithm to the provided outputs. Based on this comparison, the system 100 can determine a metric to represent the percentage of error between calculated and provided outputs. Using this error metric, the system 100 can adjust its method of
20 calculating an output. During training, the system 100 can continuously repeat analysis of different inputs and provided outputs in order to fine-tune its method of determining tire information.

In some embodiments, while the computing modules 508_x may require initial supervised learning, as the computing modules 508_x continue to gain access to data, they may be
25 able to further refine their predictive analytics based on new inputs. For example, if a user is able to confirm that an assessment (e.g. wheel imbalance) or prediction (e.g. 6 months of use left in a given tire) made by the system 100 is/was incorrect, the user can upload to the system 100 what the correct conclusion/prediction was. This allows the computing modules 508_x to continue to improve accuracy in their analysis.

In some embodiments, multiple computing modules 508_x can be configured to determine different characteristics of a given tire. Each of these modules can offer a different analysis for a given input. The processor may direct these modules to be used independently or concurrently based on an operational parameter determined by a given user. For example, the system 100 may use a different analytical technique to determine tires life compared to wheel imbalance. Based on an image communicated to the system 100 from an electronic device, the system 100 may analyze a given for tires life, wheel imbalance, or other forms of wear and/or damage.

In some embodiments, the computing modules 508_x are configured to assess a level of wear, damage and/or other deterioration of the tire 34. For example, a computing module 508_x can be configured to determine that the tread projections 27₁-27_P are worn to 30% of the level of wear that would require replacement of the tires. In some embodiments, the computing modules 508_x are configured to assess the nature of damage to the tire 34. For example, a computing module 508_x can be configured to determine that any other component of the given one of wheels 20₁-20₄ is damaged or missing.

In some embodiments, the computing modules 508_x are further configured to predict the cause of the wear and/or damage to the tire 34. In one specific example, a computing module 508₁ is configured to predict whether a specific wear pattern of the elastomeric material of a tire 34_i is caused by imbalanced wheel. In another specific example, a computing module 508₂ is configured to predict whether a specific wear pattern of the elastomeric material of a tread projections 27₁-27_P is caused by incorrectly installed tire. In another specific example, another computing module 508₃ is configured to predict whether a specific wear pattern of the tires is caused by a categorized or uncategorized event. As will be appreciated, each computing module 508_x can be implemented using a combination of deep learning, supervised or unsupervised machine learning, image recognition and/or machine vision.

In some embodiments, the system 100 is configured to capture one or more 2D images to detect specific patterns of wear and/or damage. For example, the system 100 may be

configured to implement one or more computer vision (CV) models to detect specific visible wear/damage features. Examples of such visible wear/damage features include, but are not limited to, the presents of nails, or other road debris capable of piercing tires, as well as cracks in tire sidewalls.

5 In some embodiments, the image processing system 500 may produce a three-dimensional (3D) scan to generate a 3D model of at least part of the tire 34. For example, in some embodiments, the image data received by the electronic device 501 or any other image capture means are processed by way of photogrammetry in order to create the 3D model of the tire 34 and/or another component of a given one of the
10 wheels 20₁-20₄. In some embodiments, as described in more detail below, laser line scanners are instead used to generate the 3D model of the tire 34 and/or another component of a given one of the wheels 20₁-20₄.

Such precise 3D models can be compared to 3D models of unworn and/or undamaged tires in order to precisely measure wear, damage and/or other deterioration. For
15 example, by comparing the 3D model of a worn tire 34_i to the 3D model of a new, unworn tire, it is possible to precisely measure a volumetric loss of material of the worn tire 34_i, and thereby assess the wear and/or other deterioration of the worn tire 34_i, very precisely.

With reference to Figure 34, in some embodiments, the system 100 may generate a 3D
20 model 55 of a tire 34_i, using any of the above methods, or a combination thereof. In some embodiments, the system 100 can then be superimposed onto an image of the tire 34_i captured by electronic device 501. Such superimposition may be achieved using known augmented reality (AR) techniques and processes.

As described above, in some embodiments, the system 100 can implement a 2D
25 recognition technique. In some embodiments, the system 100 can implement a 3D recognition technique. In some embodiments, the system 100 can implement a combination of a 2D recognition technique and a 3D recognition technique.

In some embodiments, the 3D recognition technique used is based on generating a 3D model using a point cloud. For example, as shown in Figure 41, method 4000 can be used to identify tire wear/damage and/or the extent thereof. At step 4001, a plurality of images of the tire can be acquired using the electronic device 501, before sending the
5 images to the image processing entity 505 at step 4002. At step 4003, the system 100 generates a 3D point cloud using the plurality of images. This can be accomplished by system 100 using, for example, open source algorithms, such as those available from Point Cloud Library (PCL). Alternatively, the point cloud can be generated a third party, through use of an Application Program Interface (API) by system 100. At step 4004, the
10 system 100 uses the generated 3D point cloud to generate a 3D model of the tire. Once generated, the 3D model is matched to known 3D models of tires in a tire database at step 4005. Once matched, at step 4006, wear, damage and/or the extent thereof can be identified by comparing the generated 3D model to the known 3D model, as described in more detail below.

15 2D recognition techniques include four basic steps, namely image acquisition, image processing, feature extraction and classification. Such techniques include, but are not limited to, Optical Character Recognition (OCR), feature detection, image gradient analysis, pattern recognition algorithms and feature/pattern classification algorithms.

In some embodiments, the system 100 can be configured to implement the method of
20 Figure 42. In particular, at step 4101, the electronic device 501 can acquire one or more images of a tire, before sending the images to the image processing entity 505 at step 4102. In some embodiments, the image processing entity 505 can perform image processing steps prior to feature extraction. For example, in some embodiments, the image processing entity 505 can be configured to perform image processing including
25 the use of fiducial markers. Then, at step 4104, the image processing entity 505 can perform feature extraction in order to detect and isolate various portions or shapes (features) of the image or images. Feature extraction can include, but is not limited to, edge detection, corner detection, blob detection, ridge detection, scale-invariant feature transform, thresholding, blob extraction, Haar-like feature extraction, template matching,
30 Hough transforms and generalized Hough transforms.

Then at step 4105, the system 100 can perform feature classification. In some embodiments, feature classification can include, but is not limited to, the use of nearest neighbor classification, cascading classifiers, neural networks, statistical classification techniques and/or Bayesian classification techniques. Once the features have been
5 classified, it is possible to separate, at step 4106, features which represent undamaged/unused parts of the tire, and features (e.g. cracks, exposed cables, etc.) which represent patterns of wear or damage. Once features relating to patterns of wear or damage have been detected, it is possible for the system 100 to perform further feature classification on the wear or damage pattern.

10 As shown in Figures 39 and 40, in some embodiments, system 100 is configured to use the system of Figure 42 in order to detect damage or wear patterns in tires. For example, as shown in Figure 39, system 100 can be configured to detect partially embedded nails 55A using the 2D analysis method described with reference to Figure 42. Similarly, as shown in Figure 40, system 100 can be configured to recognize narrow
15 (though potentially deep) cracks 55B in sidewalls of a tire. As will be appreciated by the skilled reader, such patterns are difficult to detect using volumetric analysis alone. As such, the 3D recognition techniques of the present disclosure can be combined with any of the 2D recognition techniques in order to facilitate tire matching, as well as wear and/or damage recognition and characterization. Moreover, the 2D recognition
20 techniques of the present disclosure can be used on images generated by the system 100 of various views of the 3D model generated using the 3D recognition techniques of the present disclosure.

As shown in the method of Figure 43, once a plurality of images are acquired at step 4201, the system 100 can sequentially use 3D recognition at step 4202 and then 2D
25 recognition at step 4203 in order to detect patterns of wear and/or damage on a tire. In some embodiments, 2D recognition may be performed before 3D recognition. Advantageously however, 3D recognition is performed first, as in such an arrangement, the system 100 may be configured to superimpose 2D features onto 3D models, thereby allowing a more precise classification of the type of wear and/or damage.

As shown in Figures 35 to 38, in some embodiments, the system 100 is configured to generate a 3D model 55 of a used and/or damaged tire and compare it to a 3D model 77 of an unused and undamaged tire. The 3D model 77 of an unused and undamaged tire may be generated by the system 100 based on a previously-scanned tire, may be
5 acquired by the system 100 from a database of 3D models of tires, or may be acquired by the system in any other suitable way. Once the 3D model 77 of an unused and undamaged tire is acquired or generated by the system 100, it can be compared to the 3D model 55 of a used and/or damaged tire generated by the system 100 using various volumetric comparison techniques. For example, the system 100 may compare the
10 models by calculating the amount of missing material of a given tire feature (e.g. tread projections 27_1 - 27_P). For example, volumetric comparison of the 3D model 55 of a used and/or damaged tire and a 3D model 77 of an unused and undamaged tire can establish that a given tread projection 27_x has been worn to 78% of its original volume.

In some embodiment, the cause and/or nature of the wear and/or damage of the tire 34,
15 can be established by the system 100 performing a volumetric comparison of the 3D model 55 of a used and/or damaged tire and a 3D model 77 of an unused and undamaged tire.

For example, as shown in Figure 35, based on a comparison of the 3D model 55 of a damaged tire and a 3D model 77 of an undamaged tire, the system 100 can determine
20 a pattern of damage that is indicative of the cause and/or nature of the damage. In particular, the chunking detected by the system 100 in the tread projections 27_1 - 27_P of Figure 35 is typically caused by using the tire on abrasive ground and/or on ground containing oil or some other form of contaminant.

As shown in Figure 36, based on a comparison of the 3D model 55 of a used tire and a
25 3D model 77 of an unused tire, the system 100 can determine a pattern of tread wear that is indicative of the cause and/or nature of the tread wear. In particular, the uneven tread wear detected by the system 100 in the tread projections 27_1 - 27_P of Figure 36 is typically caused by an abnormal camber angle and/or a misaligned axle.

As shown in Figures 37 and 38, based on a comparison of the 3D model 55 of a damaged tire and a 3D model 77 of an undamaged tire, the system 100 can determine a pattern of damage that is indicative of the cause and/or nature of the damage. In particular, the radial cracks detected by the system 100 between the tread projections 27₁-27_P and the sidewall 54 of Figure 37 is typically caused by inadequate installation of the tire on the wheel and/or overloading of the vehicle 10. The concentric crack damage detected by the system 100 on the side wall of the tire above the rim of Figure 38 is typically caused by an overloading of the vehicle 10.

As described above, and as shown in Figure 39, system 100 can use the 2D recognition technique described above to recognize and characterize the presence of partially embedded nails 55A. Also, as shown in Figure 40, the system 100 can use the 2D recognition technique described above to recognize and characterize the presence of cracks 55B in the sidewall of a tire.

Once the computing modules 508_x has determined the cause, level and/or nature of the wear and/or damage of the tire 34, the image processing entity 505 may send data relating to the cause, level and/or nature of the wear and/or damage of the tire 34 back to electronic device 501 for further processing and/or notification to a user. By using this information, electronic device 501 may determine that an event arising from usage of the tire 34, such as a usage threshold event (e.g. an amount of tread wear, an amount of time such as a number of hours the tire 34 has been used), wear threshold event (e.g. the number of exposed radial cracks between the projection treads 27₁-27_P and the sidewall 54) and/or damage event (e.g. minor delamination damage and/or “chunking” damage), has occurred.

According to some embodiments, the computing modules 508_x may have access to information stored elsewhere on the internet. For example, the computing modules 508_x may be configured to query databases stored on external servers by sending requests over the network in order to analyze the image based on pertinent cross-referential data. This may include weather, humidity, or information about the vehicle or tires that can be periodically updated.

Figure 5 illustrates a schematic network diagram of a system 100 for monitoring vehicles such as one or more road vehicles and off-road vehicles like the vehicle 10, according to one embodiment. In the embodiment of Figure 5, the system 100 includes an electronic device 501, a network 124, and a system server 1142 that can implement the image processing entity 505 of Figure 4. The server includes a memory 1146, processor 1144, and network interface 1148.

The electronic device 501 may include elements such as a processor, a memory, a display, a data input module, and a network interface. The electronic device 501 may include other components, but these have been omitted for the sake of brevity. In operation, the electronic device 501 is configured to perform the operations described herein. The electronic device 501 processor may be configured to execute instructions stored in memory. The instructions, when executed, cause the electronic device 501 to perform the operations described herein. In some embodiments, the instructions may be part of a software application downloaded into memory by the electronic device 501. Alternatively, some or all of the functionality described herein may be implemented using dedicated circuitry, such as an ASIC, a GPU, or a programmed FPGA for performing the operations of the processor.

In some embodiments, an application ("app", i.e., software) may be installed on the electronic device 501 to interact with the system server 1142 and or the vehicle 10. For example, in some embodiments, such as where the electronic device 501 is a smartphone, a tablet, a computer, etc., the user (e.g., the operator) may download the app from a repository (e.g., Apple's App Store, iTunes, Google Play, Android Market, etc.) or any other website onto the electronic device 501. Upon activation of the app on the electronic device 501, the user may access certain features relating to the system server 1142 and/or the vehicle 10 locally on the electronic device 501.

In operation, a user can use the electronic device 501 to generate data about the vehicle 10. For example, for embodiments where the electronic device is a smart phone equipped with a camera, the user can take one or more images of a tire 34 of the

vehicle 10. The system 100 may then take the image data captured by the electronic device 501 and transmit the image data over a network 124 to a system server 1142.

According to some embodiments, the electronic device 501 may be a portable electronic device with multiple uses such as a mobile phone, tablet or laptop. According to other embodiments, the electronic device may be a single-use electronic device, such that the device is designed to only be used in operation with the system 100. Further, the electronic device 501 may also be capable of establishing a communicable link with an accessory device. This communicable link may be wireless, wired, or partly wireless and partly wired (e.g., Bluetooth or other short-range or near-field wireless connection, WiFi or other wireless LAN, WiMAX or other wireless WAN, cellular, Universal Serial Bus (USB), etc.).

According to other embodiments, the electronic device 501 may be integrated into an internal computer 1342 in the vehicle (as shown in Figure 6). The internal computer 1342 may have a vehicle memory 1346, processor 1344, network interface 1348, and internal sensor network 1350. In some embodiments, vehicle internal computer 1342 can communicate and upload images to system server 1142 independently.

The internal sensor network 1350 can include sensors to provide information about the vehicle or the tires of the vehicle. For example, this may include a camera positioned to take images of the tires. In some embodiments where the electronic device is integrated into an internal computer in the vehicle, the system 100 may be configured to continuously monitor the tires. This can be achieved by continuously capturing data, for example, images of the vehicle tires, at various intervals. The electronic device 501 can then automatically upload the data over the network 124 to the system server 1142 for image processing. After processing, the image processing entity 505 can automatically communicate over the network 124 if a fault state has been determined.

The electronic device 501 can also send additional data to the image processing entity 505 over the network 124. For example, this can include (but is not limited to) GPS location, date and time, or any information from an onboard computer within the vehicle. This data can be cross-referenced and analyzed within the computing modules 508_x.

For example, given GPS and date and time data, the computing modules 508_x can access the specific weather and weather history for the vehicle location. In some embodiments, such information may be used in, for example, determining the end-of-life of a tire (i.e. the amount of time until a tire is expected to fail or until the likelihood of tires failure rises above a predetermined threshold).

This may be achieved by a separate electronic device 501 being communicably linked to an internal computer 1342 of a vehicle 10. The internal computer 1342 may periodically receive and record information relating to the vehicle 10 and/or the tires 34₁-34₄ determined by the internal sensor network 1350. For example, the information received from the internal sensor network 1350 may include an image taken of the tires or information about the vehicle 10, such as the speed of the vehicle 10.

According to some embodiments, the electronic device 501 may communicate a unique identifier for a specific tire under inspection. In some embodiments, the unique identifier can be a serial number of the tire. This allows the server 1146 and/or internal computer 1342 to catalog the inspection and produce a history of a given tire. According to some embodiments, the internal computer 1342 and/or the server 1146 may store data about the serial numbers of the tires installed on the vehicle 10.

According to some embodiments, the electronic device 501 may be capable of determining a serial number from a tire based on an image of the tire. This can be done by the electronic device 501 capturing an image of an embossed serial number on a surface of the tires, and using the image processing entity 505 to determine the specific characters of the serial number. This can be cross-referenced with a database stored in server memory 1146 (or otherwise accessible by system server 1142) to determine elements such as the model and date of manufacture of the tire.

Serial number analysis may be performed using AI techniques employed by the computing modules 508_x, may be performed using techniques such as optical character recognition (OCR), or a combination thereof. These techniques may include preprocessing of an image in order to improve the ability to analyze the target components, such as de-skewing, layout analysis, and binarization. In some

embodiments, a tire and/or another component of a given one of the wheels 20₁-20₄ (e.g., outer rim) can be identified by way of another marking or tag suitable for communicating information relating to the tires. Such markings or tags can include, but are not limited to, barcodes, Quick Response (QR) codes or other matrix barcodes and
5 Radio Frequency Identification (RFID) tags.

Another method of tire identification that can be performed by the electronic device 501 is tire pattern recognition. The electronic device 501 may be configured to analyze the tread pattern and measure tire width to determine a number of characteristics about the tire. The electronic device 501 may then send this data and information to the system
10 server 1142 for further data analysis to identify the type of tire. The type of tire may be a tire brand, model number, or any other suitable information capable of identifying a tire.

According to some embodiments, the vehicle may be capable of communicating all the necessary data over the network without the use of an external electronic device 501 such as a mobile phone. For example, the vehicle 10 may be equipped with a network
15 interface capable of independently communicating with the system server 1142 over the network 124.

According to some embodiments, a system server 1142 hosts the image processing entity 505. Server processor 1144 is able to access instructions stored in the memory 1146 that can initialize the image processing entity 505. This initialization can include
20 operational parameters that include which computing module 508_x to use.

Image processing entity 505 can store instructions relating to a specific computing module 508_x within the memory 1146. The processor 1144 may instruct the server to save the data received from the network via the network interface 1148 in memory 1146. The processor 1144 may analyze the data in memory 1146 and determine
25 information about the tire 34. Based on the data analysis, the processor 1144 may send a communication to the electronic device 501 over the network 124 via the network interface 1148.

Figure 7 illustrates a schematic network diagram of a system 100 for monitoring road vehicles and off-road vehicles, according to another embodiment. According to this embodiment, the system 100 can communicate with multiple vehicles 10_A-10_N. While this figure shows the vehicles 10_A-10_N communicating independently with the system
5 server 1142 over the network 124, the vehicles may alternatively each be communicably linked with an electronic device 501 as described with reference to Figure 5. According to this embodiment, the system server 1142 may communicate with an electronic device 501 located at a dispatch center 1102, a service center 1104, or a parts supplier 1107.

10 In operation, based on the analysis determined by the image processing entity 505, the system server 1142 may communicate with the user via an electronic device 501 or the vehicle 10, a dispatch center 1102, a service center 1104, or a parts supplier 1106. The system 100 may also communicate with any combination of these, or any other suitable device registered within the system 100. This communication can contain information
15 such as that indicating the determination of tire wear and/or damage concluded by the image processing entity 505. Based on this information, the dispatch center 1502 or user may schedule maintenance with the service center 1104. Based on the conclusion on tire wear and/or damage (for example, that the tire needs to be replaced) and vehicle information (tire type, vehicle type) available, the system 100 can determine the amount
20 of time required or parts available at the service center 1104 and facilitate scheduling a maintenance appointment or a shipment from the parts supplier 1106. This can be done by maintaining a database of inventory at the service center, along with a calendar.

Figure 8 A to C illustrate representations of different databases that may be generated by the server processor 1144 based on information stored in memory 1146. The server
25 memory 1146 can store a history of all information necessary for performance of the system 100, including a record of all inspections and conclusions made. These databases, or the information stored within them, may be accessible to users and administrators of the system 100, or to software able to interact with the system 100 through the use of an application programming interface (API).

Figure 8A shows an example of a visual representation of a database that can be generated by the system 100 according to an embodiment directed towards a specific tire manufacturer. This includes an indication of tire model, a serial number for the tire, the date of an inspection, the type of inspection, along with the registered owner. This database representation gives the manufacturer access to all registered tires sold and registered within the system 100, and allows access to information on tire wear and damage.

Figure 8B shows an example of a visual representation of a database that can be generated by the system 100 according to an embodiment directed towards a vehicle fleet manager. The database includes an indication of tire model, a unique identifier for the vehicle itself, the date of an inspection, tire status, and an additional field for manager notes. This database representation gives the fleet manager access to all vehicles registered within the system 100, and allows them to access a history of information on tire wear and/or damage.

Figure 8C shows an example of a visual representation of a database that can be generated by the system 100 according to an embodiment directed towards a specific vehicle manufacturer. This includes an indication of vehicle model, tire model, a date of an inspection, tire status, and an additional field for manager notes. This database representation gives the vehicle manufacturer access to all of their vehicles registered within the system 100, and allows them to access a history of information on tire wear and/or damage.

The disclosed embodiments of database representations are structured merely by way of example for illustrative purposes, and a skilled reader would know that these visual representations can be changed to include more or less information available to the system 100.

Figure 9 shows an example flowchart of the use of the system 100 which could be used (e.g., by the operator of the vehicle 10, in a rental market, etc.) to monitor usage of tires.

In operation, a user can use the electronic device 501 to generate image data relating to the tire 34 of the vehicle 10. According to some embodiments, the electronic device 501 may also access internal information stored on the vehicle onboard computer 1342. The electronic device 501 may then communicate both the data captured and the information retrieved by the electronic device 501 over the network 124 to the system server 1142 to be stored in memory 1146. Using both the data captured and the information retrieved the processor 1144 may determine information about the tire 34. Based on the data analysis, the processor 1144 may send a communication to the electronic device 501 over the network 124 via the network interface 1148.

At step 1301, the system 100 determines that an event arising from use of a tire 34, such as a usage threshold event (e.g. an amount of time such as a number of hours the tire 34 has been used) or a deterioration threshold event (e.g. the number of exposed radial cracks between the projection treads 27₁-27_P and the sidewall 54) and/or deterioration event (e.g. minor delamination damage and the “chunking” damage), has occurred. As described above, the system 100 can make these determinations by analysis of the images taken by the image capture devices described above.

At step 1302, the system 100 identifies the tire for which the usage threshold event or deterioration threshold event has occurred. In some embodiments, the tire information and information relating to the usage threshold event and deterioration threshold event is conveyed to the operator of the vehicle by the system 100 in order to facilitate scheduling of tire servicing and/or other maintenance.

For purposes of this example, it is assumed that the usage threshold event or deterioration threshold event is for the tire 34.

For example, the system 100 may issue a notification conveying this information to the operator via the user interface of the operator of the vehicle 10 and/or the electronic device 501. According to embodiments wherein the electronic device 501 is a mobile phone, this could be in the form of a push notification sent to the app over the network 124. In other embodiments, the system 100 conveys the tire information and information relating to the usage threshold event and deterioration threshold event to an

organization providing maintenance services. For example, the system 100 may issue a notification conveying this information to a system server 1142 associated with the organization via a network 124 (e.g. which may be implemented by the Internet, a cellular connection, and/or any other network infrastructure). Once the information is received, the organization can schedule maintenance of the vehicle at step 1303, and subsequently replace or repair the tire. Accordingly, tire maintenance operations can be initiated and scheduled without the need for input from the vehicle operator.

As shown in Figure 10, the system 100 may allow organizations to provide tire-as-a-service type payment/usage models, in which tires are not purchased, but are rather provided as a service to vehicle operators in exchange for a subscription fee. For example, for a monthly fee, an organization may provide vehicle operators with tires, as well as usage rights to the system 100 described herein which will allow the organization to ensure that the vehicle operator is never without an operable/functional tires, regardless of how much and how (i.e. under what circumstances) the vehicle operator uses the tires.

This can lead to significant savings in term of vehicle downtime and logistics. For example, at step 1401, the system 100 determines that an event arising from usage of a tire, such as a usage threshold event (e.g. an amount of tread wear, an amount of time such as a number of hours the tire 34 has been used), deterioration threshold event (e.g. the number of exposed radial cracks between the projection treads 27₁-27_P and the sidewall 54) and/or deterioration event (e.g. minor delamination damage and the “chunking” damage), has occurred. At step 1402, the system 100 identifies the tire for which the usage threshold event, deterioration threshold event and/or deterioration event has occurred. At step 1403, vehicle location information relating to the geographic location of the vehicle is determined. This can be achieved by any suitable means including, but not limited to, Global Positioning System (GPS) receivers. In some embodiment, the system 100 conveys the tire information, vehicle location information and information relating to the usage threshold event, deterioration threshold event and/or deterioration event to the tire-as-a-service organization.

As shown in above, the system 100 may communicate with the system server 1142 of the tire-as-a-service organization over a network 124 (e.g. which may be implemented by the Internet, a cellular connection, and/or any other network infrastructure). Then, at step 1404, the tire-as-a-service organization ships a replacement tire to a location
5 related to the geographic location of the vehicle. For example, the tire-as-a-service location could ship the replacement tire to the nearest maintenance service dispatch location or third party maintenance organization. At step 1405, the tire-as-a-service organization can schedule a maintenance of the tires. In some embodiments, the tire-as-a-service organization schedules a third party mobile maintenance team to perform
10 onsite maintenance based on the geographic location of the vehicle. Finally, at step 1406, the tire-as-a-service organization, or an agent thereof, replaces the tire. In some embodiments, this can be performed onsite, based at least in part on the vehicle location information received from the tire-as-a-service organization.

Figure 11 shows an example flowchart of the use of the system 100 which could be
15 used, for example, by a fleet manager to monitor usage of tires. In this system 100, the preferences of a given fleet manager can be included in any part purchase or system maintenance request. For example, a fleet manager may consider a specific tire to be superior to all other on the market. The fleet manager may want to only purchase that specific brand of tire. Another example of purchase preferences may include only to
20 purchase a specific tire if the supplier inventory and price database indicates that the part is available with a discount. Further, if there is no supply of a first preferred tire in the inventory, the user may store a preference for an alternate tire to be purchased. In this embodiment, steps 1501 and 1502 are the same as those described in steps 1301, 1401, and 1302, 1402 respectively.

25 At step 1503, the system 100 will query the memory to determine if the specific user has a purchase preference stored in the system 100. If the system 100 has a purchase preference stored for the given user, the system 100 will order the tire for replacement based on the saved preference at step 1506. If the system 100 does not find a purchase preference for the given user, the system 100 may send a communication to the user's
30 electronic device 501 with information indicating the part purchase options and

information about the parts (for example the various options of price and part characteristics). The system 100 may also send a communication instructing the electronic device 501 to prompt the user to store a purchase preference. Based on this information, the system 100 will order the tire at step 1507.

- 5 At step 1509, the system 100 may schedule maintenance with a given service center or technician. At this step user preferences may also be considered. For example, a user may be able to store in their profile a preference for scheduling. This may include a preference for the first available time to service the vehicle. Alternatively, a fleet manager may try and coordinate scheduling of maintenance with other vehicles within a
- 10 fleet. This could include wanting all vehicles to be serviced at the same time, or to stagger vehicle services. Scheduling preferences may also include a time of day preference for the user to have maintenance scheduled. Based on these preferences, the user may be automatically scheduled for maintenance.

According to other embodiments, the system 100 may prompt the user via a date and

15 time entry interface, such as a calendar interface, on the electronic device 501 to input a date and time for maintenance. Based on this input data, the system 100 can schedule maintenance with a technician or service center.

Finally, at step 1520, the tire-as-a-service organization, or an agent thereof, replaces the tire. In some embodiments, this can be performed onsite, based at least in part on

20 the vehicle 10 location information received from the tire-as-a-service organization.

Figure 16 shows an example flowchart of the use of the system 100 which could be used, for example, by a fleet manager to monitor usage of tires. According to this embodiment, inventory of the tires at a given service center can be monitored. The system 100 allows organizations managing large fleets (e.g. vehicle rental companies,

25 construction companies, forestry companies, etc.) to ensure that maintenance operations can be scheduled and carried out effectively and efficiently. For example, by monitoring the wear of tires, it is possible to more precisely predict when a tire will fail and/or when a replacement tire should be ordered and/or shipped.

Moreover, for an organization managing a fleet of vehicles, knowing which vehicles will shortly require maintenance and/or replacement parts contributes to efficient and effective deployment of vehicles and maintenance resources. For example, at step 1601, the system 100 determines that an event arising from usage of a tire 34, such as a usage threshold event (e.g. an amount of tread wear, an amount of time such as a number of hours the tire 34 has been used), deterioration threshold event (e.g. the number of exposed radial cracks between the projection treads 27₁-27_P and the sidewall 54) and/or deterioration event (e.g. minor delamination damage and the “chunking” damage), has occurred. At step 1602, the system 100 identifies the tire for which the usage threshold event, deterioration threshold event and/or deterioration event has occurred. In some embodiments, as shown in Figure 12, the system 100 conveys the tire information and information relating to the usage threshold event, deterioration threshold event and/or deterioration event to an automated fleet management system. The system 100 may communicate with the automated fleet management system over a network 124 (e.g. which may be implemented by the Internet, a cellular connection, and/or any other network infrastructure). At step 1603, the automated fleet management system queries a tire supply database to determine whether the identified tire is available or needs to be ordered.

The tire supply database can be managed by the fleet management system, or can be managed by a third-party tire supplier. If the identified tire is available, the vehicle can be scheduled for maintenance. If, on the other hand, the tire is not available, the fleet management system can cause the tire to be ordered at step 1604, before scheduling maintenance of the vehicle at step 1605. This system may also include ordering based on stored user preference as previously described.

In some embodiments, the scheduling of the vehicle maintenance is at least in part based on the estimated delivery time for an ordered tire. In other embodiments, the dispatching of the vehicle relating to the identified tire can, at least partially, be based on a pre-scheduled maintenance. This system 100 may also include scheduling based on stored user preference as previously described. Finally, at step 1606, the maintenance operation is carried out and the tire is replaced or repaired.

Figure 13 shows an example flowchart of the use of the system 100 which could be used, for example, by a vehicle operator to monitor usage of tires. According to this embodiment, the system 100 has determined a critical error to have taken place or imminent. In this embodiment, steps 1701 and 1702 are similar to those described in
5 steps 1301, 1401, and 1302, 1402 respectively.

If the system 100 has determined that a critical error has taken place or is imminent, it can prompt the user to establish an audiovisual and/or textual connection with a technician at 1703. This could be achieved by using a Voice Over IP (VoIP) system, a
10 phone call over a cellular network, or any other means of text, audio or video communication. This will allow the vehicle operator to communicate with the technician and get or receive pertinent information to vehicle maintenance. For example, the technician may instruct the user to drive the vehicle to a safe location and wait for the technician to arrive. In the case of a video call, the technician may be able to instruct the user to point the camera of the electronic device at a specific component of the vehicle
15 10 in order to provide the technician with more information about the vehicle status.

Figure 14 shows an example flowchart of the use of the system 100 which could be used, for example, by a vehicle operator to monitor usage of tires. According to this embodiment, the system 100 has determined a critical status of the tire and/or another component of a given one of the wheels 20₁-20₄. In this embodiment, steps 1801 and
20 1802 are similar to those described in steps 1301, 1401, and 1302, 1402 respectively.

At step 1803, the system 100 alerts relevant parties of the critical status. This can include fleet managers, technicians or other operators. For example, the system 100 may send a text message, email or app push notification to any interested party that the status and operability of a given vehicle with a unique identifier has reached a certain
25 threshold of wear or damage. Based on the information determined by the system 100, the vehicle operator or fleet manager may override the decision determined by the system 100 and continue to operate the vehicle. Alternatively, the system 100 may have the capability to safely disable the vehicle given specific parameters. For example, the system 100 may only allow the vehicle to operate for another specific distance or time,

or may not allow the vehicle to restart after it has switched off without an appointment with a technician.

Figure 15 shows an example flowchart of the use of the system 100 by, for example, a vehicle operator to monitor usage of tires. According to this embodiment, the system 100 is able to determine a specific tire brand or type, and cross-reference this brand or type with a database of compatible brands stored in a memory. In this embodiment, steps 1901 and 1902 are similar to those described in steps 1301, 1401, and 1302, 1402 respectively.

According to this embodiment, the system 100 is able to identify the tire characteristics 1903. These characteristics may include thickness, length, weight, width, tread pattern, etc. Based on an analysis of the vehicle's tires, the system 100 can determine tire alternatives at step 1904. This can be done using a pre-populated database stored on a server of all major available tire brands and products, along with compatible alternatives. Once the system 100 has determined the tire and tire characteristics, it can query the database to find all other products that could be used for the vehicle.

The system 100 can then communicate the tires to the user at step 1905. This can be done by sending the information over the network to the electronic device. The user may determine that an alternative tire could be used for the vehicle. If the user selects the alternative tire, the system 100 will send that message back to the server over the network and proceed to organize any part replacement using the user's selection.

As shown in Figures 16 to 19, image data capture is shown according to different embodiments. According to some embodiments, the electronic device 501 can display an instruction to the user to position and/or move the electronic device 501 in order to optimally capture the image.

Figure 16 shows an embodiment in which the system 100 may instruct the user to take an image of the vehicle 10. The electronic device 501 will communicate this image along with any other information to be communicated to the system server 1142 for analysis, as described above.

As shown in Figure 17, the system 100 may also or instead instruct the user to take a video of the tire 34. The electronic device 501 may then communicate this video along with any other information to be communicated to the system server 1142 for data analysis, as described above.

5 As shown in Figure 18, the system 100 can instruct the user to use an accessory device 2202 in conjunction with the vehicle 10 in order to generate data about the tire 34. According to this embodiment, the accessory device 2202 can be an optical sensor communicatively linked to the electronic device 501. The accessory device 2202 can communicate the image data captured to the electronic device 501. The electronic
10 device 501 may communicate this data along with any other information to be communicated to the system server 1142 for analysis, as described above.

As shown in Figure 19, the electronic device 501 can be communicably linked to the vehicle, according to some embodiments. According to this embodiment, the electronic device 501 communicates with an onboard computer 1342 in the vehicle 10 in order to
15 generate data about the vehicle. The electronic device 501 may communicate this data along with any other information to be communicated to the system server 1142 for analysis, as described above.

As shown in Figure 20, the information determined about the vehicle based on the analysis conducted by the system 100 is communicated to the electronic device 501
20 over the network 124. According to this embodiment, the information was a length of time before the tires needed to be replaced.

As shown in Figure 21, the system 100 has already communicated to the electronic device that based on the data analysis, vehicle maintenance is required. The electronic device 501 can then prompt the user to schedule the maintenance. If the user decides
25 to schedule the maintenance, the electronic device 501 can communicate directly with a service center 2604 in order to schedule the maintenance over the network 124. For example, the user may have access to a booking calendar for the service center and select a time. Based on this selection, the parties will be notified that maintenance has been booked. According to some embodiments, the system 100 may have access to

information about the service center 2604, such as parts inventory. Based on this inventory, the system 100 can calculate any lead time if required that can be factored into the booking span.

5 According to other embodiments such as those shown in Figure 22, the system 100 can order new parts through the network 124 by creating a request to a retailer or parts center 2704. In this embodiment, if the service center requires a unique part that they do not have, the system 100 may create a request to the parts center to ship the part to the service center in advance of the booked maintenance time.

10 According to another embodiment, the system 100 may have access to pricing information or alternative replacement parts available at the parts center 2704. The system 100 may present the user with pricing options, sale information for different components they may require ordering for replacement. The user may then inform the system 100 of their preference and the system 100 will submit the order to the parts center accordingly.

15 As shown in Figure 23, according to some embodiments, the system 100 is configured to schedule a maintenance request over the network 124 without requiring a user to select a time. This time may be based on a user preference saved in the server memory for a given vehicle owner. For example, an owner may have a preference that all vehicles are scheduled for maintenance one month before the system 100 determined
20 date. Accordingly, the system 100 can notify the user of scheduled maintenance as it is automatically scheduled.

Similarly, according to some embodiments, the system 100 is able to make purchase requests over the network 124 without requiring the user to select a part component. This choice may be based on a user preference saved in the server memory for a given
25 vehicle owner. For example, an owner may have a preference for a specific brand of vehicle parts. Accordingly the system 100 can notify the user of the part purchase as it is automatically scheduled.

As shown in Figure 24, the electronic device may be communicably linked to a technician 3204. Alongside the user of the electronic device, the technician can also be notified over the network 124 of any determined vehicle information, scheduled maintenance, parts purchased, location of maintenance etc. Based on the user selection the user can be connected to a technician 3204 via the network 124. This connection could be by way of a telephone call, wherein the system 100 communicates a phone number over the network for the electronic device. Alternatively, the system 100 may use a Voice Over IP (VoIP) connection between the user and the technician. According to other embodiments, the communication between user and technician established could be a video call, wherein the technician is able to view a feed coming from a camera module within the user's electronic device.

According to the embodiments disclosed in Figures 25 to 27, the system 100 may determine that the vehicle has a critical malfunction. This could be determined through information captured from the onboard computer's internal sensor network or through data captured via the electronic device. For example, the vehicle tires may have been damaged to the point where further driving would cause greater permanent damage to the vehicle and may endanger the safety of the driver. Using the communication link between the electronic device and the vehicle, the system 100 can instruct the electronic device to prompt a user with a notification of the critical malfunction and request instruction for whether or not the vehicle should be allowed to continue to operate. Based on this decision, the electronic device can instruct an onboard computer in the vehicle that the vehicle should not be operated again until the system 100 has determined the vehicle is no longer in a critical malfunction state.

According to another embodiment and shown in Figure 25, the electronic device may offer the user a choice to immediately disable the vehicle. Based on this decision, the electronic device can instruct an onboard computer in the vehicle that the vehicle should not be operated again until the system 100 has determined that the vehicle and/or the tires is no longer in a critical state.

According to another embodiment and shown in Figure 26, the electronic device may not offer the user a choice and immediately disable the vehicle. Based on this decision, the electronic device can instruct an onboard computer in the vehicle that the vehicle should not be operated again until the system 100 has determined the vehicle and/or the tires is no longer in a critical state.

According to yet another embodiment and shown in Figure 27, the electronic device may not offer the user a choice and may disable the vehicle once the vehicle has been returned to a specific location. This can be done by using a location coordinate determined by either the electronic device 501 or in the vehicle itself. While the vehicle may be continued to be used to complete the current job, when the location coordinate of the vehicle is determined to be the same as a specific location such as a storage facility, the electronic device can instruct an onboard computer in the vehicle that the vehicle should not be operated again until the system 100 has determined that the vehicle and/or the tires is no longer in a critical state.

In some embodiments, with additional reference to Figures 28 and 29, in addition to or instead of the electronic device 501, the system server 1142 may receive image data from an inspection station for inspecting vehicles such as the vehicle 10 when they are in proximity.

For example, in some embodiments, as shown in Figure 28, the system 100 may include a imaging inspection station 463 for inspecting tires of vehicles 461_x. In some embodiments, the imaging inspection station 463 comprises camera systems 462_x arranged to capture images of each of the tires 34₁ to 34₄ and their environment. The captured images can then be optionally processed and analyzed locally or remotely in system 100. The camera systems 462_x can include directional cameras having any configuration of lenses suitable for inspecting the tires 34₁ to 34₄ and their environment.

In other embodiments, with additional reference to Figure 29, the system server 1142 may receive image data from a scanning inspection station 473 for inspecting tires of vehicles 471_x. In some embodiments, the inspection station 473 comprises laser line scanner and/or laser area scanner systems 472_x arranged to scan each of the tires 34₁

to 34₄ and their environment as each vehicle 471_x moves past the inspection station 473. The information generated by the laser line scanner and/or laser area scanner systems 472_x can then be optionally processed and analyzed locally or remotely by system server 1142. This embodiment is particularly advantageous for producing 3D scanning data suitable for subsequent volumetric analysis, as described in more detail above.

In some embodiments, with additional reference to Figures 30 and 31, the system server 1142 may receive image data from a drone 3201 for inspecting the tire 34 and/or other components of each of the wheels 20₁ to 20₄ and/or their environment (e.g., detecting the presence of debris, etc.), so that information derived from the drone 3210 may be relayed to the operator of the vehicle 10 and/or another remote device or person. The vehicle 10 may comprise a drone mount 3220 configured to mount the drone 3220 to the vehicle 10 and release the drone 3201 when the drone 3201 is to monitor the vehicle 10 by moving around it.

In some embodiments, the drone 3201 is arranged to follow the vehicle, capture and analyze images of each of the tires 34₁ to 34₄ and their environment. In other embodiments, the drone 3201 is equipped with a laser line scanner for scanning the tires 34₁ to 34₄ and their environment. Communication between the drone 3201 and the vehicle 10 can be provided for by any suitable means, including but not limited to any combination of Global Positioning System (GPS) signals, Radio Frequency (RF) signals, Bluetooth signals, LIDAR, and RADAR signals. This embodiment is particularly advantageous for producing 3D scanning data suitable for subsequent volumetric analysis, as described in more detail above.

In this embodiment, the drone 3210 is an aerial drone configured to fly about the vehicle 10. While the drone 3201 shown in Figure 30 is a multi-rotor flying drone, other drones are possible, including but not limited to fixed-wing drones, or any other type of unmanned aerial vehicle. Also, in other embodiments, the drone 3210 may be a land drone configured to travel on the ground about the vehicle 10 (e.g., on wheels or on tracks).

In some embodiments, with additional reference to Figure 32, in addition to or instead of the electronic device 501, the system server 1142 may receive image data from a vehicle-mounted inspection device 4801 for inspecting the tire 34 of the vehicle 10. In particular, the system 100 may include one or more vehicle-mounted inspection device
5 4801 for inspecting tire 34 of vehicles by way of image data. In some embodiments, each tire 34₁ to 34₄ is provided with a vehicle-mounted inspection device 4801.

In some embodiments, the vehicle-mounted inspection device 4801 comprises a camera system arranged to capture images of the tire 34 and its environment as the tire 34 rotates. The information generated by the camera system can then be optionally
10 processed and analyzed locally or remotely by the system server 1142.

In some embodiments, the vehicle-mounted inspection device 4801 comprises a laser line scanner system and/or a laser area scanner system arranged to scan the tire 34 and its environment as the tire 34 rotates. The information generated by the laser line scanner and/or laser area scanner systems can then be optionally processed and
15 analyzed locally or remotely by system server 1142. This embodiment is particularly advantageous for producing 3D scanning data suitable for subsequent volumetric analysis, as described in more detail above.

In some embodiments, as shown in Figure 33, a given component mentioned herein (e.g., the electronic device 501, the image processing entity 505, the server 1142, etc.)
20 may comprise a computing system 1500 comprising suitable hardware and/or software (e.g., firmware) configured to implement functionality of that given component. The computing system 1500 comprises an interface 1520, a processor 1540, and a memory 1560.

The interface 1520 comprises one or more inputs and outputs allowing the computing
25 system 1500 to receive signals from and send signals to other components to which the computing system 1500 is connected (i.e., directly or indirectly connected).

The processor 1540 comprises one or more processing devices for performing processing operations that implement functionality of the computing system 1500. A

processing device of the processor 1540 may be a general-purpose processor executing program code stored in the memory 1560. Alternatively, a processing device of the processor 1540 may be a specific-purpose processor comprising one or more preprogrammed hardware or firmware elements (e.g., application-specific integrated
5 circuits (ASICs), electrically erasable programmable read-only memories (EEPROMs), etc.) or other related elements).

The memory 1560 comprises one or more memory elements for storing program code executed by the processor 1540 and/or data used during operation of the processor 1540. A memory element of the memory portion 1560 may be a semiconductor medium
10 (including, e.g., a solid state memory), a magnetic storage medium, an optical storage medium, and/or any other suitable type of memory element. A memory element of the memory portion 1560 may be read-only memory (ROM) and/or random-access memory (RAM), for example.

In some embodiments, two or more elements of the computing system 1500 may be
15 implemented by devices that are physically distinct from one another (e.g., located in a common site or in remote sites) and may be connected to one another via a bus (e.g., one or more electrical conductors or any other suitable bus) or via a communication link which may be wired, wireless, or both and which may traverse one or more networks (e.g., the Internet or any other computer network such as a local-area network (LAN) or
20 wide-area network (WAN), a cellular network, etc.). In other embodiments, two or more elements of the computing system 1500 may be implemented by a single device.

While in embodiments considered above the vehicle 10 is a passenger vehicle, in other embodiments, the vehicle 10 may be another type of work vehicle (such as a tractor, etc.) for performing forestry work, or a military vehicle (e.g., reconnaissance vehicle,
25 military light utility vehicle, etc.) for performing military work, a carrier (e.g. carrying a boom, a rig, and/or other equipment), or may be any other type of vehicle operable on paved road. Also, while in embodiments considered above the road vehicle 10 is driven by a human operator in the vehicle 10, in other embodiments, the vehicle 10 may be an

unmanned ground vehicle (e.g., a teleoperated or autonomous unmanned ground vehicle).

Any feature of any embodiment discussed herein may be combined with any feature of any other embodiment discussed herein in some examples of implementation.

- 5 Certain additional elements that may be needed for operation of certain embodiments have not been described or illustrated as they are assumed to be within the purview of those of ordinary skill in the art. Moreover, certain embodiments may be free of, may lack and/or may function without any element that is not specifically disclosed herein.

- 10 Although various embodiments and examples have been presented, this was for purposes of description, but should not be limiting. Various modifications and enhancements will become apparent to those of ordinary skill in the art.

CLAIMS

1. A system for monitoring a tire of a vehicle, the system comprising:
 - an interface configured to receive data regarding at least one image of the tire;
 - and
 - 5 a processor configured to:
 - process the data regarding the at least one image of the tire to obtain an indication of a physical state of the tire; and
 - generate a signal based on the indication of the deterioration of the tire.
- 10 2. The system of claim 1, wherein the data regarding the at least one image of the tire is representative of a three-dimensional model of at least part of the tire.
3. The system of claim 2, wherein the information regarding deterioration of the tire includes an indication of a volumetric loss of material of the tire.
- 15 4. The system of any one of claims 1 to 3, wherein the system is configured to issue a signal based on the indication of the deterioration of the tire to inform a user of the system of an action to be performed in respect of the tire.
- 20 5. The system of claim 4, wherein the action to be performed in respect of the tire is replacement of the tire by a new tire.

6. The system of claim 4 or 5, wherein the signal based on the indication of the deterioration of the tire is directed to the vehicle.

7. The system of claim 6, wherein the signal based on the indication of the deterioration of the tire is issued to control the vehicle.

8. A wheel monitoring system, the system comprising:

an image data capture device configured to capture image data relating to a wheel component;

an image processing device, in data communication with the image capture device, the image processing device being configured to:

receive captured image data from the image data capture device;

generate a 3D model of at least a portion of the wheel component based on the image data; and

compare the 3D model to at least one known 3D model of a wheel component to determine at least one aspect of the physical state of the wheel component.

9. The system of claim 8, wherein the at least one aspect of the physical state of the wheel component includes information regarding deterioration of the wheel component.

10. The system of claim 9, wherein the information regarding deterioration of the wheel component includes an indication of a volumetric loss of material of the wheel component.
- 5 11. The system of any one of claims 8 to 10, wherein a signal based on the determination of at least one aspect of the physical state of the wheel component is issued to inform a user of the system of the physical state of the wheel component.
- 10 12. The system of any one of claims 8 to 11, wherein a signal based on the determination of at least one aspect of the physical state of the wheel component is issued to inform a user of the system of an action to be performed in respect of the wheel component.
- 15 13. The system of claim 12, wherein the action to be performed in respect of the wheel component is replacement of the wheel component by a new wheel component.
14. The system of any one of claims 11 to 13, wherein the signal based on the
20 determination of at least one aspect of the physical state of the wheel component is directed to the vehicle.

15. The system of claim 14, wherein the signal based on the determination of at least one aspect of the physical state of the wheel component is issued to control the vehicle.

5 16. The system of any one of claims 8 to 15, wherein the image data relating to the wheel component is captured by a wireless communication device.

17. The system of any one of claims 8 to 16, wherein the 3D model is generated using a 3D point cloud.

10

18. The system of any one of claims 8 to 17, wherein the system is further configured to:

recognize a 2D pattern in the image data relating to the wheel component; and

determine at least one further aspect of the physical state of the wheel

15 component based on the recognized 2D pattern.

19. The system of any one of claims 8 to 18, wherein the system is further configured to:

recognize a 2D pattern in the 3D model of at least a portion of the wheel

20 component based on the image data; and

determine at least one further aspect of the physical state of the wheel component based on the recognized 2D pattern.

20. A method for monitoring a wheel component, the method comprising the steps of:

capturing image data relating to a wheel component;

generating a 3D model of at least a portion of the wheel component based on the

5 image data; and

comparing the 3D model to at least one known 3D model of a wheel component to determine at least one aspect of the physical state of the wheel component.

1/38

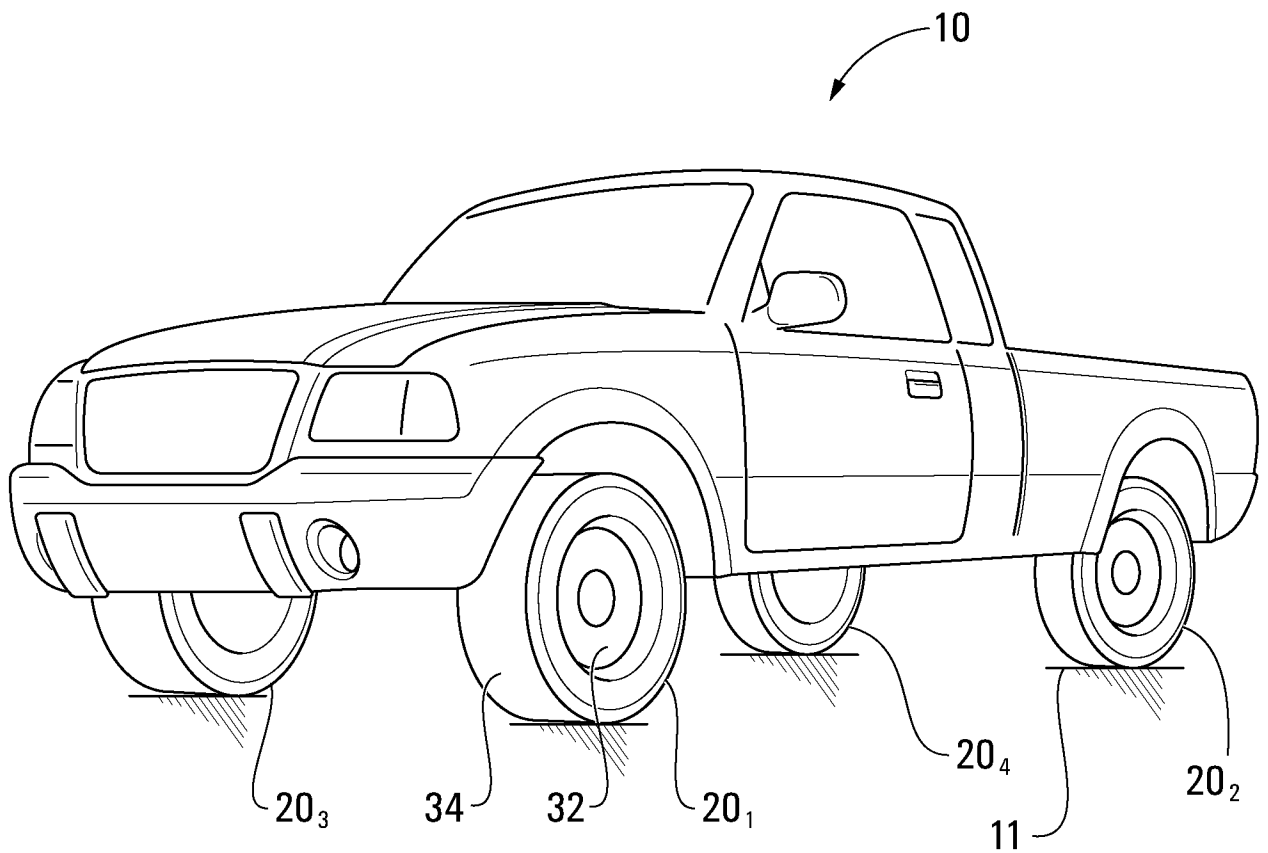
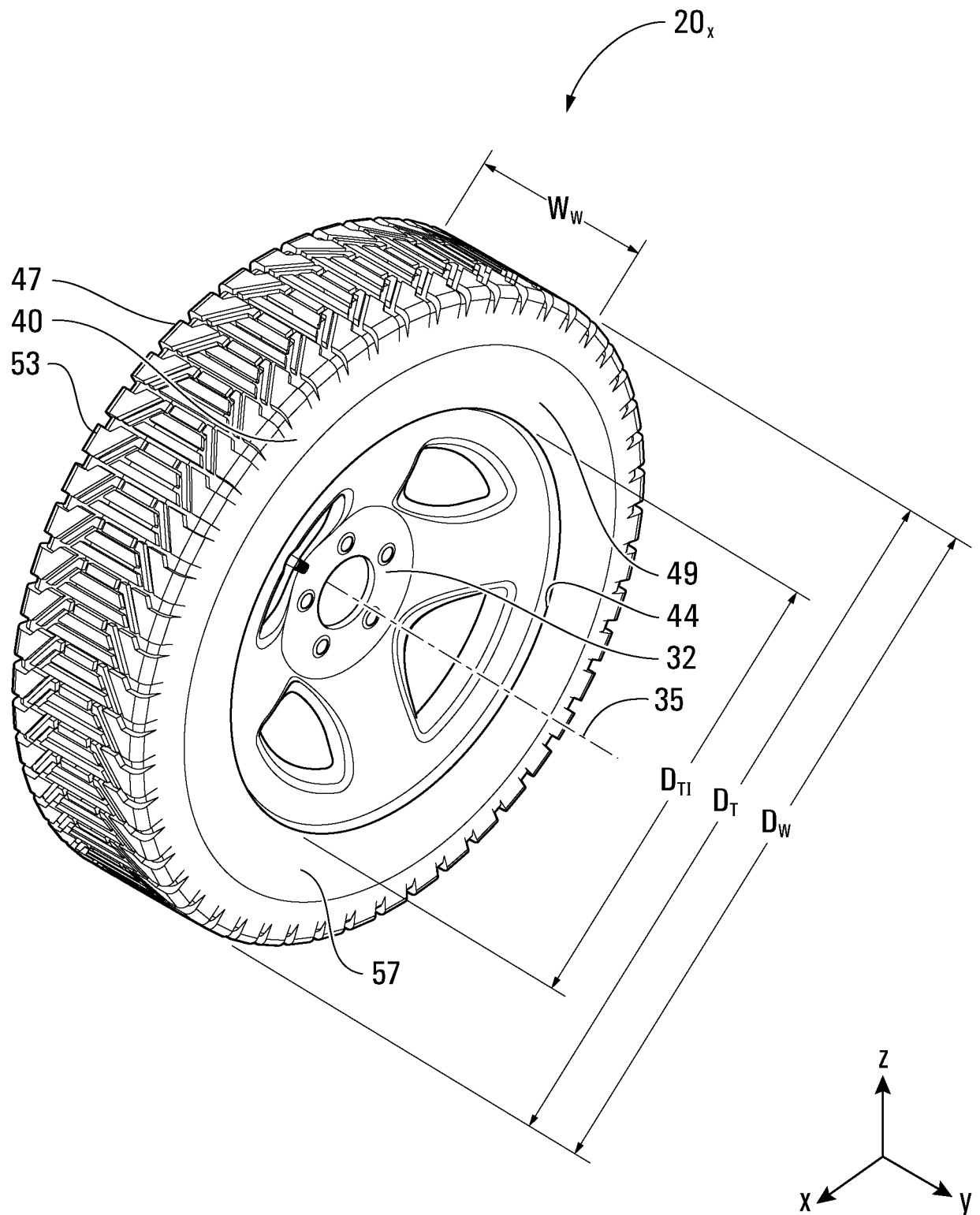
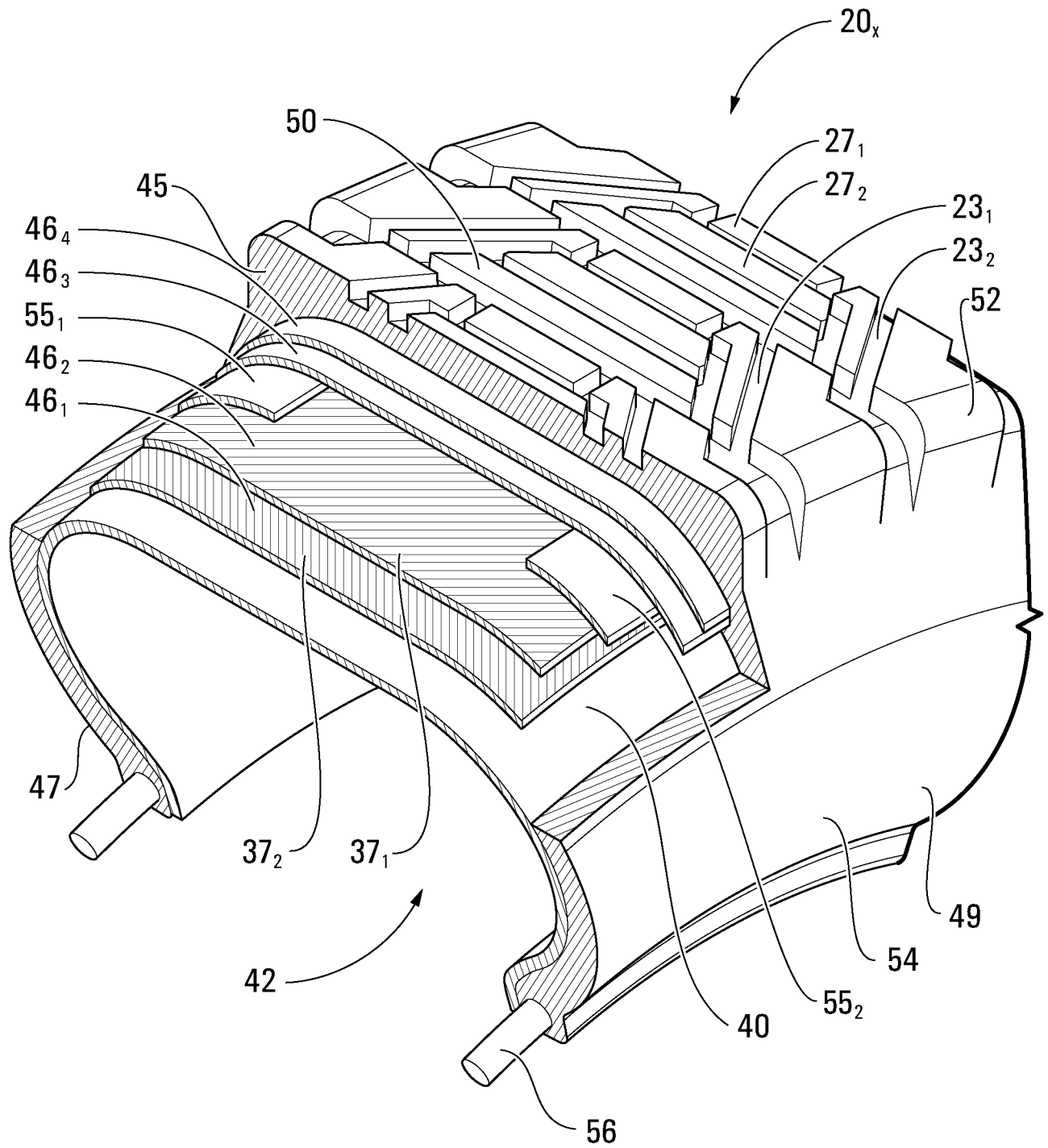


FIG. 1

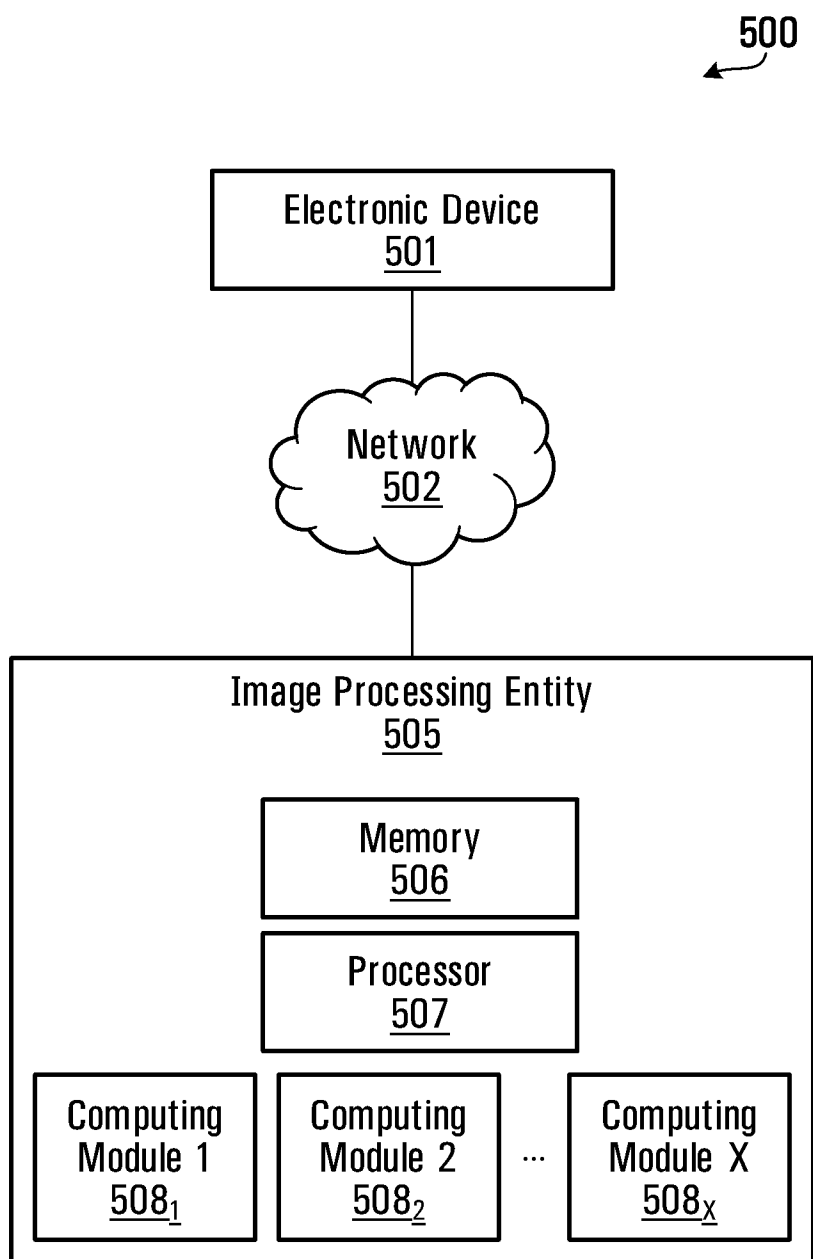
2/38

**FIG. 2**

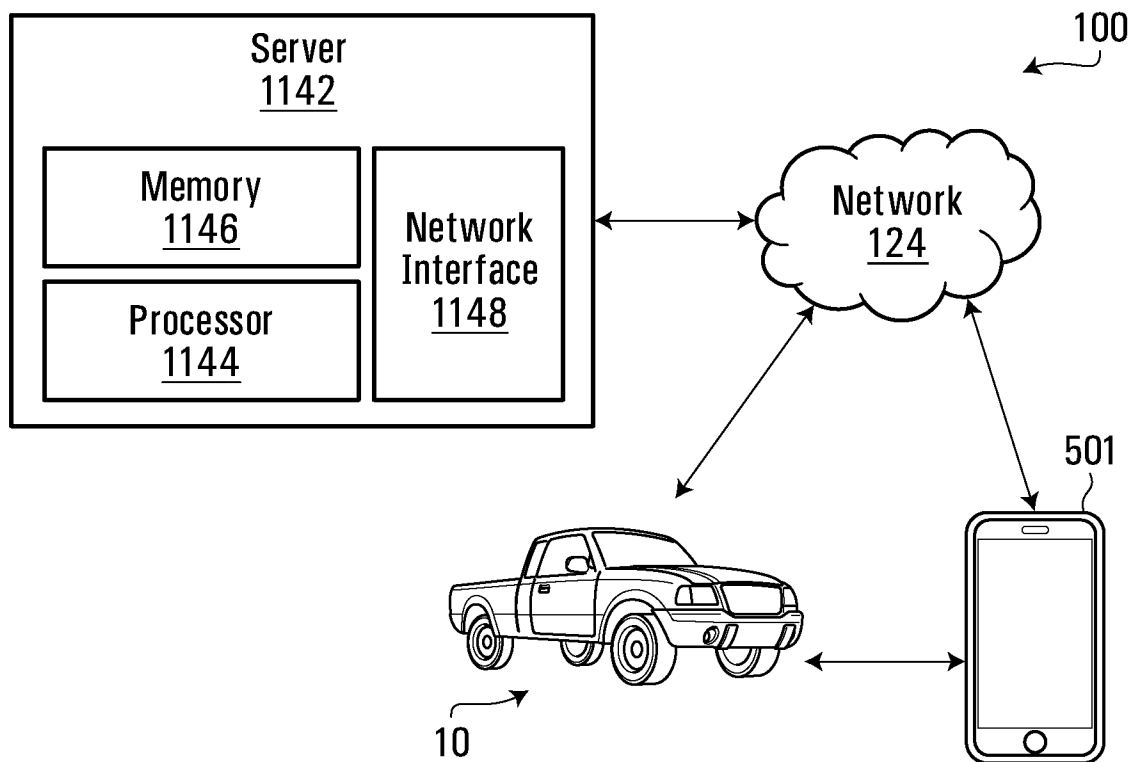
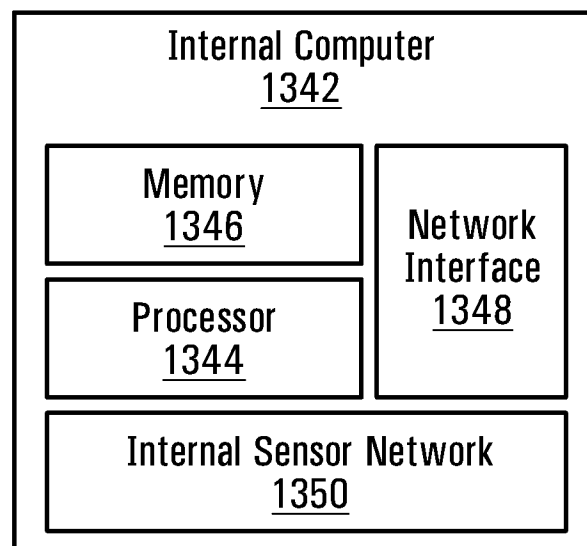
3/38

**FIG. 3**

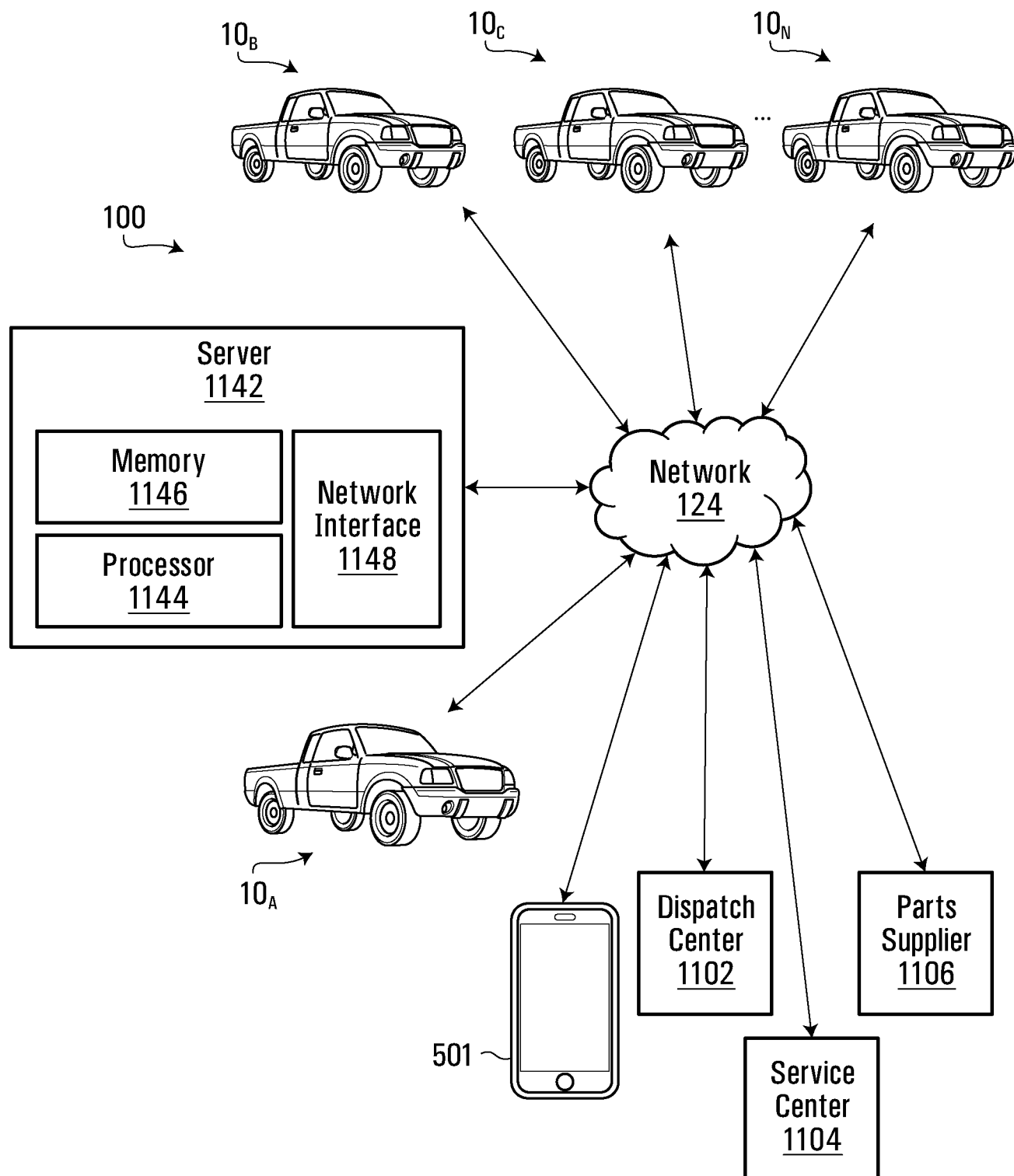
4/38

**FIG. 4**

5/38

**FIG. 5****FIG. 6**

6/38

**FIG. 7**

7/38

Tire Model	Serial Number	Inspection Date	Type of Inspection	Registered Owner
Model 1	001	05/27/2018	Full Inspection	Owner 1
Model 2	002	06/11/2018	Tire Alignment	Owner 2
⋮	⋮	⋮	⋮	⋮
Model N	NNN	MM/DD/YYYY	Type N	Owner N

FIG. 8A

8/38

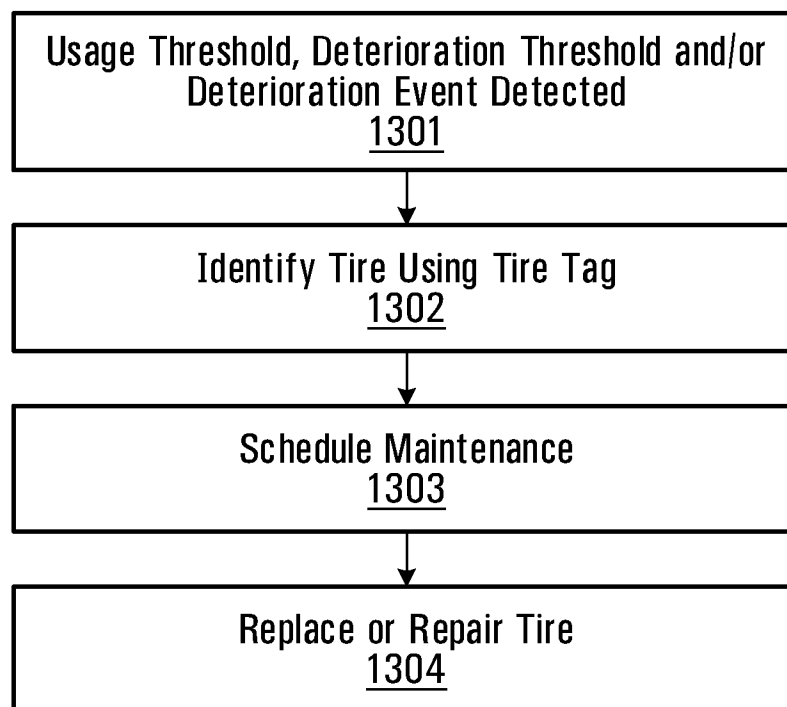
Tire Model	On Vehicle	Last Inspection Date	Tire Status	Notes
Model 1	V001	05/27/2017	OK	• Two weeks before critical • Maintenance scheduled
Model 2	V002	06/11/2018	Service Required	• Two years before critical
⋮	⋮	⋮	⋮	⋮
Model X	VXXX	MM/DD/YYYY	Status X	• Note 1 ⋮ • Note N

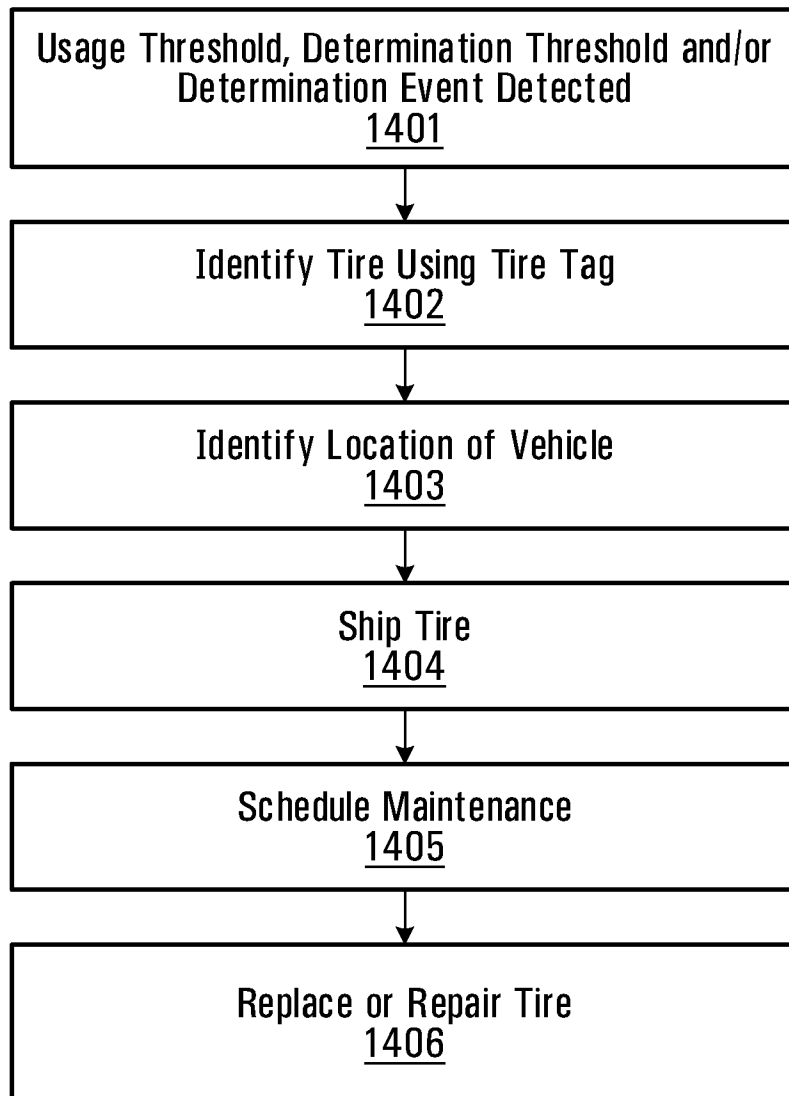
FIG. 8B

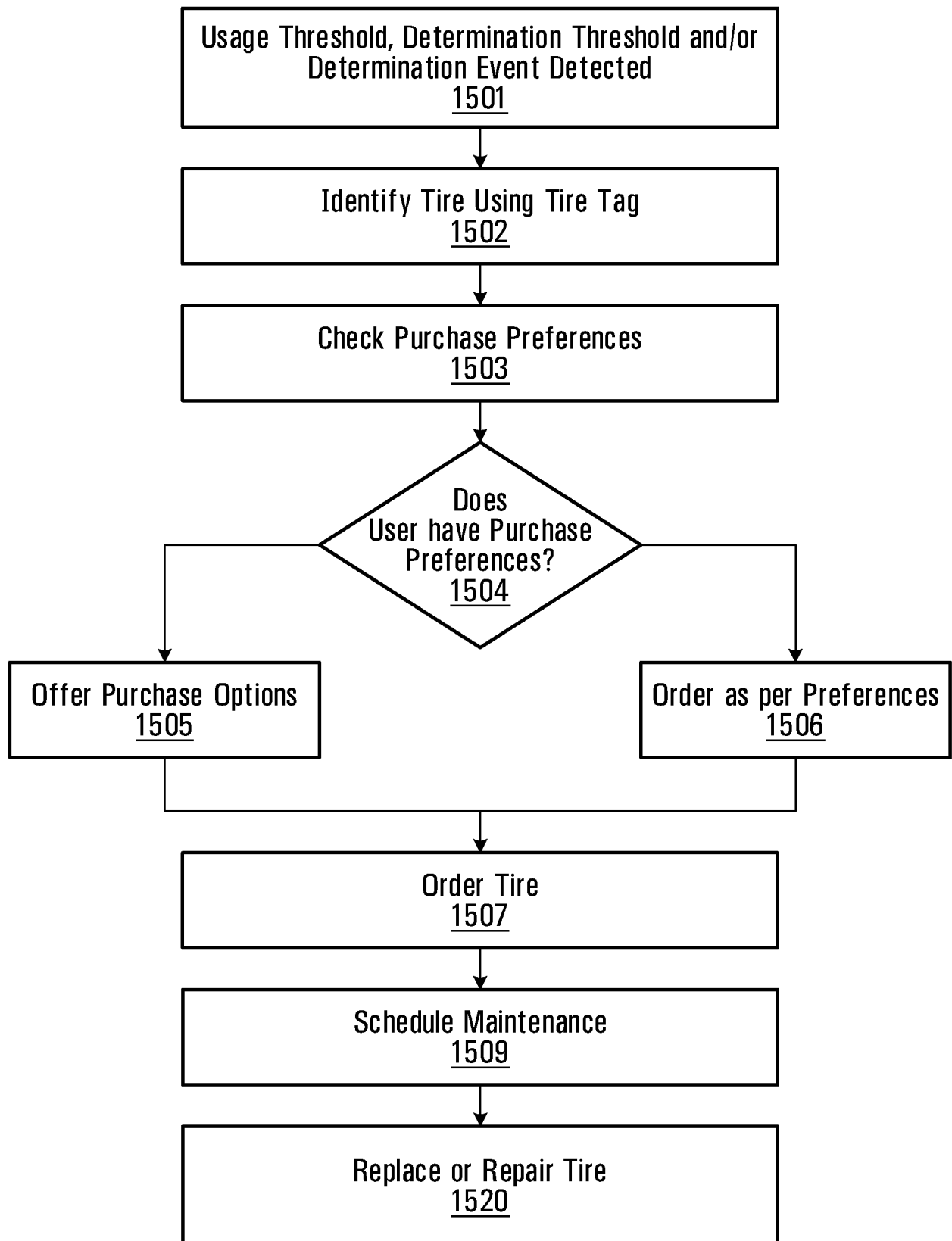
9/38

Vehicle Model	Tire Model	Last Inspection Date	Tire Status	Notes
Model 1	Model 1	05/27/2017	OK	• Two weeks before critical • Maintenance scheduled
Model 2	Model 2	06/11/2018	Service Scheduled	• Normal operation • No service scheduled
⋮	⋮	⋮	⋮	⋮
Model X	Model X	MM/DD/YYYY	Status X	• Note 1 ⋮ • Note N

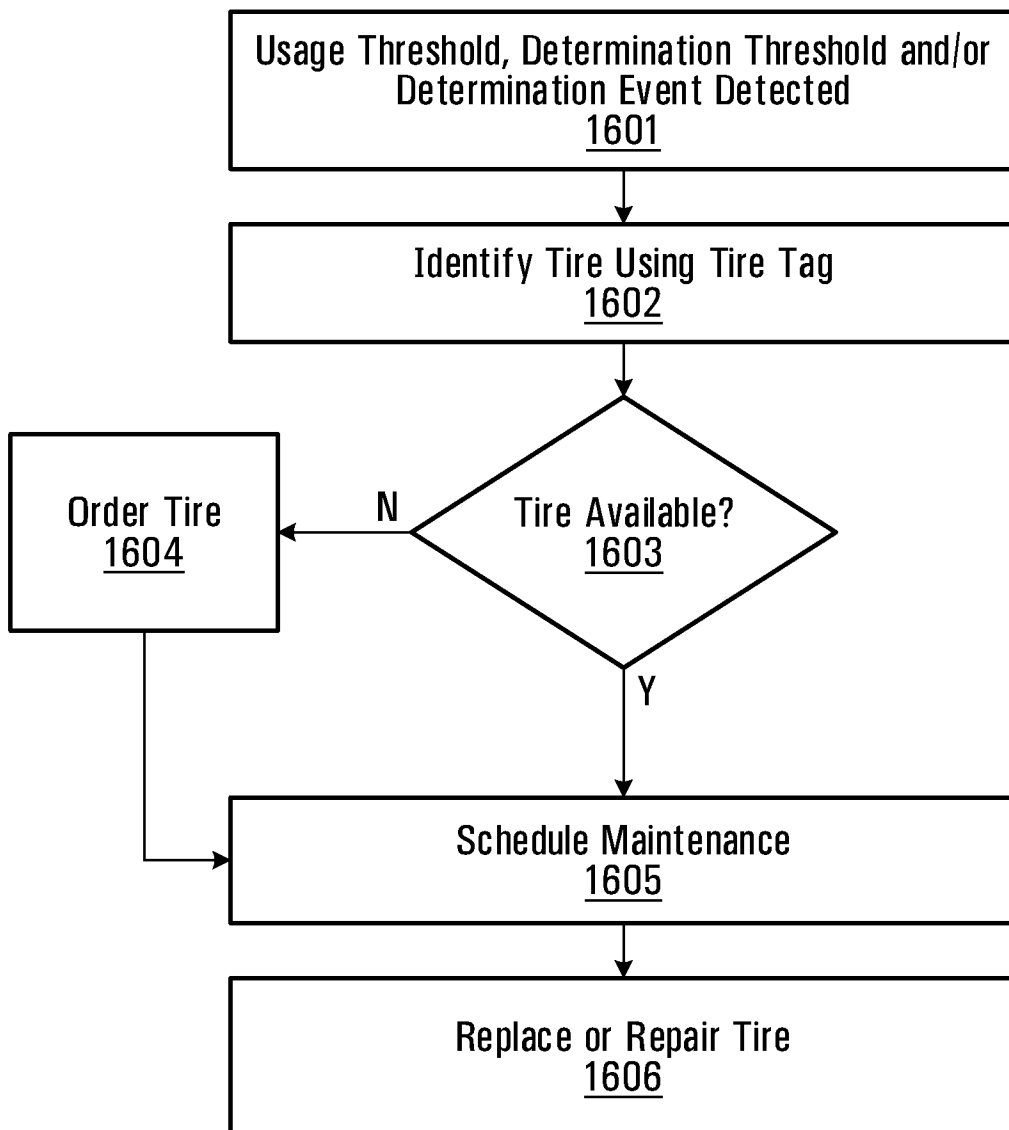
FIG. 8C

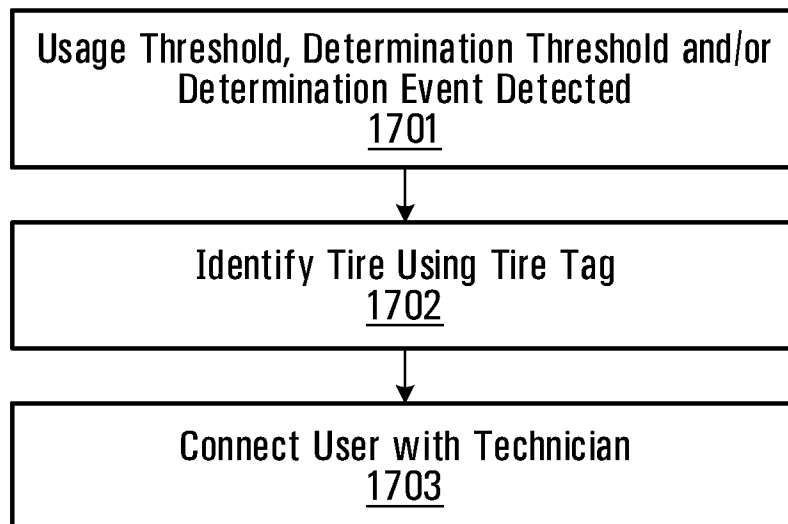
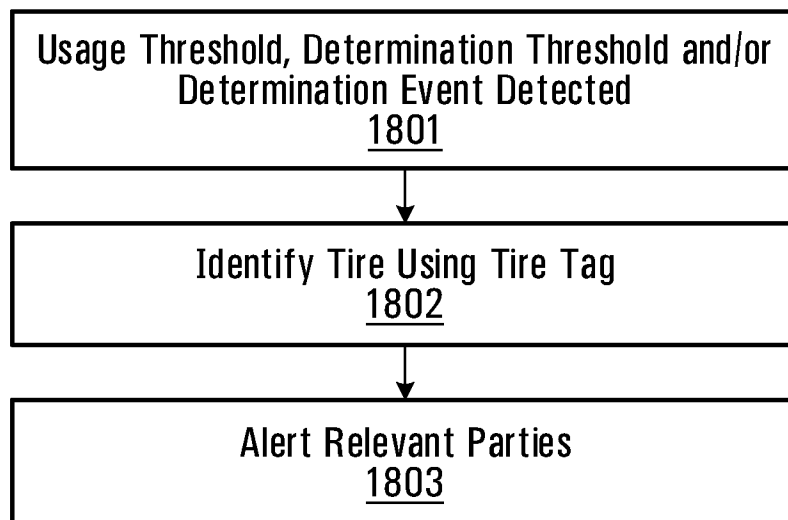
10/38**FIG. 9**

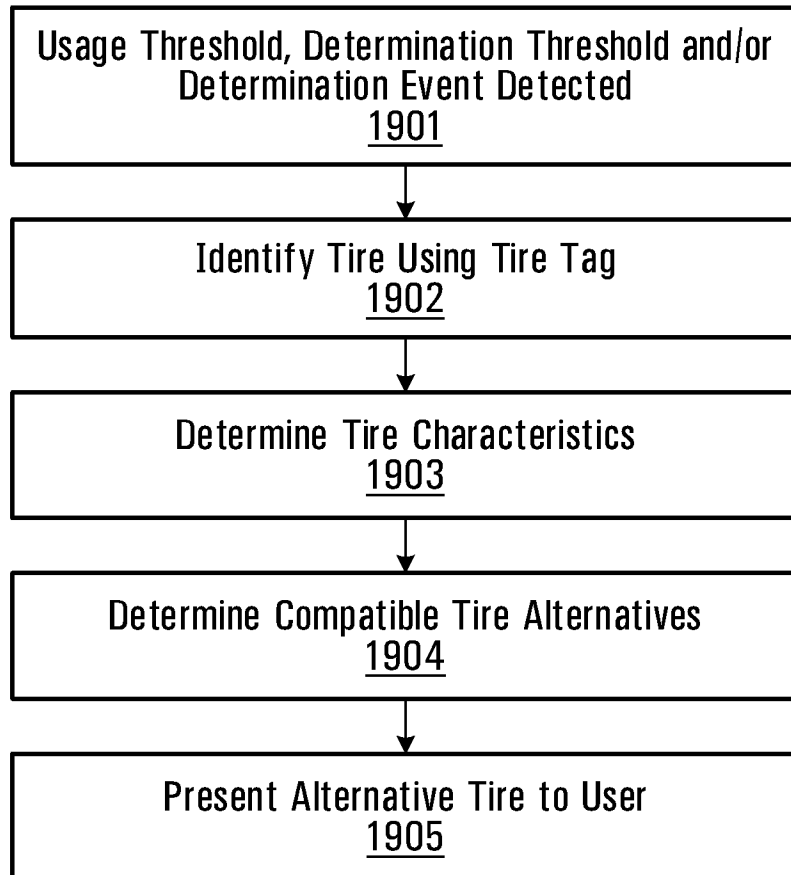
11/38**FIG. 10**

12/38**FIG. 11**

13/38

**FIG. 12**

14/38**FIG. 13****FIG. 14**

15/38**FIG. 15**

16/38

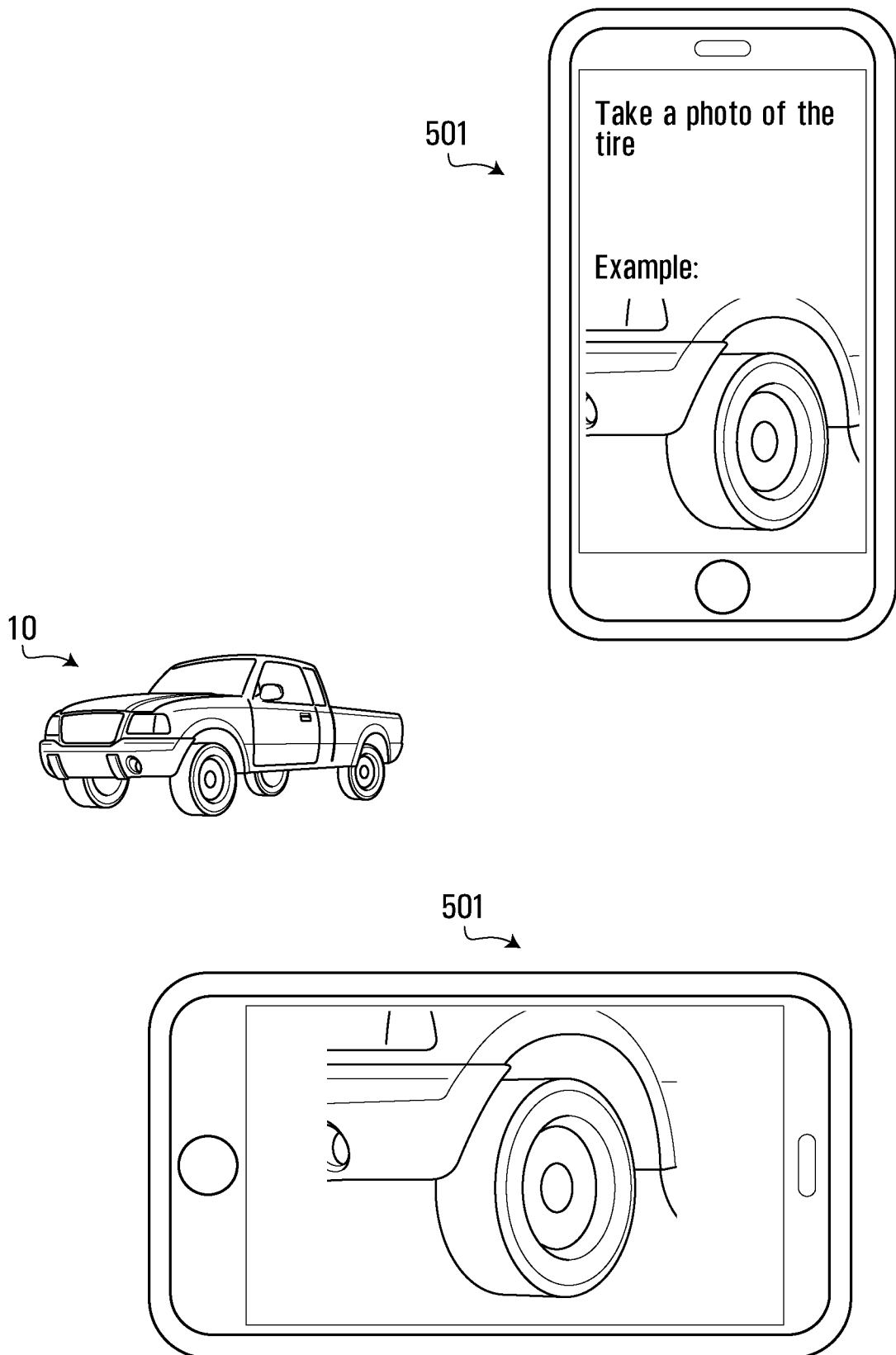


FIG. 16

17/38

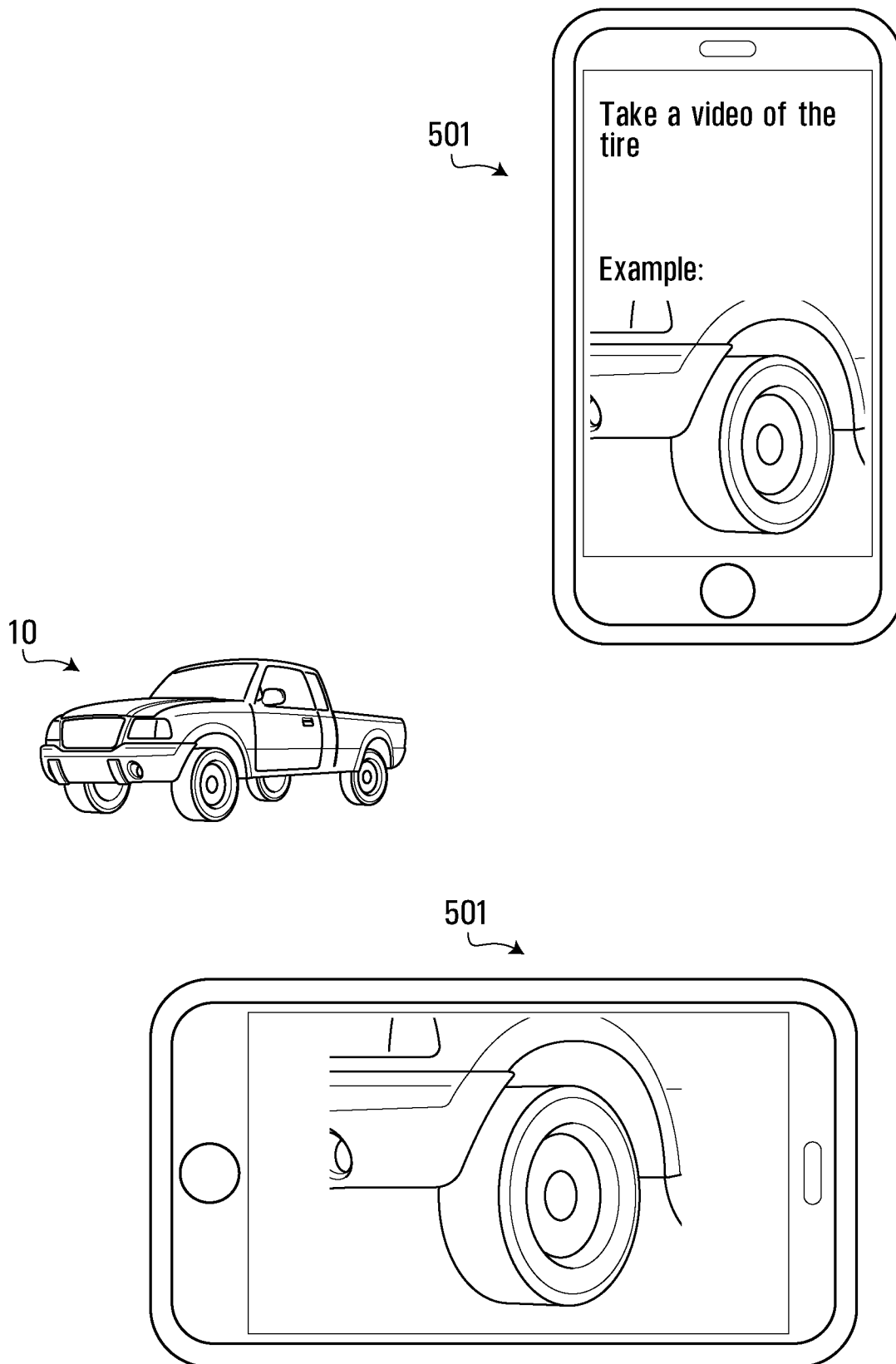


FIG. 17

18/38

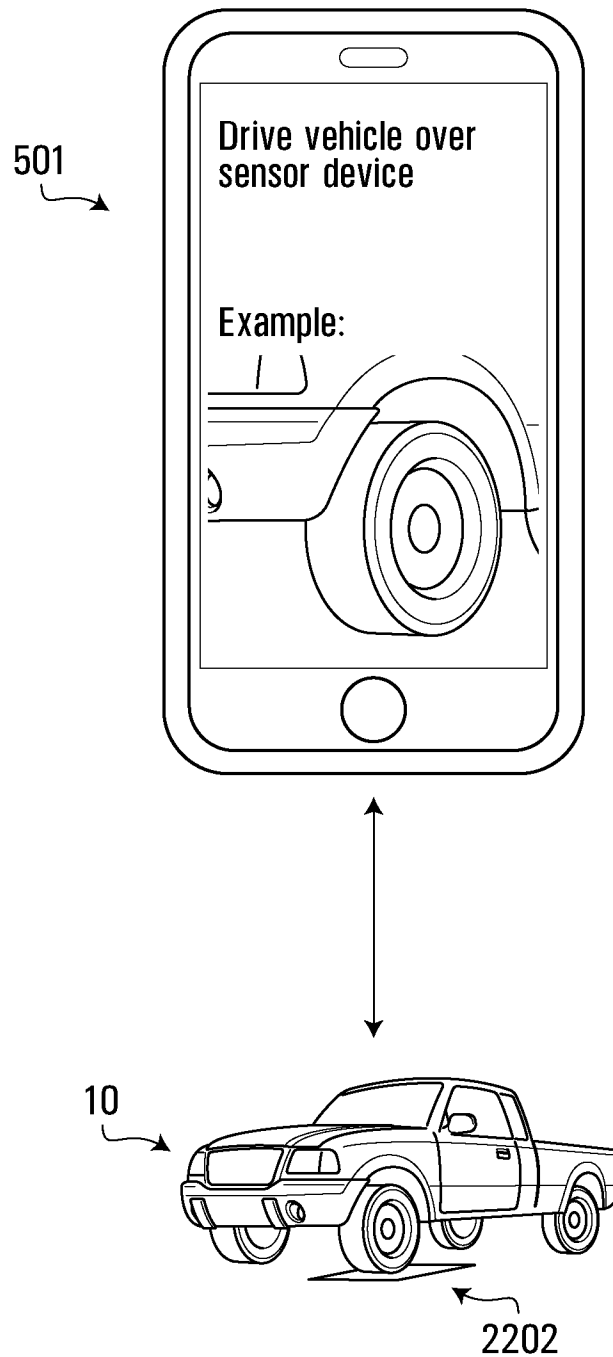
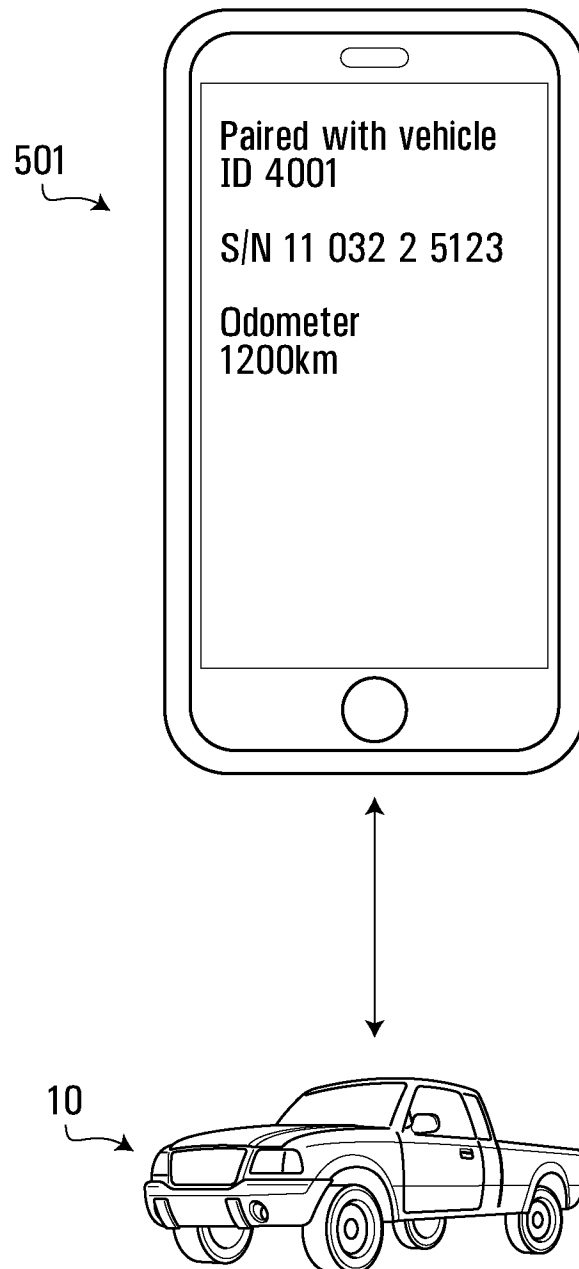


FIG. 18

19/38**FIG. 19**

20/38

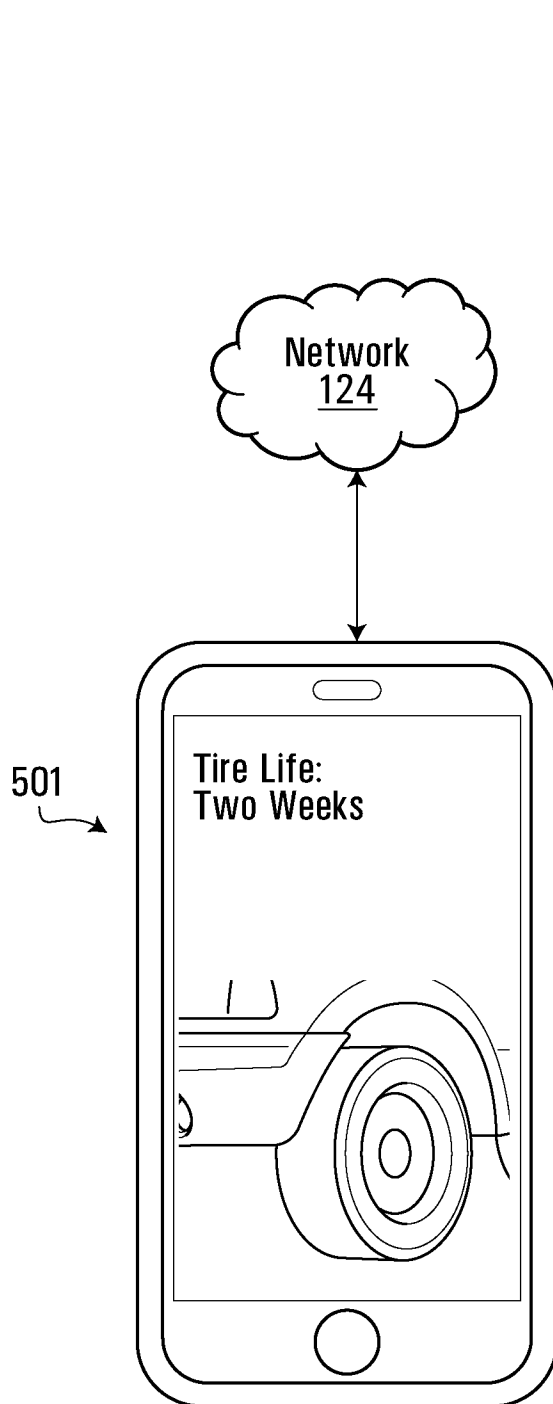


FIG. 20

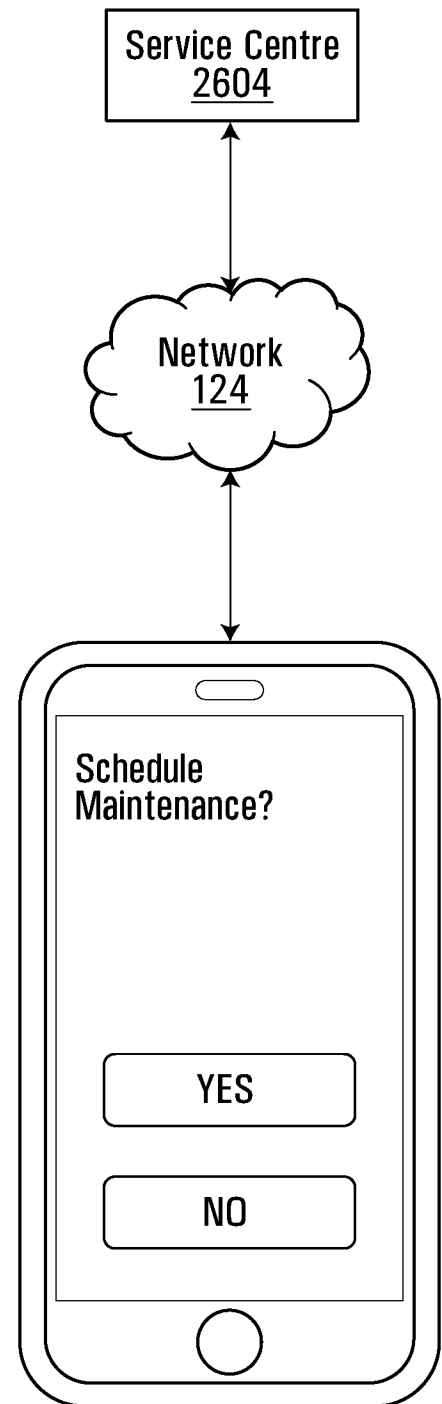
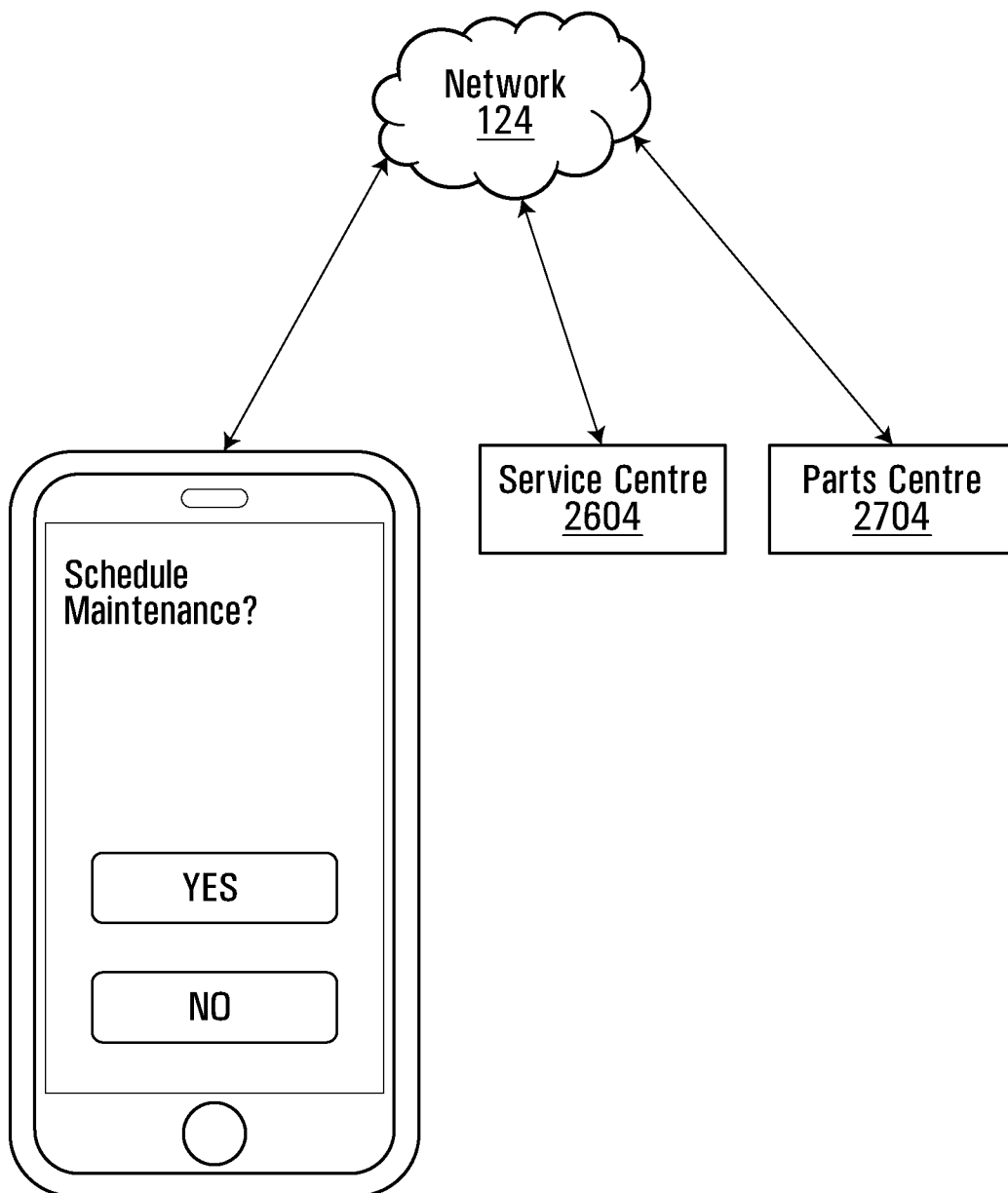


FIG. 21

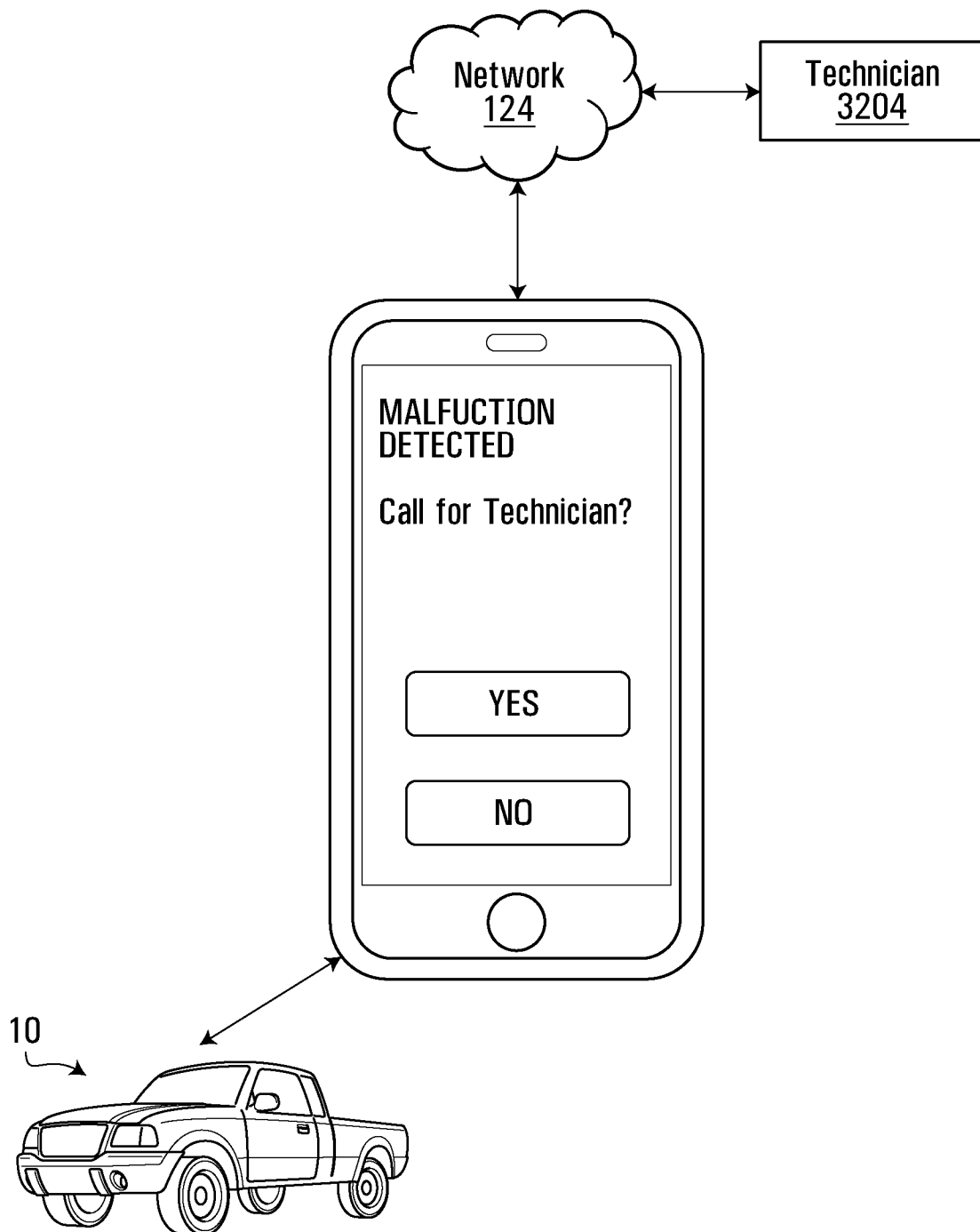
21/38

**FIG. 22**

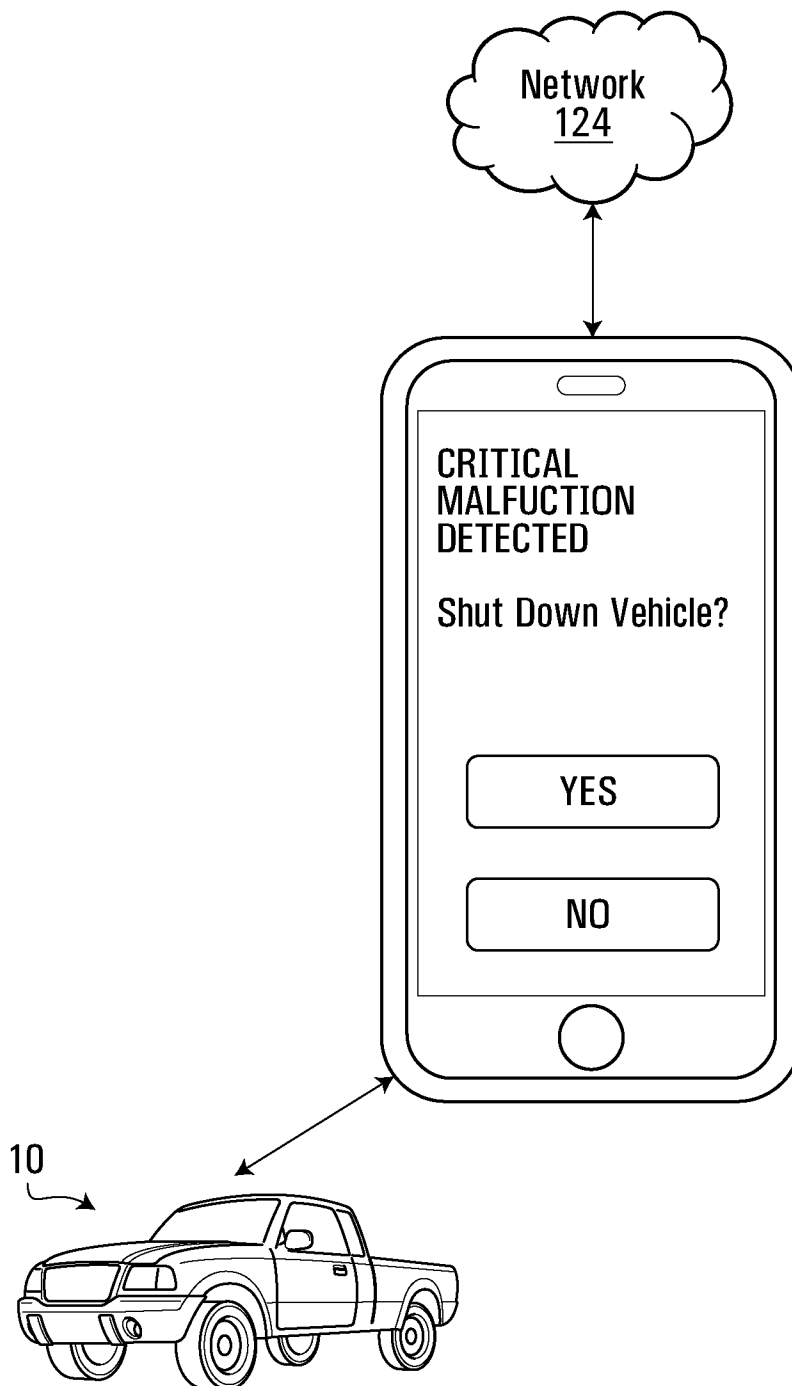
22/38

**FIG. 23**

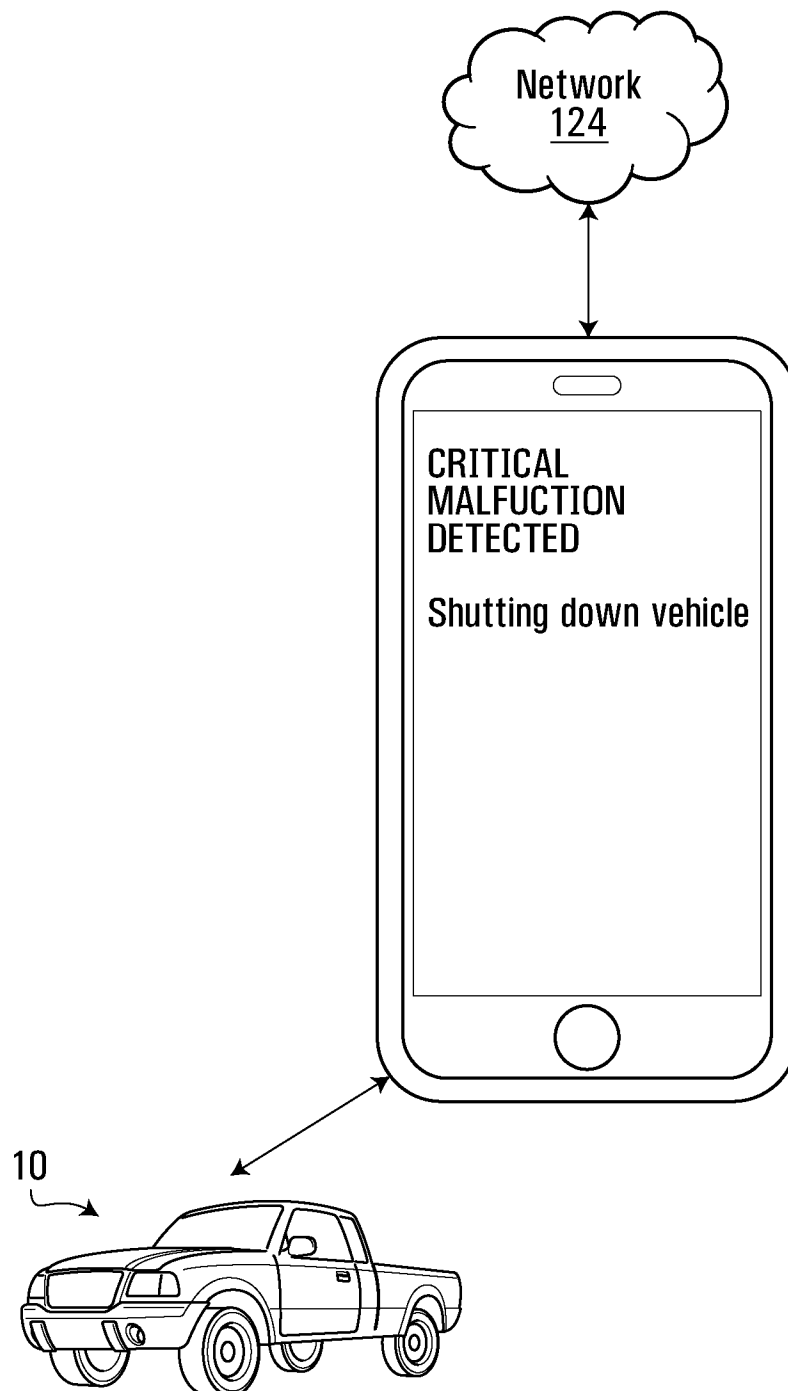
23/38

**FIG. 24**

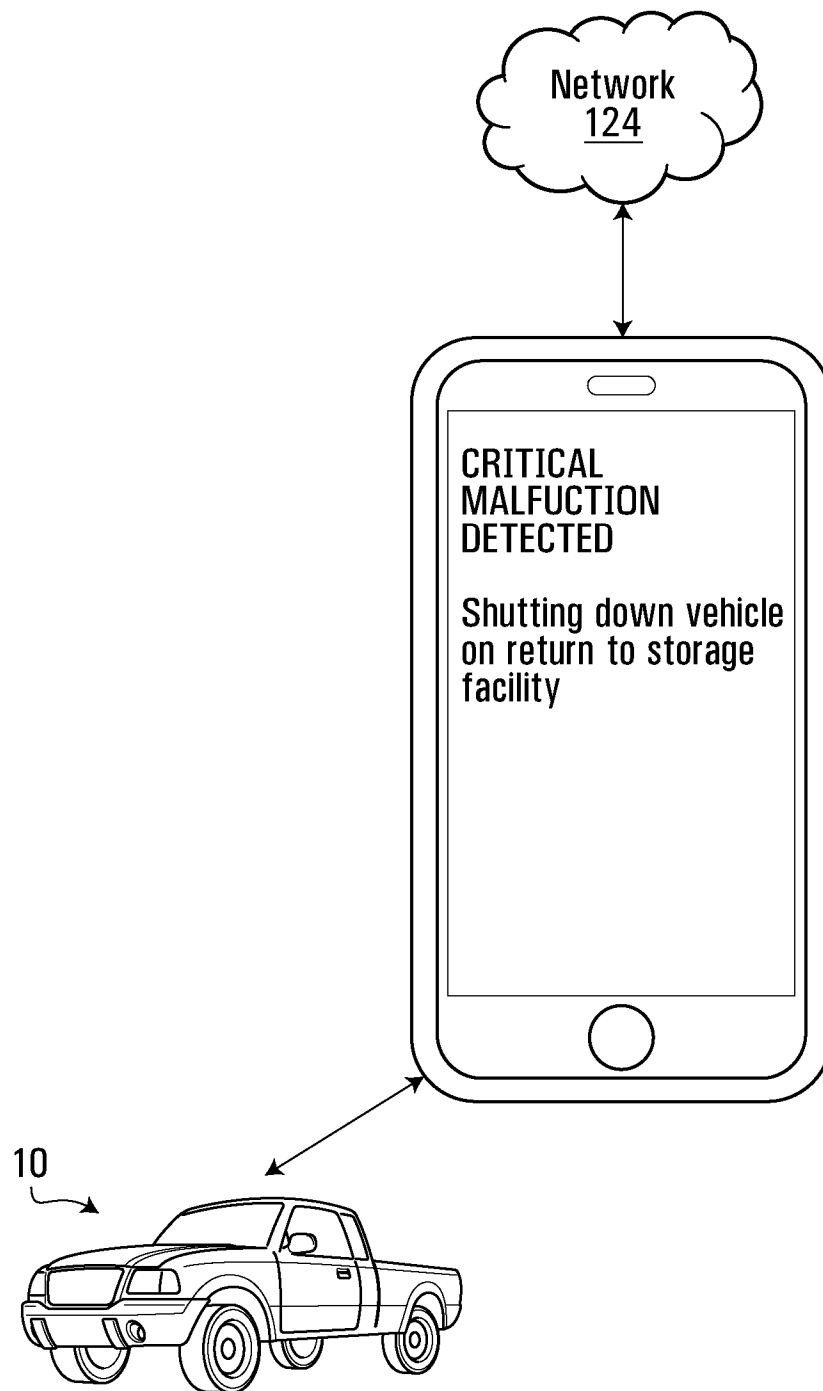
24/38

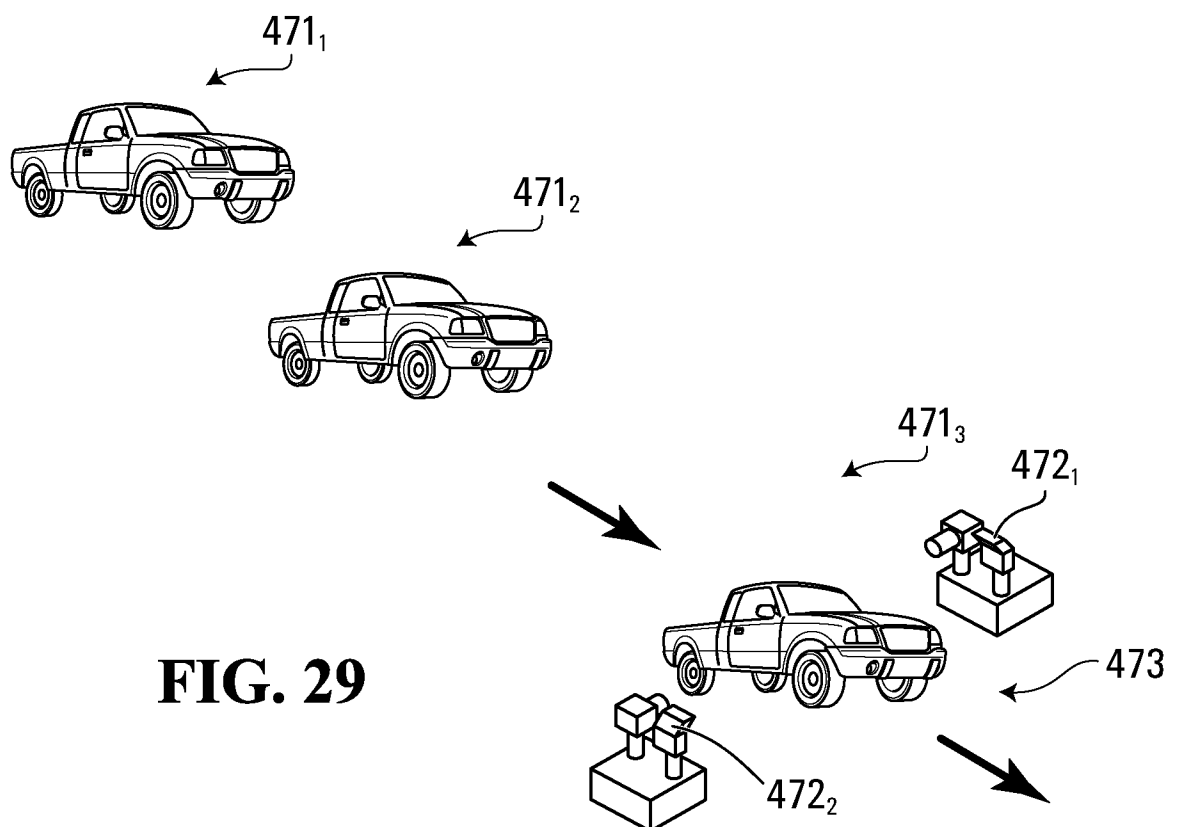
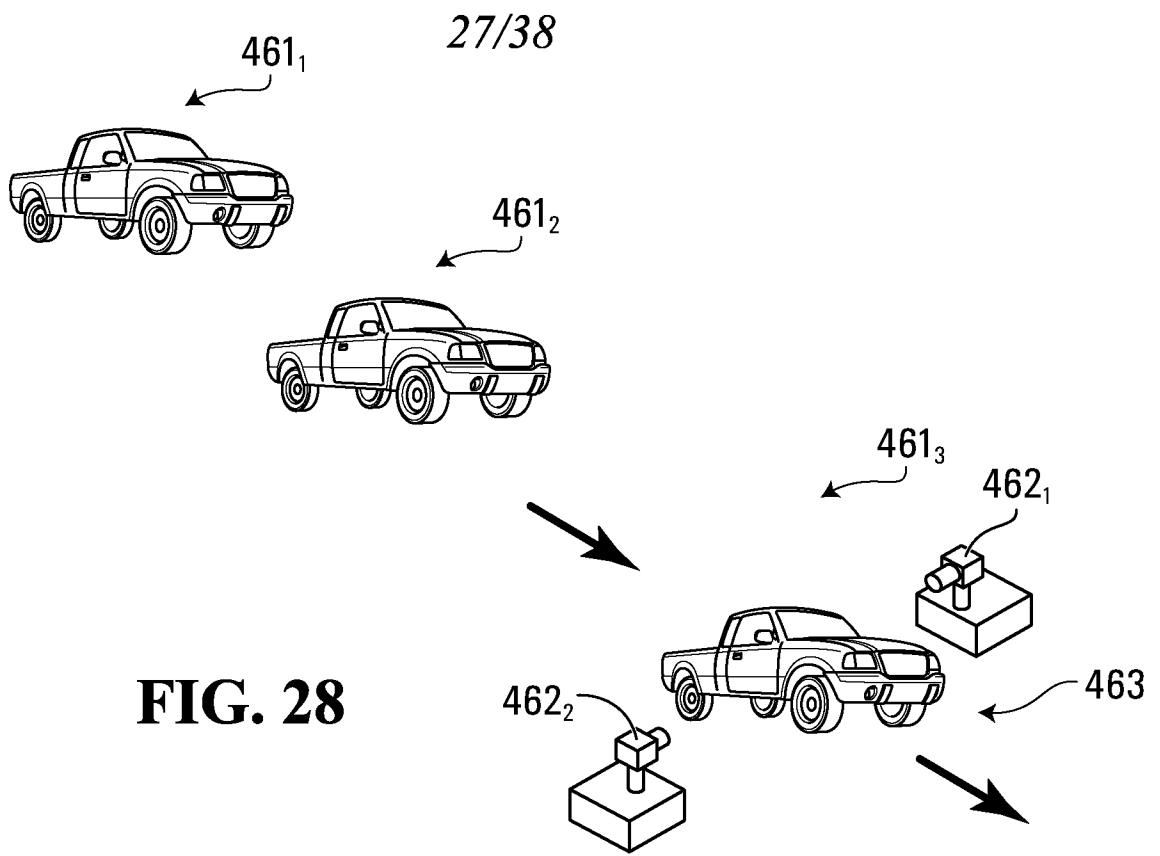
**FIG. 25**

25/38

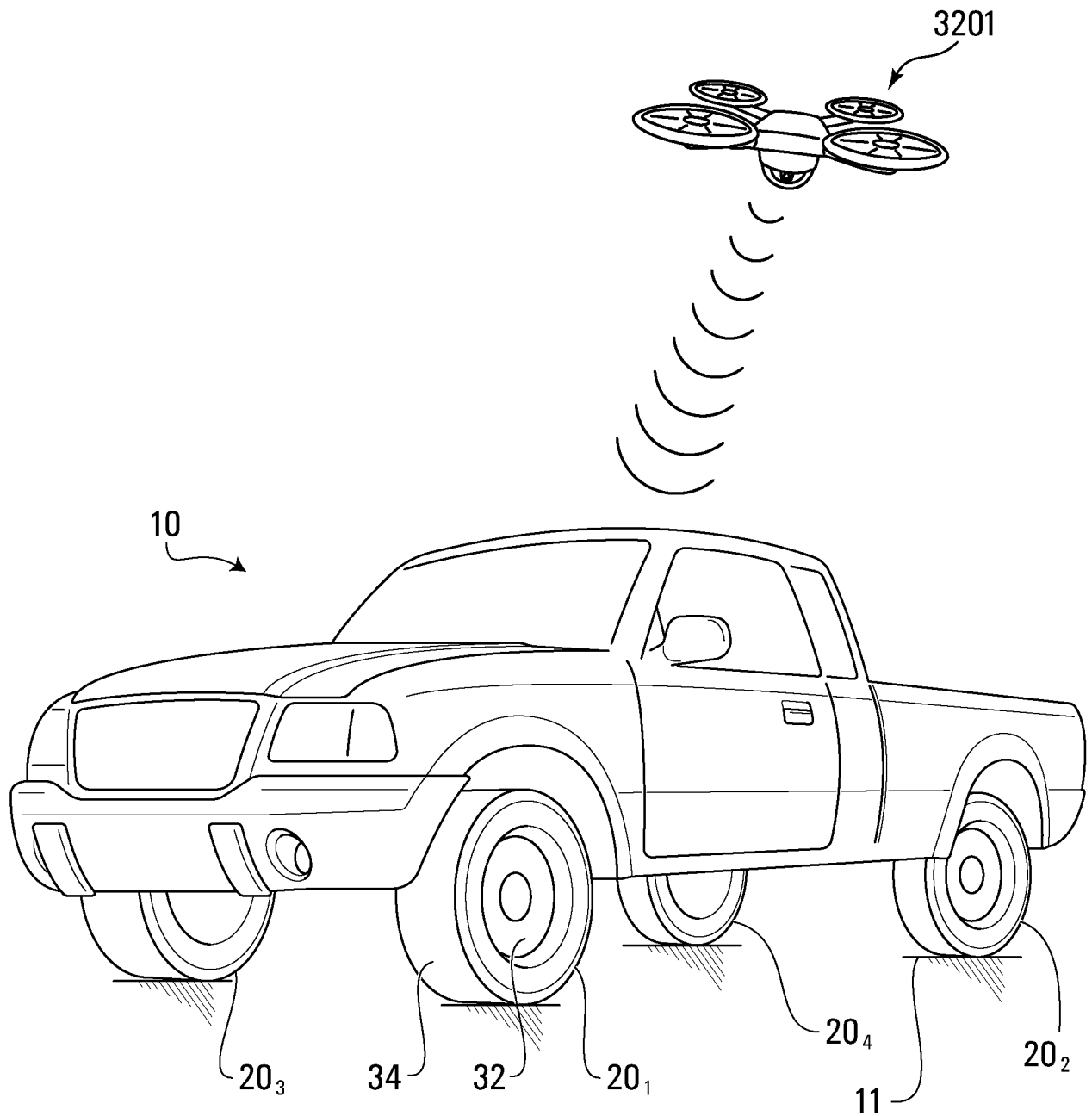
**FIG. 26**

26/38

**FIG. 27**



28/38

**FIG. 30**

29/38

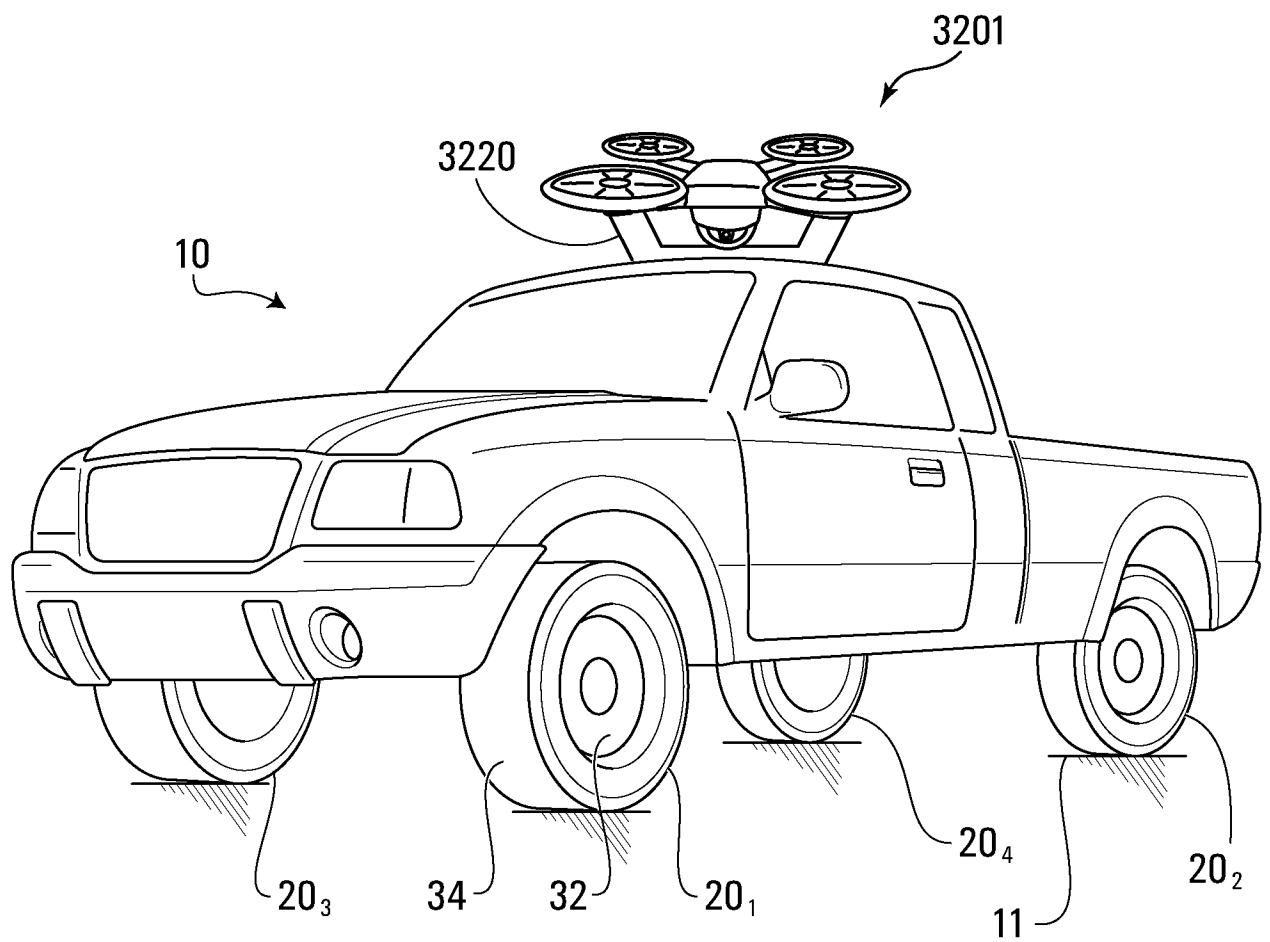


FIG. 31

30/38

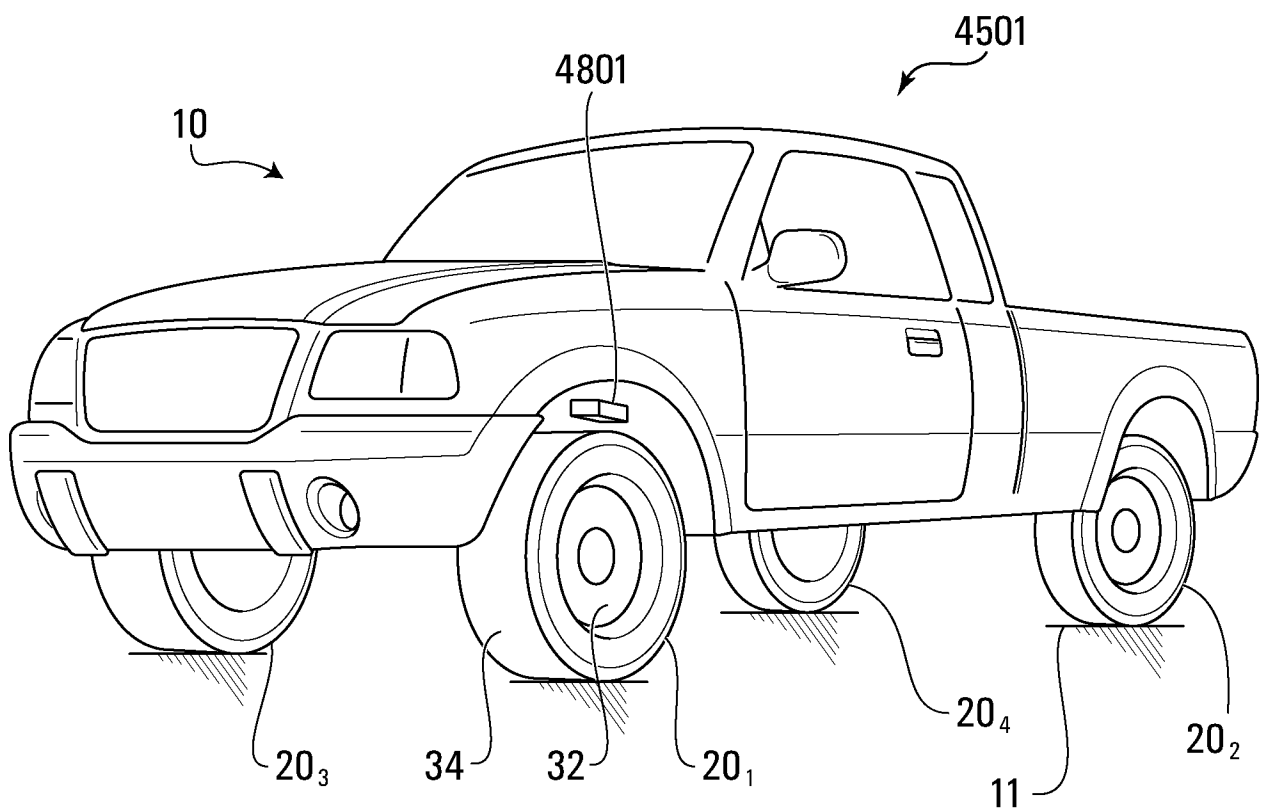


FIG. 32

31/38

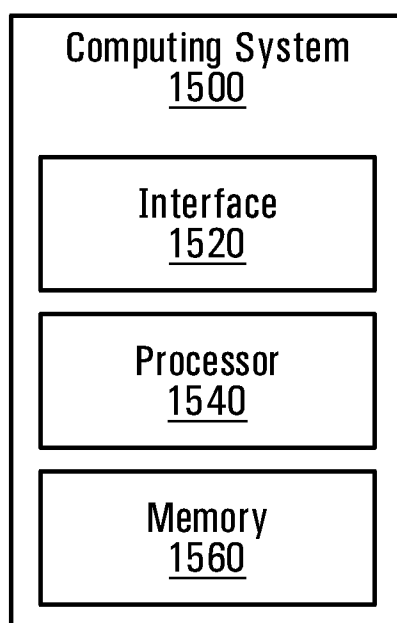


FIG. 33

32/38

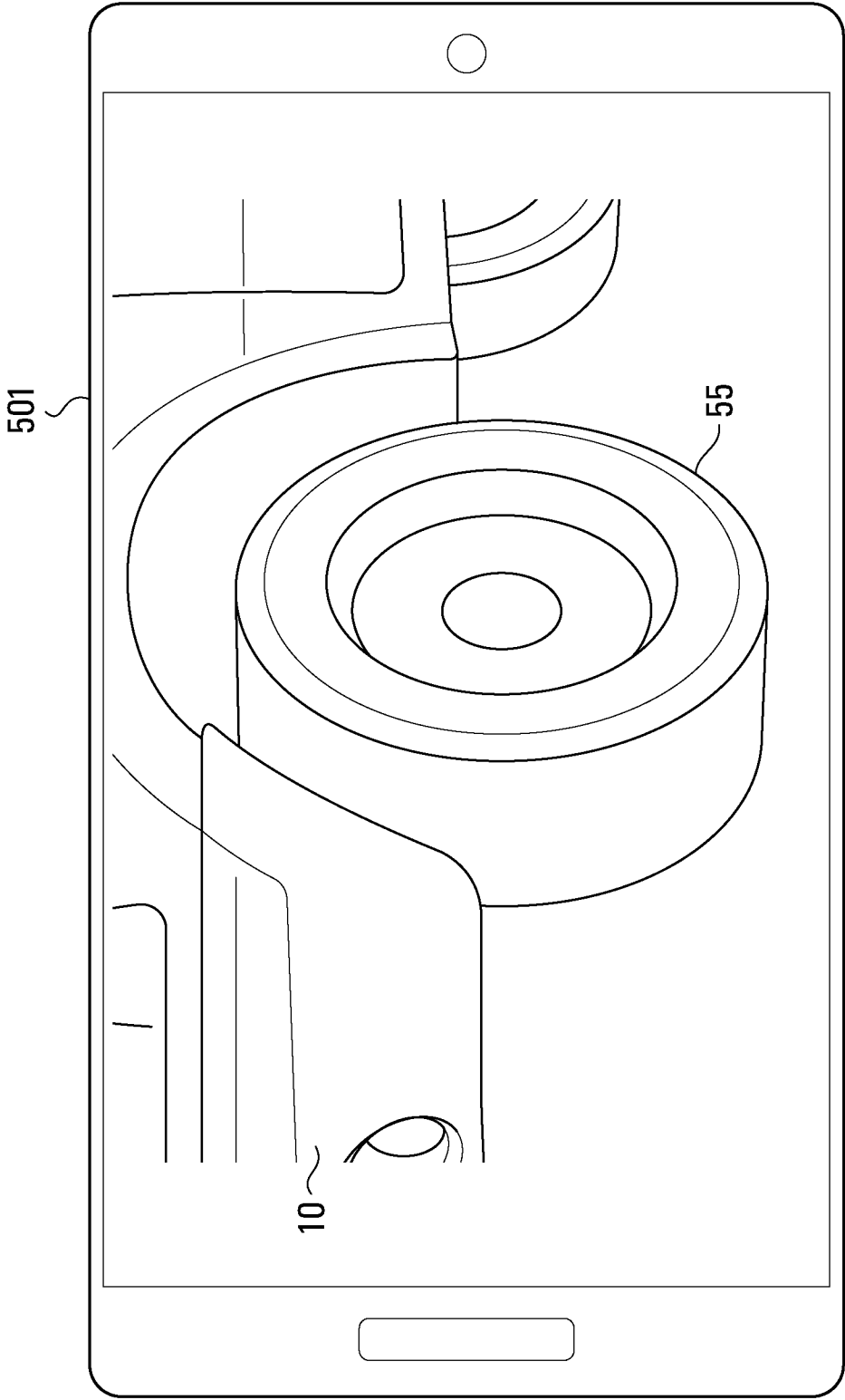


FIG. 34

33/38

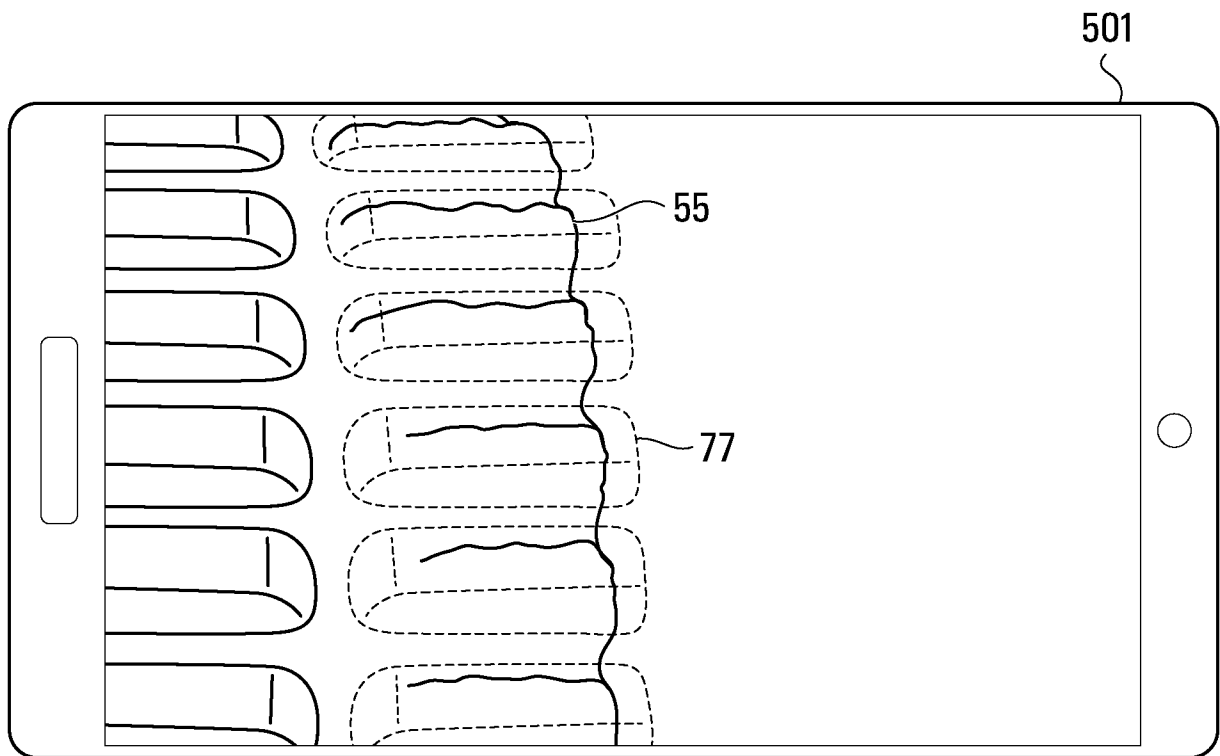


FIG. 35

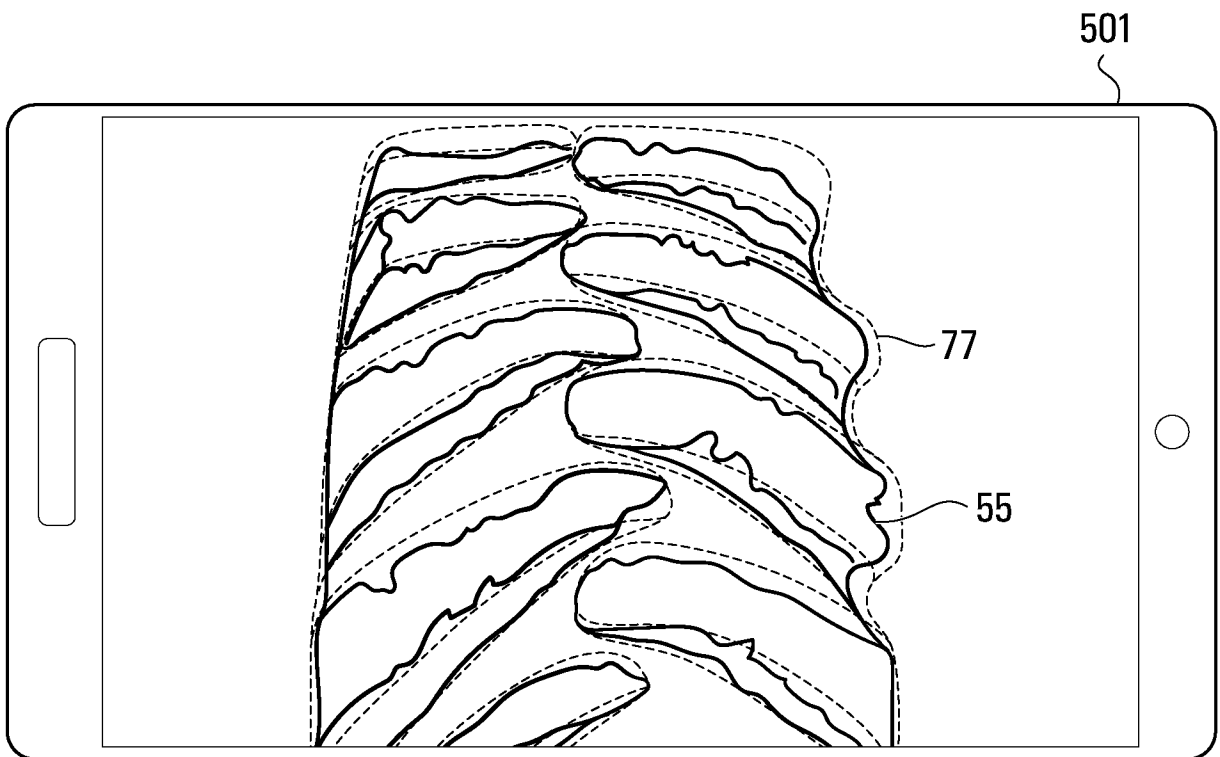


FIG. 36

34/38

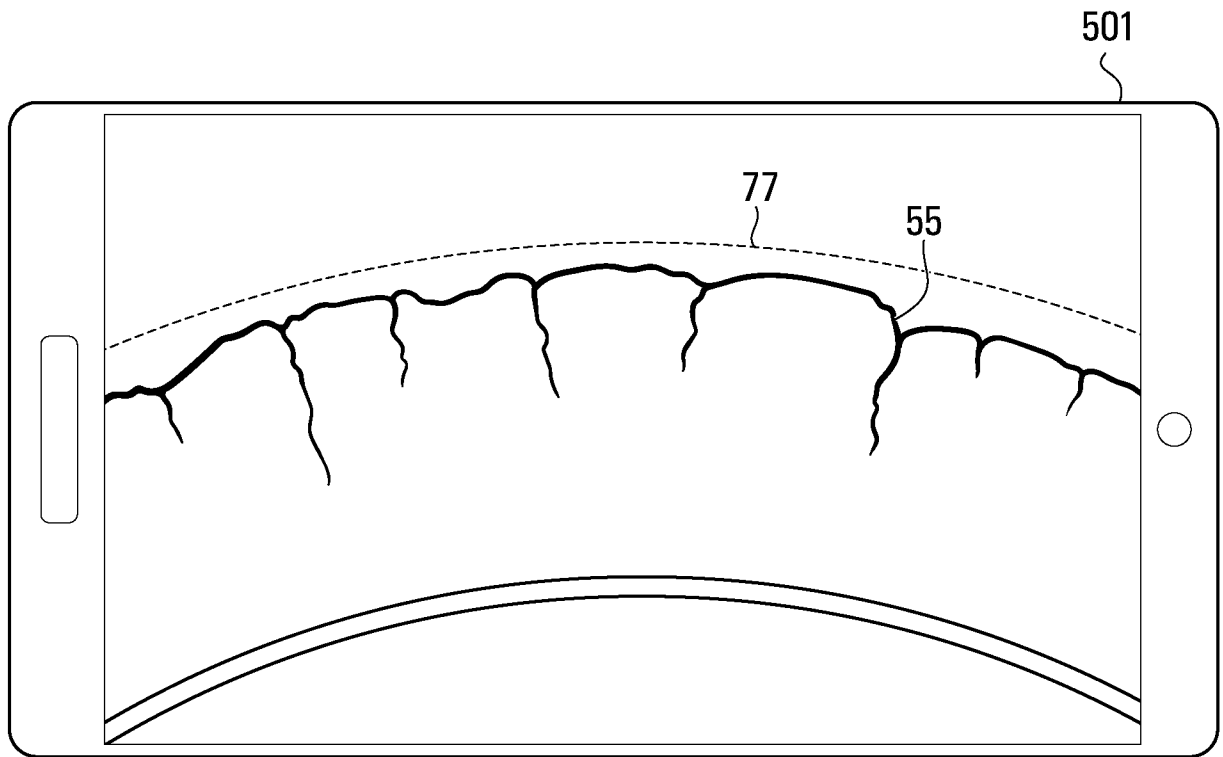


FIG. 37

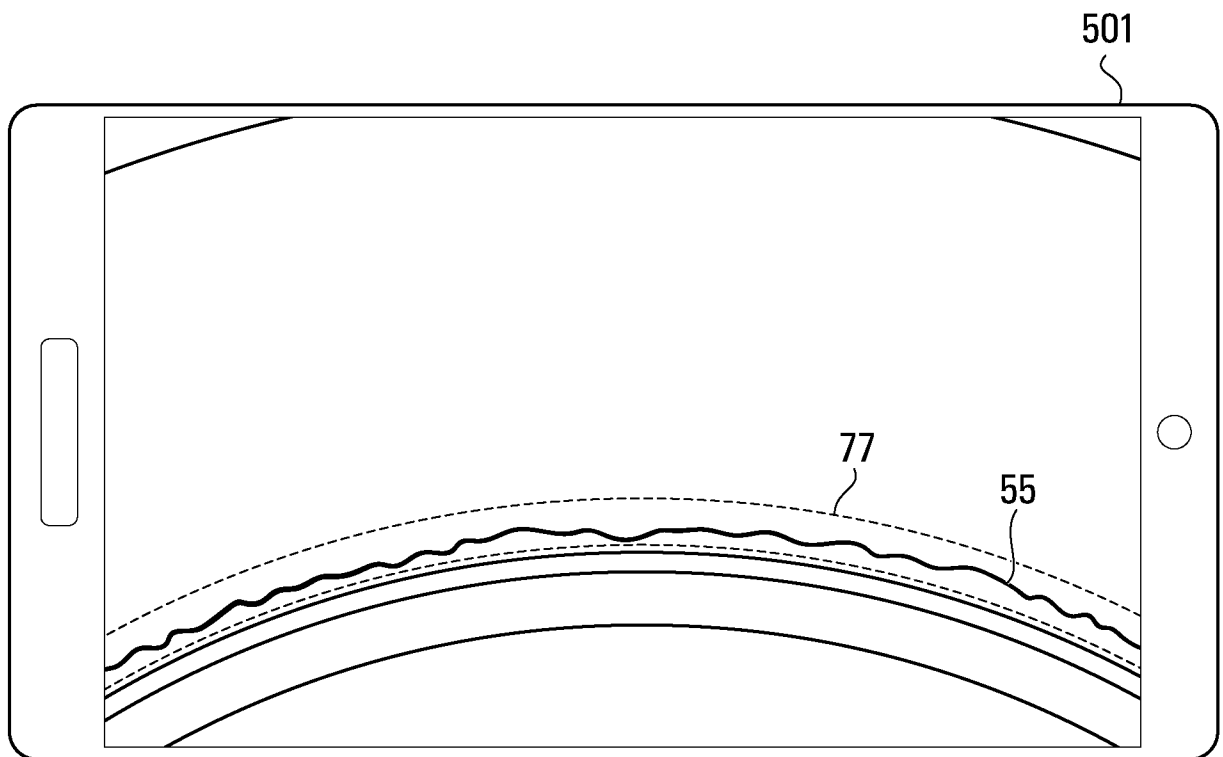


FIG. 38

35/38

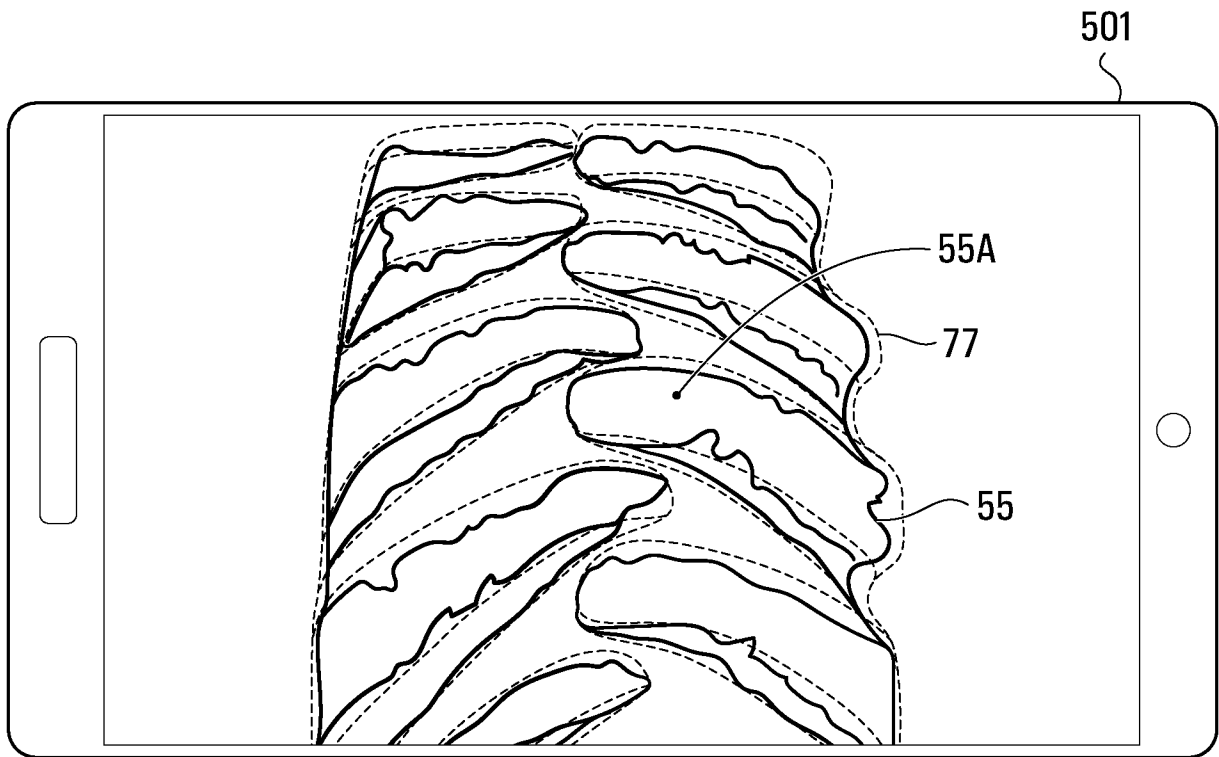


FIG. 39

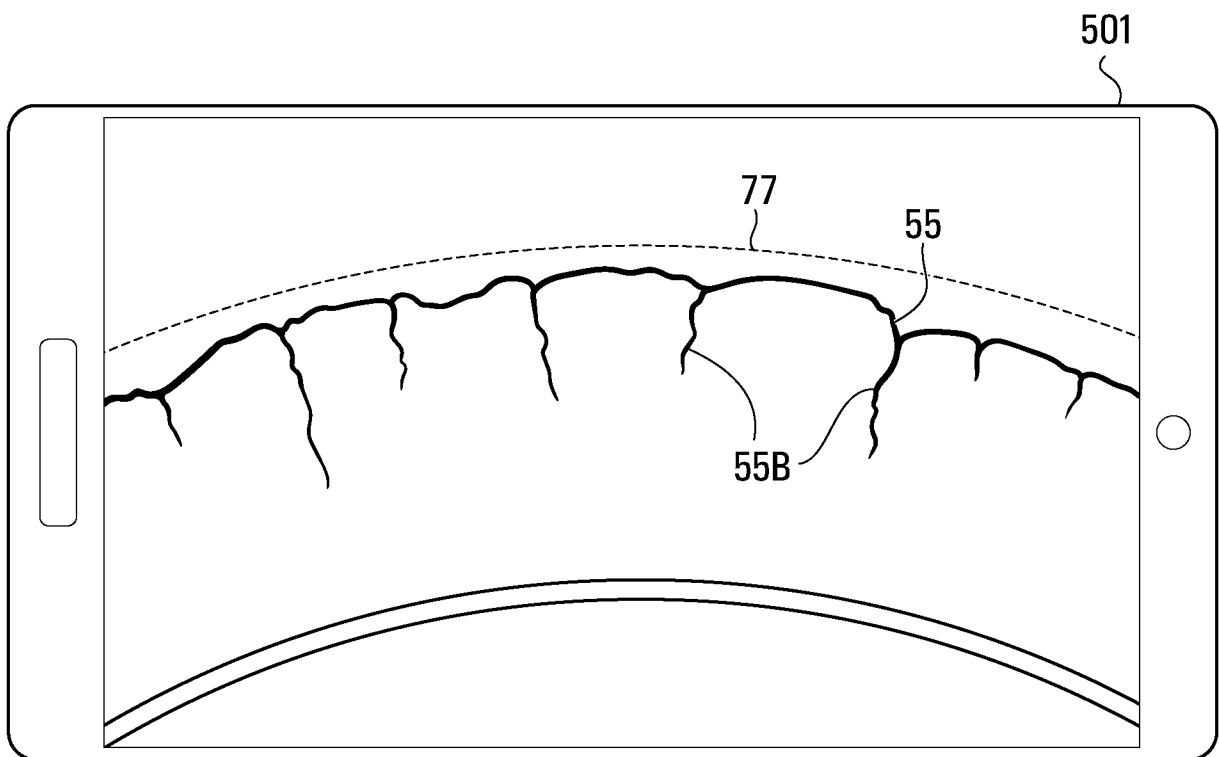
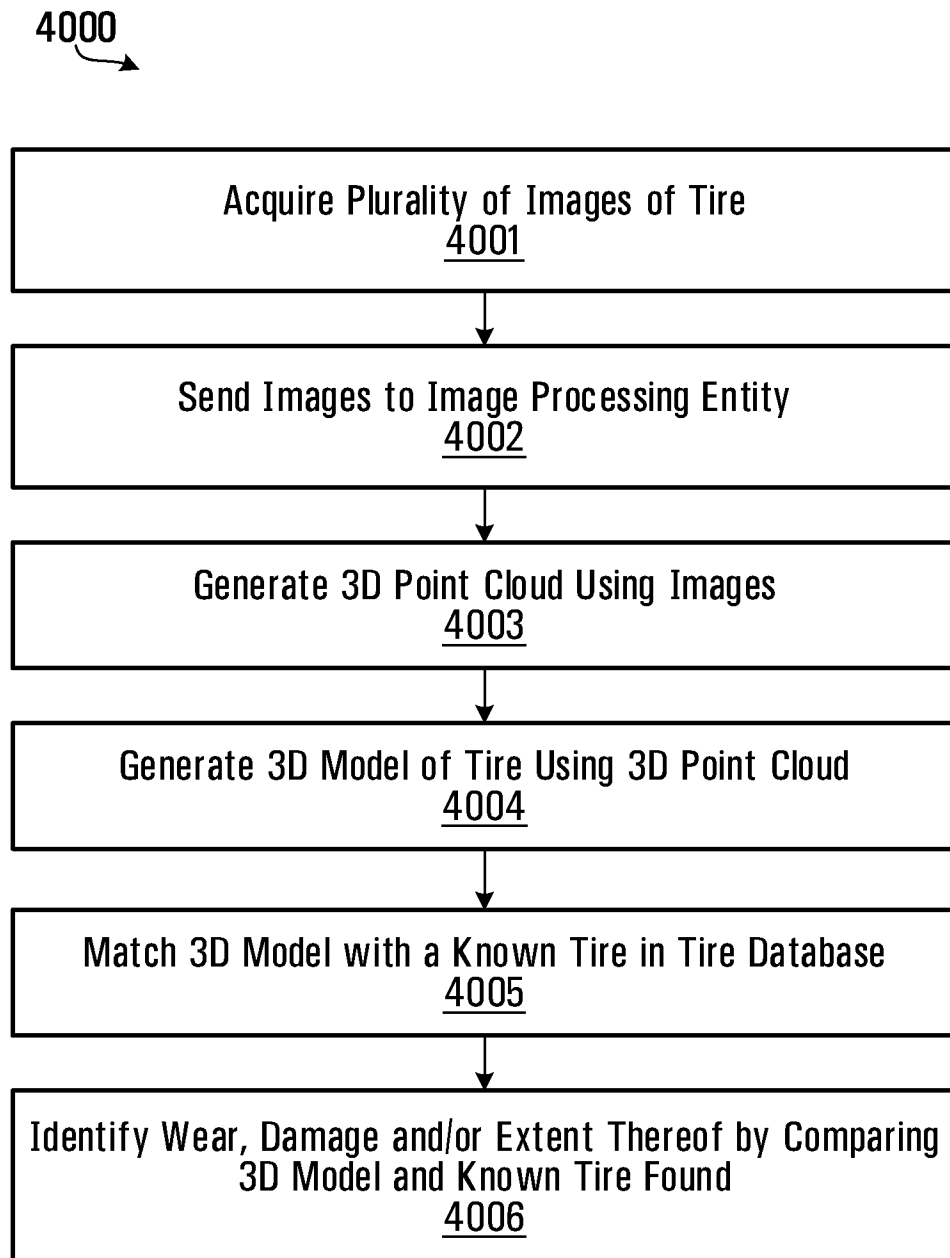
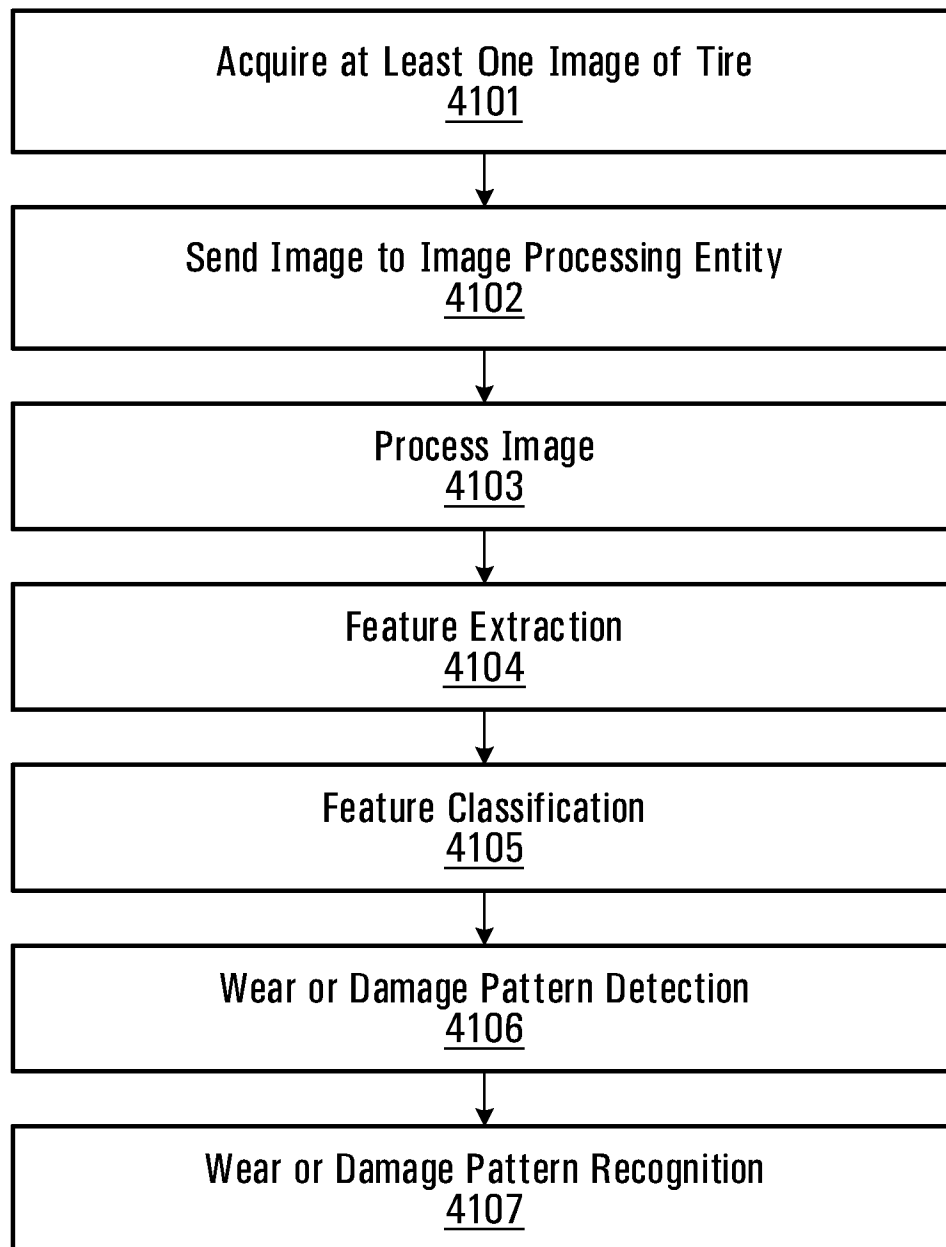


FIG. 40

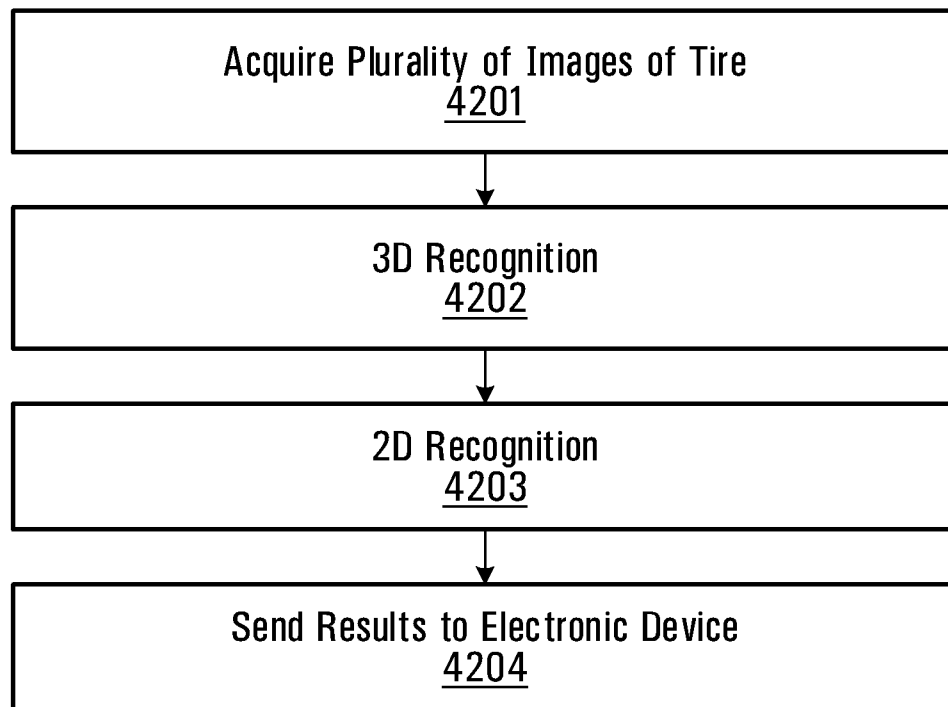
36/38

**FIG. 41**

37/38

4100
→**FIG. 42**

38/38

4200
→**FIG. 43**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2019/051219

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **G01M 17/013** (2006.01), **B60C 99/00** (2006.01), **G01M 17/02** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G01M (2006.01); B60C (2006.01)

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

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

Canadian Patents Database; Questel-Orbit; Google Patents

Keywords: vehicle, tire, monitor, image, processor, state, signal, deterioration, model

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US10006836 B2 (Monty S. et al.) 26 June 2018 (26-06-2018) *abstract, claim 1; col. 10, lines 37-63*	1, 4, 5 2, 3, 12-15
X	KR20120055071 A (Hahm et al.) 31 May 2012 (31-05-2012) *see whole document*	1, 4, 6, 7
X Y	US2018/0172557 A1 (Ghidotti Piovan A. et al.) 21 June 2018 (21-06-2018) *abstract, Fig. 1, par. 0012, 0017, claim 48*	8-11, 16-20 2, 3, 12-15

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* "A" "D" "E" "L" "O" "P"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance document cited by the applicant in the international application earlier application or patent but published on or after the international filing date 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) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	"T" "X" "Y" "&"	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 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 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
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Date of the actual completion of the international search
26 October 2019 (26-10-2019)Date of mailing of the international search report
29 October 2019 (29-10-2019)Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
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Gatineau, Quebec K1A 0C9
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2019/051219

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US10006836B2	26 June 2018 (26-06-2018)	US2017350794A1 US10006836B2 BR112017013330A2 CN108093647A CN108093647B EP3237876A1 EP3237876B1 JP6279163B1 JP2018506707A MX2017008040A MX361397B WO2016103131A1 WO2016103131A9	07 December 2017 (07-12-2017) 26 June 2018 (26-06-2018) 20 February 2018 (20-02-2018) 29 May 2018 (29-05-2018) 05 March 2019 (05-03-2019) 01 November 2017 (01-11-2017) 20 February 2019 (20-02-2019) 14 February 2018 (14-02-2018) 08 March 2018 (08-03-2018) 20 October 2017 (20-10-2017) 04 December 2018 (04-12-2018) 30 June 2016 (30-06-2016) 03 August 2017 (03-08-2017)
KR2012/0055071A	31 May 2012 (31-05-2012)	None	
US2018172557A1	21 June 2018 (21-06-2018)	US2018172557A1 CN107771341A EP3317855A1 MX2017016137A RU2018101232A WO2017001969A1	21 June 2018 (21-06-2018) 06 March 2018 (06-03-2018) 09 May 2018 (09-05-2018) 18 June 2018 (18-06-2018) 31 July 2019 (31-07-2019) 05 January 2017 (05-01-2017)