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(54) **CONTROLLING A VEHICLE BASED ON DATA PROCESSING FOR A FAULTY TIRE**

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G07C 5/08 (2006.01)

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2002/0107694 A1* 8/2002 Lerg B60C 23/06 704/273
2006/0111829 A1 5/2006 Williams
2007/0265749 A1* 11/2007 Fitzgibbons B60W 50/00 701/37

(Continued)

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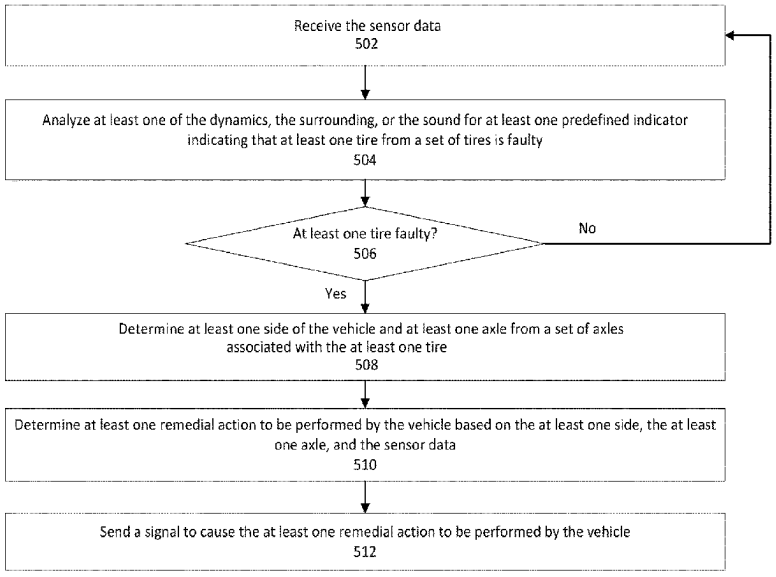
(57) **ABSTRACT**

Sensor data is received at a processor of a vehicle including at least one sensor, a plurality of axles, and a plurality of tires coupled to the plurality of axles. A determination is made by the processor if at least one tire from the plurality of tires is faulty based on the sensor data. A determination is made by the processor of at least one side of the vehicle and at least one axle from the set of axles associated with the at least one tire in response to the determining that the at least one tire is faulty. A determination is made by the processor of at least one remedial action to be performed by the vehicle based on the sensor data, the at least one side, and the at least one axle.

20 Claims, 5 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2017/0308097	A1	10/2017	Switkes et al.	
2018/0065622	A1	3/2018	Nishimine et al.	
2018/0099712	A1*	4/2018	Bean	G08B 13/126
2018/0237001	A1	8/2018	Lian et al.	
2018/0244281	A1	8/2018	Jankowski et al.	
2019/0047500	A1	2/2019	Ghannam et al.	
2019/0118751	A1	4/2019	Ghannam et al.	
2020/0023859	A1	1/2020	Schmitt et al.	
2020/0192360	A1	6/2020	Zheng et al.	
2020/0319638	A1	10/2020	Bowen	
2021/0174140	A1*	6/2021	DeLuca	G16Y 20/10
2021/0181737	A1*	6/2021	Patnaik	B60W 60/0015
2021/0188252	A1*	6/2021	Lu	B60W 40/12
2021/0370922	A1	12/2021	Smith	
2021/0405185	A1*	12/2021	Price	G01S 13/46
2022/0036664	A1	2/2022	Jankowski	

* cited by examiner

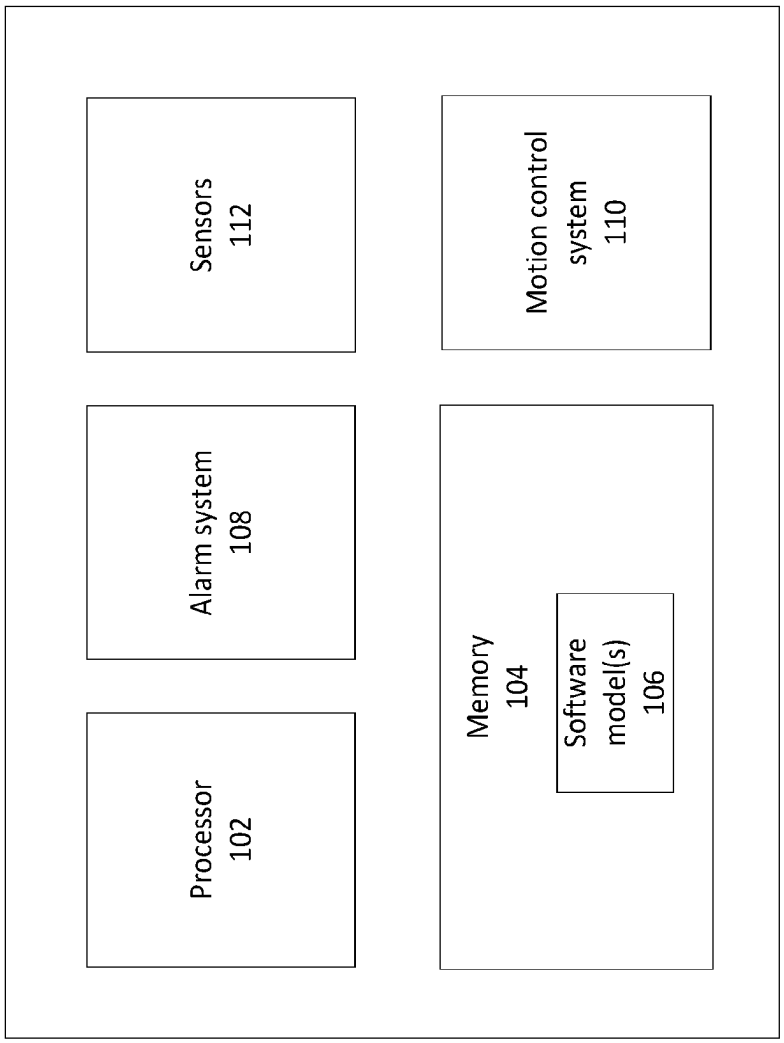

Sensors
112
Motion control
system
110
Alarm system
108
Memory
104
Software
model(s)
106
Processor
102

Figure 1

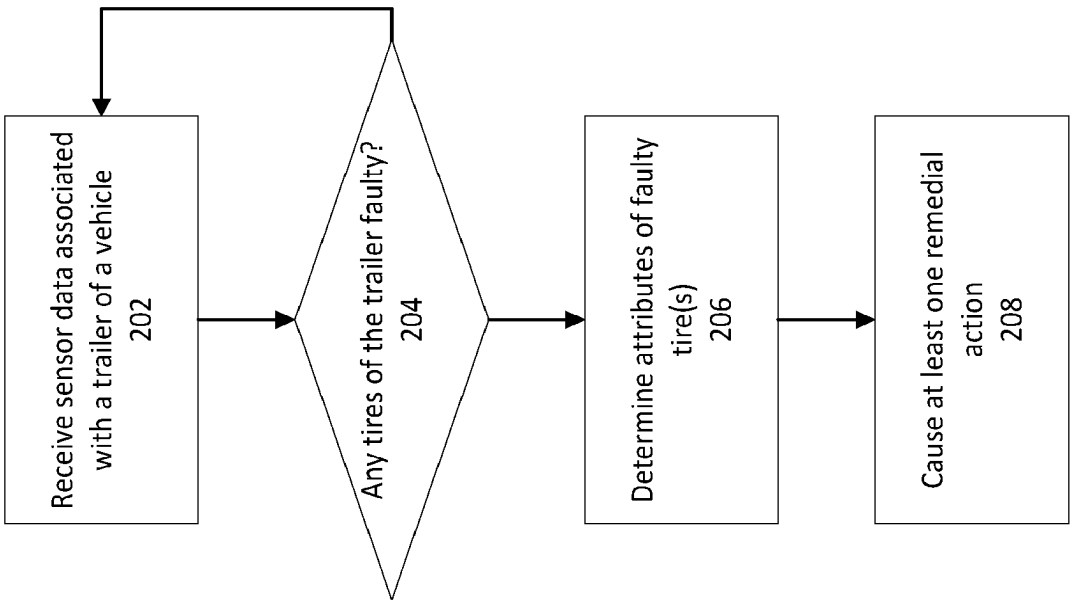

Receive sensor data associated with a trailer of a vehicle
202
Any tires of the trailer faulty?
204
Determine attributes of faulty tire(s)
206
Cause at least one remedial action
208

Figure 2

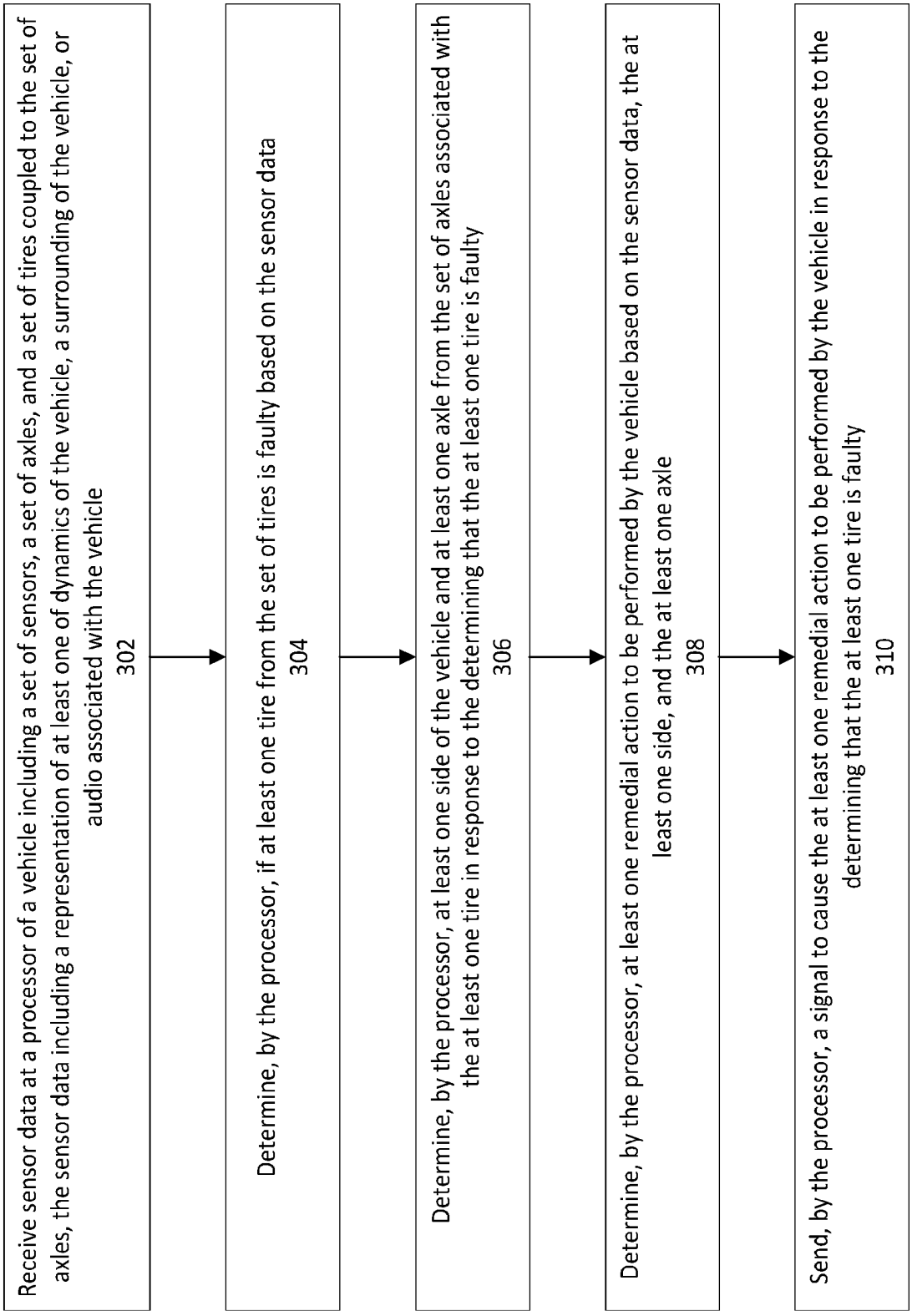

Receive sensor data at a processor of a vehicle including a set of sensors, a set of axles, and a set of tires coupled to the set of axles, the sensor data including a representation of at least one of dynamics of the vehicle, a surrounding of the vehicle, or audio associated with the vehicle
302
Determine, by the processor, if at least one tire from the set of tires is faulty based on the sensor data
304
Determine, by the processor, at least one side of the vehicle and at least one axle from the set of axles associated with the at least one tire in response to the determining that the at least one tire is faulty
306
Determine, by the processor, at least one remedial action to be performed by the vehicle based on the sensor data, the at least one side, and the at least one axle
308
Send, by the processor, a signal to cause the at least one remedial action to be performed by the vehicle in response to the determining that the at least one tire is faulty
310

Figure 3

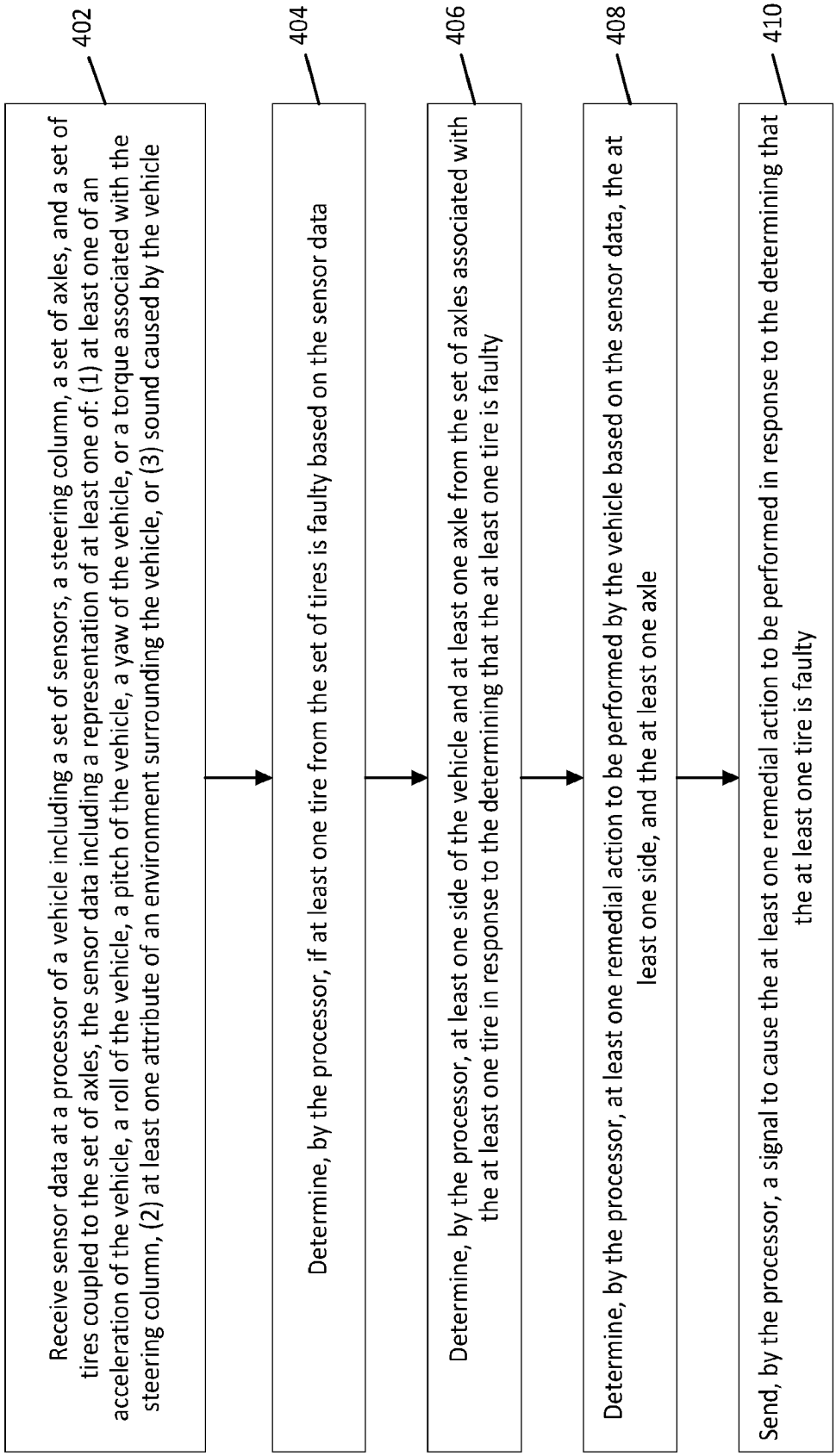

402
Receive sensor data at a processor of a vehicle including a set of sensors, a steering column, a set of axles, and a set of tires coupled to the set of axles, the sensor data including a representation of at least one of an acceleration of the vehicle, a roll of the vehicle, a pitch of the vehicle, a yaw of the vehicle, or a torque associated with the steering column, (2) at least one attribute of an environment surrounding the vehicle, or (3) sound caused by the vehicle
404
Determine, by the processor, if at least one tire from the set of tires is faulty based on the sensor data
406
Determine, by the processor, at least one side of the vehicle and at least one axle from the set of axles associated with the at least one tire in response to the determining that the at least one tire is faulty
408
Determine, by the processor, at least one remedial action to be performed by the vehicle based on the sensor data, the at least one side, and the at least one axle
410
Send, by the processor, a signal to cause the at least one remedial action to be performed in response to the determining that the at least one tire is faulty

Figure 4

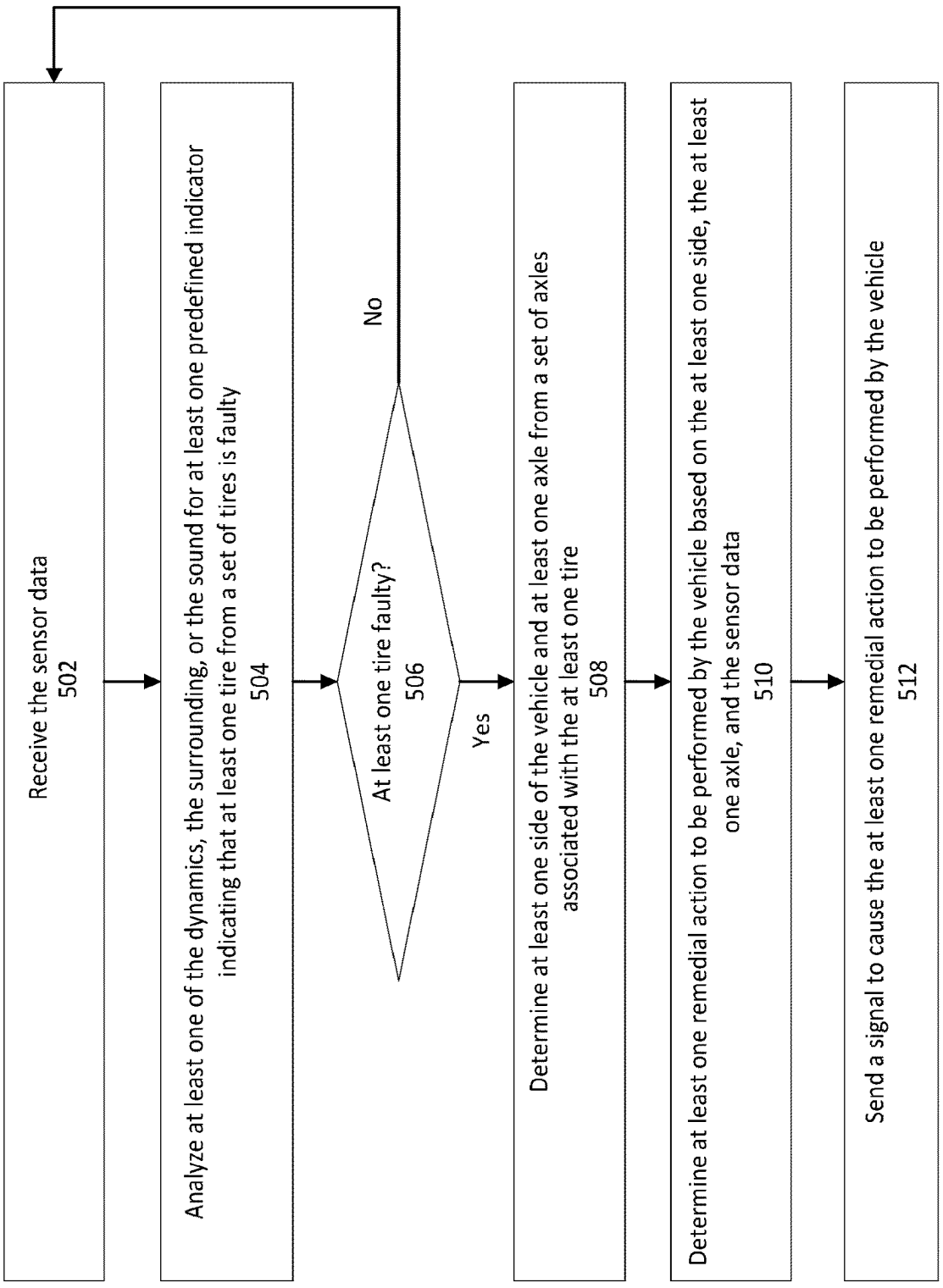

Receive the sensor data
502
Analyze at least one of the dynamics, the surrounding, or the sound for at least one predefined indicator indicating that at least one tire from a set of tires is faulty
504
At least one tire faulty?
506
No
Yes
Determine at least one side of the vehicle and at least one axle from a set of axles associated with the at least one tire
508
Determine at least one remedial action to be performed by the vehicle based on the at least one side, the at least one axle, and the sensor data
510
Send a signal to cause the at least one remedial action to be performed by the vehicle
512

Figure 5

CONTROLLING A VEHICLE BASED ON DATA PROCESSING FOR A FAULTY TIRE

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 17/708,577, filed Mar. 30, 2022, entitled "CONTROLLING A VEHICLE BASED ON DATA PROCESSING FOR A FAULTY TIRE," which is incorporated herein by reference.

FIELD

In one or more embodiments, a vehicle is controlled to perform one or more remedial actions based on one or more software models determining that at least one tire included in the vehicle is faulty.

BACKGROUND

A faulty tire can pose risks for all types of vehicles, such as passenger cars, and semi-trucks. These risks can include the vehicle swerving and/or rolling over.

Some risks can be aggravated for heavier vehicles, such as semi-trucks, due to their larger sizes, relatively heavier weights, and loads that are often hauled by such heavier vehicles. Furthermore, such heavier vehicles sometimes include a truck (e.g., tractor), where the truck can be attached to various types of trailers having different size, weights, shapes, number of tires, sensors, etc. Not all trailers, however, have circuitry configured detect if a tire at the trailer is faulty and/or to notify the truck that a tire included in the trailer is faulty.

SUMMARY

In some embodiments, a method includes receiving sensor data at a processor of a vehicle including at least one sensor, a plurality of axles, and a plurality of tires coupled to the plurality of axles. The sensor data includes a representation of at least one of dynamics of the vehicle, a surrounding of the vehicle, or audio associated with the vehicle. A determination is made by the processor if at least one tire from the plurality of tires is faulty based on the sensor data. A determination is made by the processor of at least one side of the vehicle and at least one axle from the set of axles associated with the at least one tire in response to the determining that the at least one tire is faulty. A determination if made by the processor of at least one remedial action to be performed by the vehicle based on the sensor data, the at least one side, and the at least one axle. A signal is sent by the processor to cause the at least one remedial action to be performed by the vehicle in response to the determining that the at least one tire is faulty.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a block diagram of a vehicle that can be controlled to perform one or more remedial actions based on data processing for a faulty tire, according to an embodiment.

FIG. **2** shows a flowchart of a method for controlling a vehicle based on detecting one or more faulty tires at a trailer of a vehicle, according to an embodiment.

FIG. **3** shows a flowchart of a method for controlling a vehicle based on detecting one or more faulty tires at the vehicle, according to an embodiment.

FIG. **4** shows a flowchart of a method for controlling a vehicle based on detecting one or more faulty tires at the vehicle, according to an embodiment.

FIG. **5** shows a flowchart of a method for controlling a vehicle based on detecting one or more faulty tires at the vehicle, according to an embodiment.

DETAILED DESCRIPTION

Faulty tires of a vehicle can be detected based on dynamics of the vehicle, a surrounding the vehicle, and/or audio associated with the vehicle. A software model can analyze the dynamics, surrounding, and/or audio to determine that at least one tire is faulty. If at least one tire is determined to be faulty, the software model can also determine attributes associated with the at least one tire determined to be faulty, such as a side of the vehicle the faulty tire(s) is located and/or an axle of the vehicle the faulty tire(s) is located. Further, if at least one tire is faulty, the vehicle can perform one or more remedial actions.

The techniques described herein can be applied to any type of vehicle, including vehicles that have trucks attached to trailers (e.g., semi-trucks). The techniques described herein can be desirable for trucks that attach to trailers because the truck can detect if a tire at an attached trailer includes a faulty tire without requiring, for example, a driver of the truck to leave the truck and check the trailer, the attached trailer to include circuitry (e.g., sensors, processor) for detecting a faulty tire, and/or the attached trailer to include circuitry for sending/or and receiving signals to/from the truck. In some scenarios, without using the techniques described herein, a truck/passenger of the truck may not know that a trailer attached to the truck has a faulty tire.

FIG. **1** shows a block diagram of a vehicle **100** that can detect if at least one tire included in the vehicle **100** is faulty, according to an embodiment. The vehicle **100** includes a processor **102**, memory, **104**, alarm system **108**, motion control system **110**, and sensor(s) **112**. The processor **102**, memory, **104**, alarm system **108**, sensor(s) **112**, and at least a portion of the motion control system **110** are operatively coupled to one another (e.g., via a system bus). The vehicle **100** can operate in a fully autonomous mode (and not a semi-autonomous or manual mode), a semi-autonomous mode (and not a fully autonomous or manual mode), a manual mode (and not a fully autonomous or semi-autonomous mode), or a combination thereof.

In some implementations, the vehicle **100** can be a medium truck, heavy truck, very heavy truck, semi-truck, greater than 14,000 pounds, greater than 26,000 pounds, greater than 70,000 pounds, or greater than 80,000 pounds.

In some implementations, the vehicle **100** includes a trailer (e.g., for holding a load) and a truck, where the truck has an engine and the trailer does not. In some implementations, the techniques described herein can monitor all axles of the vehicle **100** for a faulty tire. In some implementations, the techniques described herein can monitor a subset of the axles of the vehicle **100** for a faulty tire (e.g., only the axles at the trailer). In some implementations, the truck (not the trailer) includes the processor **102**, alarm system **108**, sensor(s) **112**, and memory **104**, and the trailer does not include any circuitry configured detect if a tire at the trailer is faulty and/or to notify the truck that a tire included in the trailer is faulty.

The motion control system **110** includes components for controlling the movement of the vehicle **100**, such as a steering wheel, steering column, brake pedal, acceleration pedal, engine, axles, wheels, tires, etc. The motion control system **110** can be used to control movement of the vehicle **100**, such as speeding up, slowing down, moving forward, moving backward, and turning. In a scenario where a tire of the vehicle **100** is determined to be faulty, the processor **102** may send a signal to cause the motion control system **110** to perform at least one remedial action, such as decelerating and/or navigating to a shoulder area.

The alarm system **108** can include at least one of a display, speaker, vibration device, or hazard lights. The alarm system **108** can be located at an interior portion of the vehicle **100**, exterior portion of the vehicle **100**, or a combination thereof. The display can output information visually to a passenger (e.g., driver) of the vehicle **100** and/or others surrounding the vehicle **100**. In some implementations, where the vehicle **100** includes a truck and a trailer, the display is located within the cab of the truck. The speaker can output information audibly to the passenger of the vehicle **100** and/or others surrounding the vehicle **100**. In some implementations, where the vehicle **100** includes a truck and a trailer, the speaker can be located within the cab of the truck and/or at an exterior portion of the truck. The vibration device can cause vibrations to be felt by the passenger. In some implementations, the vibration device is located at an interior portion of the vehicle **100** such that vibrations can be felt by a passenger (e.g., driver). The hazard lights can be located at an exterior portion of the vehicle **100** and can provide warning to other vehicles, pedestrians, etc. near the vehicle **100** (e.g., within visual range) to proceed with caution. In a scenario where a tire of the vehicle **100** is determined to be faulty, the processor **102** may send a signal to cause the alarm system **108** to perform at least one remedial action, such as displaying a warning or outputting an audio message.

The sensor(s) **112** can include one or more sensors for collecting sensor data. The sensor(s) **112** can be used to observe and gather any information that would be useful for performing the techniques discussed herein, such as information associated with a surrounding environment of the vehicle **100** and/or the vehicle **100** itself. The sensor(s) **112** can include, for example, at least one of a camera, a radar, a lidar, a tire pressure sensor, a microphone, an inertial measurement unit (IMU), or a gyroscope. The sensor(s) **112** can collect sensor data that includes representations of attributes associated with the vehicle **100**, such as the vehicle's **100** speed, location, acceleration, size, weight, tire pressure, torque of steering wheel, angle of steering wheel, vehicle height, wheel speed, sound, etc. The sensor(s) **112** can collect sensor data that includes representations of attributes associated with a surrounding of the vehicle **100**, such as a speed, location, acceleration, size, type, relative distance, movement pattern, sound, etc. of other vehicles, pedestrians, animals, obstacles, etc., or location, type, relative distance, size, etc. of signs, lane markers, shoulder areas, etc. In some implementations, the sensor data includes information from a control area network (CAN).

The processor **102** can be, for example, a hardware based integrated circuit (IC) or any other suitable processing device configured to run and/or execute a set of instructions or code. For example, the processor **102** can be a general-purpose processor, a central processing unit (CPU), an accelerated processing unit (APU), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a programmable logic array (PLA), a complex programmable logic device (CPLD), a programmable logic controller (PLC) and/or the like. In some implementations, the processor **102** can be configured to run any of the methods and/or portions of methods discussed herein.

The memory **104** can be, for example, a random-access memory (RAM), a memory buffer, a hard drive, a read-only memory (ROM), an erasable programmable read-only memory (EPROM), and/or the like. The memory **104** can be configured to store sensor data collected by the sensor(s) **112**, data received from a separate compute device (not shown in FIG. **1**), and any other data used by the processor **102** to perform the techniques discussed herein. In some instances, the memory **104** can store, for example, one or more software programs and/or code that can include instructions to cause the processor **102** to perform one or more processes, functions, and/or the like. In some embodiments, the memory **104** can include extendible storage units that can be added and used incrementally. In some implementations, the memory **104** can be a portable memory (for example, a flash drive, a portable hard disk, and/or the like) that can be operatively coupled to the processor **102**. In some instances, the memory **104** can be remotely operatively coupled with the compute device. For example, a remote database device (not shown) can serve as a memory and be operatively coupled to the vehicle **100**.

The memory **104** also includes a software model(s) **106**. The software model(s) **106** can be, for example, an artificial intelligence (AI) model, machine learning (ML) model, analytical model, or mathematical model. The software model(s) **106** can be used to determine that at least one tire of the vehicle **100** is faulty (e.g., blown out, flat) based on sensor data collected by the sensor(s) **112**. In addition, the software model(s) **106** can be used to determine where each faulty tire is located, such as the specific axle and side of the vehicle **100** for each faulty tire. For example, the software model(s) **106** can determine that a tire included in the vehicle **100** faulty, the faulty tire is located at the left side of the vehicle **100**, and the faulty tire is located at the rear-most axle of the vehicle **100**.

In some implementations, the software model(s) **106** can consider a variety of factors independently or in combination to determine that a tire is likely faulty, such as dynamics of the vehicle **100**, a surrounding of the vehicle **100**, or audio associated with the vehicle **100**. In some implementations, the software model(s) **106** generates a confidence metric indicating a likelihood that a tire is faulty, and the tire determined to be faulty if the confidence metric is within a predetermined range (e.g., more than 99%, 95%, 90%, 80%, etc. confident that a tire has blown out). In some implementations, certain attributes of the vehicle's **100** dynamics, surroundings, and/or associated audio can cause the confidence metric to be increased, while other attributes of the vehicle's **100** dynamics, surroundings, and/or associated audio can cause the confidence metric to be decreased.

In some implementations, the software model(s) **106** can consider sensor data indicating dynamics of the vehicle **100** when determining a likelihood that a tire is faulty, such as an acceleration, a roll, a pitch, a yaw, or a steering wheel torque of the vehicle **100**. Detecting certain dynamics can indicate to the software model(s) **106** a greater likelihood that a tire is blown out, such as an excessive vibration, the steering wheel torque increasing, deceleration of the vehicle, the yaw increasing, the roll increasing, the pitch being forward, or any other dynamic that could indicate that a tire of the vehicle **100** is faulty. In some implementations, the software model(s) **106** can analyze the acceleration, the roll, the pitch, the yaw, the steering wheel torque, or a combination thereof

for a predetermined relationship suggesting that at least one tire is faulty. The predetermined relationship could be, for example, the steering wheel torque increasing, deceleration of the vehicle, the yaw increasing, the roll increasing, and the pitch being forward.

In some implementations, the software model(s) **106** can consider sensor data indicating a surrounding of the vehicle **100** when determining a likelihood that a tire is faulty, such as detecting for debris/dust/smoke near the vehicle **100** and/or analyzing other vehicles' reactions/behaviors (if present). Detecting certain attributes can indicate to the software model(s) **106** a greater likelihood that a tire is blown out, such as debris/dust/smoke being produced near a tire of the vehicle **100**, other vehicles honking, other vehicles moving away from the vehicle **100**, a combination thereof, or any other behavior of surrounding vehicles that could indicate that a tire of the vehicle **100** is faulty.

In some implementations, the software model(s) **106** can consider sensor data indicating audio associated of the vehicle **100** when determining a likelihood that a tire is faulty, such as sound caused by the vehicle **100**. Detecting certain sounds can indicate to the software model(s) **106** a greater likelihood that a tire is blown out, such as an abrupt sound indicating that a tire has blown out, a scraping sound of a wheel scraping the ground, or repetition of a flapping sound indicating that a tire is flat.

The software model(s) **106** can also consider the dynamics, surrounding, and/or audio associated with the vehicle **100** when determining the axle and/or side of the faulty tire. As an example, a faulty tire at a left side of the vehicle **100** could cause the vehicle **100** to roll left and/or spin counterclockwise. As another example, a faulty tire at a right side of the vehicle **100** could cause the vehicle **100** to roll right and/or spin clockwise. As another example, a faulty tire at a front axle of the vehicle **100** could cause the vehicle **100** to pitch forward. As another example, a faulty tire at a rear axle of the vehicle **100** could cause the vehicle **100** to pitch backwards. As another example, a faulty tire at a left side of the vehicle **100** could cause debris/dust/smoke to be detected at a left side of the vehicle **100** and/or only cause other vehicles that are in front of, behind, and/or to the left of the vehicle **100** to react accordingly. As another example, a faulty tire at a right side of the vehicle **100** could cause debris/dust/smoke to be detected at a right side of the vehicle **100** and/or only cause other vehicles that are in front of, behind, and/or to the right of the vehicle **100** to react accordingly. As another example, a faulty tire at a left side of the vehicle **100** would cause a sound indicting that a tire is faulty to be generated from a left side of the vehicle. As another example, a faulty tire at a right side of the vehicle **100** would cause a sound indicting that a tire is faulty to be generated from a right side of the vehicle

The software model(s) **106** can also consider the dynamics, surrounding, and/or audio associated with the vehicle **100** when determining the axle of the faulty tire. The vehicle **100** can include two or more axles. In some implementations, where the vehicle **100** includes a truck and a trailer, the truck can include two or more axles and the trailer can include two or more axles. In some implementations, because a faulty tire at one axle can cause the vehicle **100** to have different dynamics compared to a faulty tire at a different axle, dynamics can be used to determine which axle is associated with the faulty tire. In some implementations, the roll, pitch, and/or yaw of the vehicle **100** can be collected (e.g., via a gyroscope, inertial measurement unit) and analyzed. For example, a forward pitch of the vehicle **100** could indicate a faulty tire at a front axle, while a backward pitch of the vehicle **100** could indicate a faulty tire at a rear axle of the vehicle **100**. Moreover, a faulty tire at a front axle of the vehicle **100** may affect steering much more compared to a faulty tire at a rear axle of the vehicle **100**. For example, a greater torque at a steering column may indicate that a tire at a front axle of the vehicle **100** is faulty, while a lesser torque at the steering column may indicate that a tire at a rear axle of the vehicle **100** is faulty. In some implementations, a surrounding of the vehicle **100** can be used to determine which axle is associated with the faulty tire by determining the axle closest to debris/dusk/smoke being generated. In some implementations, audio associated with the vehicle **100** can be used to determine which axle is associated with the faulty tire based on a magnitude (i.e., loudness) of the audio captured by a microphone indicating that a tire is likely faulty, where a larger magnitude indicates the axle associated with the faulty tire is closer to the microphone and a smaller magnitude indicates the axle associated with the faulty tire is farther from the microphone. If, for whatever reason, the axle of the faulty tire cannot be determined, in some implementations, a remedial action that mitigates a risk and/or causes the vehicle **100** to operate more safely can be performed (e.g., pulling over to a shoulder and/or safe area, decreasing speed of the vehicle **100**, alerting a passenger and/or driver included in the vehicle **100**, turning on hazard lights, etc.).

In some implementations, the software model(s) **106** can estimate a set of weights (e.g., of a load carried by the vehicle) held at at least one axle and/or left and right portion of at least one axle included in the vehicle **100** as the vehicle **100** is driving. Knowing that a flat or blown out tire would cause an axle and/or portion of the axle to carry less weight, a sudden change of weight held by at least one axle and/or left and right portion of at least one axle can indicate to the software model(s) **106** a greater likelihood that a tire is faulty. Knowing which axle and portion of the axle had a decrease in weight can also be used by the software model(s) **106** in determining the side and axle of the vehicle **100** associated with the faulty tire.

In some implementations, the estimated set of weights includes estimated weights at the axles and/or portions of the axles (i.e., left portion and right portion of each axle) for the entire vehicle **100**. For example, if the vehicle **100** includes a front axle and a rear axle, the software model(s) **106** can estimate a weight at the front left axle, the front right axle, the rear left axle, and the rear right axle, as well as a weight at the front axle (e.g., by adding the weight at the front left axle and the weight at the front right axle), and rear axle (e.g., by adding the weight at the rear left axle and the weight at the rear right axle). In some implementations, where the vehicle **100** includes a tractor and a trailer, the estimated set of weights includes estimated weights at the axles and/or portions of the axles (i.e., left portion and right portion of each axle) for the trailer (and not the tractor). For example, if the vehicle **100** includes a tractor with a front and rear axle, and a trailer with a front and rear axle, the software model(s) **106** can estimate a weight at the front and rear axles of the trailer without estimating a weight at the front and rear axles of the tractor.

In some implementations, the estimated set of weights include absolute values (e.g., 1,050 pounds at front left axle, 950 pounds at front right axle, 1,000 pounds at rear right axle, and 975 pounds at rear left axle). In some implementations, the estimated set of weights include relative values (e.g., 30% of total weight at front left axle, 25% of total weight at front right axle, 25% of total weight at rear right axle, and 20% of total weight at rear left axle). In some

implementations, absolute values of weights at the axles and/or left and right portions of the axles can be estimated using (1) pre-measured weights at the axles and/or left and right portions of the axles of the vehicle **100** when stationary (e.g., via a scale), and (2) relative values of weights at the axles and/or left and right portions of the axles. For example, if 60% of the total weight is at the front axle during a drive, 40% of the total weight is at the back axle during the drive, and the total weight of the vehicle **100** was measured to be 30,000 pounds prior to the drive, the software model(s) **106** can approximate that 18,000 pounds are at the front axle and 12,000 pounds are at the rear axle.

In some implementations, the software model(s) **106** can estimate the set of weights associated with the axles as the vehicle **100** drives using an air spring suspension system included in the vehicle **100** (not shown in FIG. **1**). The air spring suspension system can include an air pump or compressor, where the air pump or compressor can pump air into flexible bellows (not shown in FIG. **1**) of the air spring suspension system. The air can inflate the bellows and raise a chassis (not shown in FIG. **1**) of the vehicle **100** from the axles. The air spring suspension system can output air pressure values near the left and right portions of each axle. The air pressure values can then be used by the software model(s) **106** to estimate an absolute and/or relative set of weights at the left and right portions of axles that are of interest.

In some implementations, the software model(s) **106** can estimate the set of weights associated with the axles (as the vehicle **100** drives) using a frequency response function associated with a center of gravity of the vehicle **100**. The frequency response function associated with the center of gravity indicates a vertical frequency of the vehicle **100** and a roll frequency of the vehicle **100**. A vertical frequency value provided by the frequency response function and a roll frequency value provided by the frequency response function can indicate a weight distribution of the vehicle **100**, and a difference between the vertical frequency value and the roll frequency value being outside a predetermined range can indicate that an abnormal weight distribution exists.

In some implementations, the software model(s) **106** can estimate the set of weights associated with the axles (as the vehicle **100** drives) by analyzing a height change associated with the vehicle **100**. In some implementations, the sensor(s) **112** can collect sensor data indicating a set of heights at various points of the vehicle **100** when the vehicle **100** is not moving, such as the highest points of the vehicle **100** above the left and right portions of axles that are of interest (e.g., all axles of the vehicle **100**, only axles at a trailer of the vehicle **100**). Knowing heights at these various points of the vehicle **100**, as well as weights at various points of the vehicle **100** when stationary (e.g., via pre-measured weights at the axles and/or left and right portions of the axles measured using a scale), a set of weights can be estimated as the vehicle **100** is driving by analyzing changes in height at the various points of the vehicle. Knowing that additional weight decreases height, a set of weights including absolute and/or relative values can be estimated based on the change in height at the various points.

In some implementations, the software model(s) **106** can estimate the set of weights associated with the axles by analyzing a tire pressure change between tires included in the vehicle **100**. In some implementations, tire pressures values can be captured at each tire of the vehicle **100** prior to driving, and again during driving. Knowing that adding weight at a tire could increase that tire's pressure, a tire pressure increase during driving can indicate that additional weight has been added near that tire (and vice versa). The amount of tire pressure increase and/or decrease can be used to estimate the set of weights.

In some implementations, the software model(s) **106** can estimate the set of weights associated with the axles by analyzing a relative wheel speed difference between two or more wheels included in the vehicle **100**. Weight can cause a tire of the vehicle **100** to compress, which can cause a radius/diameter of the tire/wheel to change. A smaller radius/diameter can mean the tire/wheel needs to rotate faster relative to a tire/wheel with a larger radius/diameter (and vice versa). In some implementations, the sensor(s) **112** can capture sensor data indicating wheel speeds at each wheel of the vehicle **100** and/or each wheel of a trailer included in the vehicle **100**, and the software model(s) **106** can analyze the wheel speeds to determine if differences exist. If differences do not exist, weights at the axles/left and right portions of the axles are likely to be similar to the weights of the axles and/or left and right portions of the axle measured when stationary. If, however, differences do exist, weights at the axles/left and right portions of the axles are likely to have deviated from the measured weights (e.g., where wheels with faster wheel speeds have larger weights compared to wheels with slower wheel speeds). Furthermore, the amount of difference in wheel speed between wheels can also be used to estimate absolute and/or relative values for the set of weights.

In some implementations, after the software model(s) **106** determines that a tire is faulty, at least one remedial action is performed (e.g., automatically without requiring human input). In some implementations, after the software model(s) **106** determines that a tire is faulty, what side of the vehicle **100** the faulty tire is at, the axle associated with the faulty tire, or a combination thereof, at least one remedial action is performed (e.g., automatically without requiring human input).

In some implementations, after the software model(s) **106** determines that a tire is faulty, what side of the vehicle **100** the faulty tire is at, the axle associated with the faulty tire, or a combination thereof, the software model(s) **106** can determine what remedial action should be performed. In some implementations, the remedial action can be chosen based on sensor data collected by the sensor(s) **112**, what side of the vehicle **100** the faulty tire is at, the axle associated with the faulty tire, or a combination thereof. In some implementations, a remedial action can be chosen that minimizes and/or does not increase the amount of estimated weight at the side and/or axle associated with the faulty tire. In some implementations, a remedial action can be chosen that does not increase a center of gravity of the vehicle **100**. In some implementations, a remedial action can be chosen that does not increase a likelihood that the vehicle **100** will fishtail, sway, and/or rollover. In some implementations, a remedial action can be chosen that is possible to perform safely for a given scenario (as detected by the sensor(s) **112**). In some implementations, a remedial action can be chosen that does not cause the vehicle **100** to perform any maneuvers that are predetermined to be prohibited for a given side and/or axle of the vehicle **100** associated with a faulty tire (e.g., if the faulty tire is at the left side, the remedial action does not force the vehicle **100** to turn left; if the faulty tire is at the rear-most axle of the vehicle **100**, the remedial action does not force the vehicle **100** to decelerate faster than a predetermined deceleration rate). In some implementations, a remedial action can be chosen that does not increase the amount of estimated weight at an axle and/or left and

right portion of the axle beyond a predetermined limit (e.g., 4,250 pounds, 6,000 pounds, 8,500 pounds, 12,000 pounds).

Upon determining that at least one remedial action should be performed, the processor **102** can cause the at least one remedial action to be performed. In some implementations, the processor can send a signal to the alarm system **108** and/or motion control system **110** to cause the at least one remedial action to be performed.

In some implementations, the at least one remedial action includes automatically and/or autonomously decreasing a speed of the vehicle **100** without requiring human input. In some implementations, the processor **102** can send a signal to the motion control system **110** to cause the vehicle **100** to slow down to a speed beneath a predetermined speed threshold if the vehicle **100** is travelling faster than the predetermined speed limit.

In some implementations, the at least one remedial action includes automatically causing the motion control system **110** to adjust the vehicle's **100** dynamics without requiring human input. For example, the processor **102** can send a signal to the motion control system **110** to cause the vehicle **100** to decrease the vehicle's speed and/or acceleration. As another example, the processor **102** can send a signal to the motion control system **110** to cause the vehicle **100** to decrease a roll angle of the vehicle **100** and/or a steering wheel angle of a steering wheel included in the motion control system **110**.

In some implementations, the at least one remedial action includes automatically navigating the vehicle **100** to a predetermined safe location without requiring human input. In some implementations, the predetermined safe location can be a safe place to stop, such as a shoulder or parking lot. In some implementations, the predetermined safe location can be a road with less turns, a flatter bank, less traffic, a lower speed limit, etc.

In some implementations, the at least one remedial action includes alerting a passenger of the vehicle **100** using the alarm system **108**. In some implementations, the at least one remedial action includes using the alarm system **108** to output information visually to the passenger to inform the passenger that at least one tire is faulty, attributes associated with the at least one tire (e.g., side and axle), recommended actions for the passenger, etc. In some implementations, the at least one remedial action includes using the alarm system **108** to output information audibly to the passenger to inform the passenger that at least one tire is faulty, attributes associated with the at least one tire (e.g., side and axle), recommended actions for the passenger, etc. In some implementations, the at least one remedial action includes using the alarm system **108** to cause vibrations to be felt by the passenger, which can be used to increase the passenger's alertness. In some implementations, the at least one remedial action includes using the alarm system **108** to turn on hazard lights.

In some implementations, the vehicle **100** is operating in a first mode prior to performing the at least one remedial action, and the at least one remedial action causes the vehicle **100** to operate and/or initiate a process to operate in a second mode different than the first mode. The first mode could be four-wheel drive, two-wheel drive, an autonomous driving mode, a semi-autonomous driving mode, a manual driving mode, cruise control, etc. The second mode could be four-wheel drive, two-wheel drive, an autonomous driving mode, a semi-autonomous driving mode, a manual driving mode, cruise control, etc.

In some implementations, the vehicle **100** is operating in an autonomous driving mode prior to performing the at least one remedial action, and the at least one remedial action initiates causing a passenger of the vehicle **100** to perform a series of tasks to cause the vehicle **100** to operate in a manual driving mode if the passenger performs the series of tasks. In some implementations, a set of tasks required to switch the vehicle from operating in the autonomous driving mode to the manual driving mode are determined, and the set of tasks are made known to the driver via the alarm system **108**. Additional details related to performing a series of tasks to switch an operating mode of the vehicle **100** are discussed in U.S. patent application Ser. No. 16/799,067, the contents of which are incorporated by reference herein in its entirety.

In some implementations, the vehicle **100** is operating in a first mode prior to performing the at least one remedial action, and the at least one remedial action causes the vehicle **100** to be prevented from and/or refrain from operating in a second mode different than the first mode. The first mode could be four-wheel drive, two-wheel drive, an autonomous driving mode, a semi-autonomous driving mode, a manual driving mode, cruise control, etc. The second mode could be four-wheel drive, two-wheel drive, an autonomous driving mode, a semi-autonomous driving mode, a manual driving mode, cruise control, etc.

In some implementations, after estimating a set of weights held at one or more axles and/or left and right portions of axles of the vehicle **100**, a determination can be made whether the set of weights indicate that the vehicle **100** is unbalanced. In some implementations, the vehicle **100** is unbalanced if the set of weights indicate that a left portion of an axle is holding more weight and/or substantially (e.g., 5%, 10%, 15%, 20%, etc.) more weight than a right portion of that axle (or vice versa). In some implementations, the vehicle **100** is unbalanced if a first axle of the vehicle (e.g., rear axle) is holding more weight than a second axle of the vehicle (e.g., front axle). In some implementations, the vehicle **100** is unbalanced if a first axle of the vehicle (e.g., front axle) is not holding substantially (e.g., 5%, 10%, 15%, 20%, etc.) more weight than a second axle of the vehicle (e.g., rear axle). Determining that the vehicle **100** is unbalanced could cause at least one remedial action to be performed.

In some implementations, the vehicle **100** can include a truck and trailer coupled to the truck, where the truck can include an engine but the trailer does not. The processor **102**, alarm system **108**, sensor(s) **112**, memory **104**, and at least a portion of the motion control system **110** (e.g., steering wheel, engine, axles, wheels attached to the axles, tires fit over the wheels) are included in the truck, while the trailer can include axles, wheels attached to left and right portions of the axles, and tires fit over the wheels. The trailer does not include any circuitry configured detect if a tire at the trailer is faulty and/or to notify the truck that a tire included in the trailer is faulty. For such a vehicle, FIG. **2** shows a flowchart of a method for causing at least one remedial action in response to determining that a tire at the trailer is faulty, according to an embodiment. The method discussed with respect to FIG. **2** can be performed by a processor (e.g., processor **102**) located at the truck.

At **202**, sensor data associated with the trailer is received. The sensor data can include representations of dynamics of the trailer, a surrounding of the trailer, audio associated with the trailer, or a combination thereof. For example, the sensor data can include representations of a speed of the trailer, acceleration of the trailer, roll of the trailer, pitch of the trailer, yaw of the trailer, debris/dust/smoke caused by the trailer, behavior of objects near the trailer, sounds caused by

the trailer, etc. In some implementations, the sensor data can also include a representation of a steering wheel torque of a steering wheel included at the truck.

At **204**, a determination is made if any of the tires at the trailer are faulty. This determination at **204** can be performed using the sensor data received at **202** and a software model (e.g., software model(s) **106**) configured to detect faulty tires at trailers based on dynamics associated with the trailer, a surrounding associated with the trailer, audio associated with the trailer, or a combination thereof. A tire at the trailer can be detected to be faulty by the software model if, for example, the steering wheel torque of the trailer and/or truck has increased, the acceleration at the trailer and/or truck has decreased, the yaw at the trailer and/or truck has increased, the roll at the trailer and/or truck has increased, the trailer and/or truck has a forward pitch, debris/dust/smoke is being produced near a tire of the trailer, other vehicles near the trailer and/or truck are honking, other vehicles previously near the trailer and/or truck are moving away from the trailer and/or truck, a predetermined sound pattern and/or a predetermined sound is detected (e.g., an abrupt sound indicating that a tire has blown out, a scraping sound of a wheel scraping the ground, repetition of a flapping sound indicating that a tire is flat), etc.

If **204** is yes, the method proceeds to **206**. If **204** is no, the method returns to **202**.

At **206**, one or more attributes of the faulty tire(s) are determined. In some implementations, the attribute(s) can include a side of the trailer that the faulty tire(s) is located and/or an axle of the trailer that the faulty tire(s) is located. In some implementations, the one or more attributes can be determined using the sensor(s) **112** (e.g., camera, lidar, radar, microphone, IMU). In some implementations, **206** is optional, in which **204** proceeds to **208** if **204** is yes.

At **208**, at least one remedial action is caused to be performed. In some implementations, the at least one remedial action to be performed is based on the one or more attributes of the faulty tire(s). In some implementations, the at least one remedial action is predetermined (i.e., the at least one remedial action is determined prior to **202**, **204**, **206**, and/or **208**) and performed automatically in response to **206** being complete and/or **204** being yes.

FIG. **3** shows a flowchart of a method for detecting a faulty tire at a vehicle (e.g., vehicle **100**), according to an embodiment. The method discussed with respect to FIG. **3** can be performed by a processor (e.g., processor **102**) included at the vehicle.

At **302**, sensor data is received at a processor (e.g., processor **102**) of a vehicle (e.g., vehicle **100**) including at least one sensor (e.g., sensor(s) **112**), a plurality of axles, a plurality of wheels coupled to the plurality of axels, and a plurality of tires coupled to the plurality of wheels. The sensor data can include, for example, a representation of at least one of dynamics of the vehicle, a surrounding of the vehicle, or audio associated with the vehicle. The plurality of axles includes at least one wheel at a left portion of each axle from the plurality of axles and at least one wheel at a right portion of each axle from the plurality of axles. Furthermore, the plurality of tires are mounted on the wheels at the plurality of axles. The representation of the dynamics can include a speed, acceleration, roll, pitch, yaw, steering wheel torque, etc. associated with the vehicle. The representation of the surrounding can represent, for example, debris/dust/smoke caused by the vehicle and/or behavior of objects near the vehicle. The representation of audio associated with the vehicle can include a recording of and/or represent, for example, sounds received and/or generated by the vehicle.

At **304**, a determination is made by the processor if at least one tire from the plurality of tires is faulty based on the sensor data. The processor can use at least one software model (e.g., software model(s) **106**) configured to detect faulty tires at the vehicle. A tire at the vehicle can be detected to be faulty by the software model if, for example, the steering wheel torque of the vehicle has increased, the acceleration of the vehicle has decreased, the yaw of the vehicle has increased, the roll of the vehicle has increased, the vehicle has a forward pitch, debris/dust/smoke is being produced near a tire of the vehicle, other vehicles near the vehicle are honking, other vehicles previously near the vehicle are moving away from the vehicle, a predetermined sound pattern is detected (e.g., an abrupt sound indicating that a tire has blown out, a scraping sound of a wheel scraping the ground, repetition of a flapping sound indicating that a tire is flat), etc.

At **306**, at least one side of the vehicle and at least one axle from the plurality of axles associated with the at least one tire is determined (or identified) by the processor in response the determining that the at least one tire is faulty. Said similarly, if **304** determines that at least one tire from the plurality of tires is faulty, at **306**, the side(s) and axle(s) of the vehicle where each faulty tire is located is determined (or identified). The at least one side and at least one axle can be determined (or identified).using at least one software model (e.g., software model(s) **106**) based on sensor data received at **302**.

At **308**, at least one remedial action to be performed by the vehicle is determined by the processor based on the sensor data, the at least one side, and/or the at least one axle. Said similarly, the at least one remedial action to be performed can be determined while taking into consideration attributes of a surrounding of the vehicle and/or attributes of the vehicle itself, and/or a location(s) of the at least one tire determined to be faulty. For example, the at least one remedial action can cause the vehicle to perform an action that will cause minimum risk (or reduced risk) to other vehicles surrounding the vehicle, and that will minimize and/or not add additional force, pressure, and/or momentum to the at least one tire determined to be faulty.

At **310**, a signal to cause the at least one remedial action to be performed by the vehicle is sent by the processor in response to the determining that the at least one tire is faulty. The signal could be sent, for example, from the processor to a motion control system (e.g., motion control system **110**) so that the vehicle can perform a driving maneuver and/or to an alarm system (e.g., alarm system **108**) so that a passenger, driver, nearby person, etc. is notified of the faulty tire and/or other actions that should and/or are recommended to take place. In some implementations, the at least one remedial action includes the vehicle sending a signal (e.g., via a communication interface included in the vehicle and over a network) to another compute device (e.g., server and/or another vehicle) wirelessly connected to the vehicle's processor (e.g., processor **102**) indicating, for example, that at least one tire is faulty, attributes associated with the at least one faulty tire (e.g., side, axle), attributes associated with the vehicle (e.g., location, dynamics), etc.

FIG. **4** shows a flowchart of a method for detecting a faulty tire at a vehicle (e.g., vehicle **100**), according to an embodiment. The method discussed with respect to FIG. **4** can be performed by a processor (e.g., processor **102**) included at the vehicle.

At **402**, sensor data is received at a processor of a vehicle including at least one sensor, a steering column, a plurality of axles, a plurality of wheels coupled to the plurality of axles, and a plurality of tires coupled to the plurality of wheels. The sensor data can include, for example, a representation of at least one of: (1) at least one of an acceleration of the vehicle, a roll of the vehicle, a pitch of the vehicle, a yaw of the vehicle, or a torque associated with the steering column, (2) at least one attribute of an environment surrounding the vehicle, or (3) sound caused by the vehicle. The at least one attribute of the environment surrounding the vehicle can refer to, for example, debris/dust/smoke produced near a tire of the vehicle, other vehicles near the vehicle that are honking, other vehicles previously near the vehicle that are moving away from the trailer, etc.

At **404**, a determination is made by the processor if at least one tire from the plurality of tires is faulty based on the sensor data. The processor can use at least one software model (e.g., software model(s) **106**) configured to detect faulty tires at the vehicle. A tire at the vehicle can be detected to be faulty by the software model if, for example, the steering wheel torque of the vehicle has increased, the acceleration of the vehicle has decreased, the yaw of the vehicle has increased, the roll of the vehicle has increased, the vehicle has a forward pitch, debris/dust/smoke is being produced near a tire of the vehicle, other vehicles near the vehicle are honking, other vehicles previously near the vehicle are moving away from the trailer, a predetermined sound pattern is detected (e.g., an abrupt sound indicating that a tire has blown out, a scraping sound of a wheel scraping the ground, repetition of a flapping sound indicating that a tire is flat), etc.

At **406**, at least one side of the vehicle and at least one axle from the plurality of axles associated with the at least one tire is determined (or identified) by the processor in response the determining that the at least one tire is faulty. Said similarly, if **404** determines that at least one tire from the plurality of tires is faulty, at **406**, a side(s) and axle(s) of the vehicle where each faulty tire is located is determined (or identified). The at least one side and at least one axle can be determined (or identified) using at least one software model (e.g., software model(s) **106**) and sensor data received at **402**.

At **408**, at least one remedial action to be performed by the vehicle is determined by the processor based on the sensor data, the at least one side, and the at least one axle. Said similarly, the at least one remedial action to be performed can be determined while taking into consideration attributes of a surrounding of the vehicle and/or attributes of the vehicle itself, and a location(s) of the at least one tire determined to be faulty. For example, the at least one remedial action can cause the vehicle to perform an action that will cause minimum risk to other vehicles surrounding the vehicle, and that will minimize and/or not add additional weight to the at least one tire determined to be faulty.

At **410**, a signal to cause the at least one remedial action to be performed by the vehicle is sent by the processor in response to the determining that the at least one tire is faulty. The signal could be sent, for example, from the processor to a motion control system (e.g., motion control system **110**) so that the vehicle can perform a driving maneuver and/or to an alarm system (e.g., alarm system **108**) so that a passenger, driver, nearby person, etc. is notified of the faulty tire and/or other actions that should and/or are recommended to take place.

FIG. **5** shows a flowchart of a method for detecting a faulty tire at a vehicle (e.g., vehicle **100**), according to an embodiment. The method discussed with respect to FIG. **5** can be performed by a processor (e.g., processor **102**) included at the vehicle.

At **502**, sensor data collected by at least one sensor (e.g., sensor(s) **112**) included in a vehicle (e.g., vehicle **100**) is received. The sensor data can include, for example, a representation of at least one of (1) dynamics of the vehicle, (2) a surrounding of the vehicle, or (3) sound caused by the vehicle.

At **504**, at least one of the dynamics, the surrounding, or the sound are analyzed (e.g., by software model(s) **106**) for at least one predefined indictor indicating that at least one tire from a plurality of tires is faulty. The plurality of tires can be all tires included in the vehicle, or a portion of all tires included in the vehicle (e.g., only tires included at a trailer of the vehicle). The at least one predefined indicator could be, for example, a steering wheel torque associated with the vehicle increasing, an acceleration of the vehicle decreasing, a yaw of the vehicle increasing, a roll of the vehicle increasing, the vehicle having a forward pitch, debris/dust/smoke is being produced near a tire of the vehicle, other vehicles near the vehicle honking, other vehicles previously near the vehicle moving away from the trailer, detecting a predetermined sound pattern (e.g., an abrupt sound indicating that a tire has blown out, a scraping sound of a wheel scraping the ground, repetition of a flapping sound indicating that a tire is flat), or any combination thereof.

At **506**, a determination is made if the at least one tire is faulty. If the at least one predefined indicator is found at **504**, the method proceeds to **508**. If the at least one predefined indicator is not found at **504**, **506** proceeds to **502**.

At **508**, at least one side of the vehicle and at least one axle from the plurality of axles associated with the at least one tire is determined by the processor. Said similarly, if **506** determines that the at least one tire from the plurality of tires is faulty, at **508**, a side(s) and axle(s) of the vehicle where each faulty tire is located is determined. The at least one side and at least one axle can be determined using at least one software model (e.g., software model(s) **106**) and sensor data received at **502**.

At **510**, at least one remedial action to be performed by the vehicle is determined by the processor based on the sensor data, the at least one side, and/or the at least one axle. Said similarly, the at least one remedial action to be performed can be determined while taking into consideration attributes of a surrounding of the vehicle and/or attributes of the vehicle itself, and/or a location(s) of the at least one tire determined to be faulty. For example, the at least one remedial action can cause the vehicle to perform an action that will cause minimum risk (or reduced risk) to other vehicles surrounding the vehicle, and that will minimize and/or not add additional force, pressure, and/or momentum to the at least one tire determined to be faulty.

At **512**, a signal to cause the at least one remedial action to be performed by the vehicle is sent by the processor in response to the determining that the at least one tire is faulty. The signal could be sent, for example, from the processor to a motion control system (e.g., motion control system **110**) so that the vehicle can perform a driving maneuver and/or to an alarm system (e.g., alarm system **108**) so that a passenger, driver, nearby person, etc. is notified of the faulty tire and/or other actions that should and/or are recommended to take place.

In some implementations, any of the methods discussed with respect to FIGS. **2-5** can further include estimating a set of weights placed at axles and/or left and right portions of axles included in the vehicle by the vehicle (including any

loads the vehicle may be carrying) as the vehicle is driving. In some implementation, the set of weights are estimated for axles and/or left and right portions of axles included in a trailer (and not a truck). At least one of determining if a tire is faulty, determining a side and axle associated with a faulty tire, or determining a remedial action to be performed can be based on the estimated set of weights. In some implementations, estimating the set of weights is the at least one remedial action, and determining (e.g., by software model(s) **106**) that the vehicle is (1) unbalanced and/or (2) a weight at an axle and/or left or right portion of an axle is above a predetermined threshold value can automatically cause another remedial action to be performed.

In some embodiments, a method comprises: receiving sensor data at a processor of a vehicle including at least one sensor, a plurality of axles, and a plurality of tires coupled to the plurality of axles, the sensor data including a representation of at least one of dynamics of the vehicle, a surrounding of the vehicle, or audio associated with the vehicle; determining, by the processor, if at least one tire from the plurality of tires is faulty based on the sensor data; determining, by the processor, at least one side of the vehicle and at least one axle from the plurality of axles associated with the at least one tire in response to the determining that the at least one tire is faulty; determining, by the processor, at least one remedial action to be performed by the vehicle based on the sensor data, the at least one side, and the at least one axle; and sending, by the processor, a signal to cause the at least one remedial action to be performed by the vehicle in response to the determining that the at least one tire is faulty.

In some implementations, the vehicle is a semi-truck.

Some implementations further comprise determining, by the processor, a set of weights associated with the plurality of axles in response to the determining that the at least one tire is faulty, the determining the at least one remedial action further based on the set of weights.

In some implementations, the determining if the at least one tire is faulty includes generating a confidence metric indicating a likelihood that the at least one tire is already faulty based on the sensor data, the at least one tire determined to be faulty if the confidence metric is within a predetermined range.

In some implementations, the vehicle further includes a steering column, and the sensor data indicates an acceleration of the vehicle, a roll of the vehicle, a pitch of the vehicle, a yaw of the vehicle, and a torque associated with the steering column.

In some implementations, the determining if the at least one tire is faulty includes analyzing the acceleration, the roll, the pitch, the yaw, and the torque for a predetermined relationship, the at least one tire is determined to be faulty if the at least one predetermined relationship is detected.

In some implementations, the vehicle is a first vehicle and the sensor data representing the surrounding of the first vehicle indicates at least one of: (1) behavior of at least one second vehicle near the first vehicle, or (2) attributes associated with debris caused by the first vehicle.

In some implementations, the at least one sensor includes a microphone, and at least one imaging sensor.

In some implementations, the at least one remedial action includes, by the processor, autonomously and automatically slowing down the vehicle and alerting a passenger of the vehicle that the at least one tire is faulty.

In some implementations, the vehicle is operating in a first mode during the receiving, and the at least one remedial action causes the vehicle to operate in a second mode different than the first mode.

In some implementations, the determining if the at least one tire from the plurality of tires is faulty includes analyzing the audio for a predetermined pattern, the at least one tire determined to be faulty if the predetermined pattern is detected.

In some implementations, the vehicle includes a truck and a trailer coupled to the truck, the at least one sensor is included in the truck, the plurality of tires are included in the trailer, and the trailer does not include sensors configured to measure attributes associated with the plurality of tires.

In some embodiments, a method comprises: receiving sensor data at a processor of a vehicle including at least one sensor, a steering column, a plurality of axles, and a plurality of tires coupled to the plurality of axles, the sensor data including a representation of at least one of: (1) at least one of an acceleration of the vehicle, a roll of the vehicle, a pitch of the vehicle, a yaw of the vehicle, or a torque associated with the steering column, (2) at least one attribute of an environment surrounding the vehicle, or (3) sound caused by the vehicle; determining, by the processor, if at least one tire from the plurality of tires is faulty based on the sensor data; determining, by the processor, at least one side of the vehicle and at least one axle from the plurality of axles associated with the at least one tire in response to the determining that the at least one tire is faulty; determining, by the processor, at least one remedial action to be performed by the vehicle based on the sensor data, the at least one side, and the at least one axle; and sending, by the processor, a signal to cause the at least one remedial action to be performed in response to the determining that the at least one tire is faulty.

In some implementations, the vehicle is an autonomous vehicle, and the at least one remedial action causes the vehicle to automatically pull over to a shoulder of a drivable area without requiring additional human input.

In some implementations, the vehicle is operating in a manual driving mode prior to the causing of the at least one remedial action to be performed, and the at least one remedial action inhibits the vehicle from operating in an autonomous driving mode.

In some implementations, the at least one remedial action is a first remedial action and the first remedial action includes estimating a set of weights associated with the plurality of axles, the method further comprising: causing a second remedial action to be performed in response to determining that the vehicle is unbalanced based on the set of weights.

In some embodiments, a system comprises: at least one sensor to collect sensor data, the sensor data including a representation of at least one of (1) dynamics of the system, (2) a surrounding of the system, or (3) sound caused by the system; and processing circuitry operatively coupled to the at least one sensor and configured to: receive the sensor data; analyze at least one of the dynamics, the surrounding, or the sound for at least one predefined indicator indicating that at least one tire from a plurality of tires is faulty; and in response to determining, using the sensor data, that the at least one tire is faulty, (1) determine at least one side of the system and at least one axle from a set of axles associated with the at least one tire, (2) determine at least one remedial action to be performed by the system based on the at least one side, the at least one axle, and the sensor data, and (3) send a signal to cause the at least one remedial action to be performed by the system.

In some implementations, the system includes a truck and a trailer coupled to the truck, the at least one of sensor is included in the truck, the plurality of tires are included in the trailer, and the trailer does not include sensors configured to measure attributes associated with the set of tires.

In some implementations, the system is operating in an autonomous driving mode prior to sending the signal to cause the at least one remedial action to be performed, and the at least one remedial action causes the system to operate in a manual driving mode.

In some implementations, the at least one remedial action is a first remedial action and the first remedial action includes estimating a set of weights associated with the plurality of axles, and the processing circuitry is further configured to: cause a second remedial action to be performed in response to determining that the system is unbalanced based on the set of weights.

All combinations of the foregoing concepts and additional concepts discussed here (provided such concepts are not mutually inconsistent) are contemplated as being part of the subject matter disclosed herein. The terminology explicitly employed herein that also may appear in any disclosure incorporated by reference should be accorded a meaning most consistent with the particular concepts disclosed herein.

The skilled artisan will understand that the drawings primarily are for illustrative purposes, and are not intended to limit the scope of the subject matter described herein. The drawings are not necessarily to scale; in some instances, various aspects of the subject matter disclosed herein may be shown exaggerated or enlarged in the drawings to facilitate an understanding of different features. In the drawings, like reference characters generally refer to like features (e.g., functionally similar and/or structurally similar elements).

To address various issues and advance the art, the entirety of this application (including the Cover Page, Title, Headings, Background, Summary, Brief Description of the Drawings, Detailed Description, Embodiments, Abstract, Figures, Appendices, and otherwise) shows, by way of illustration, various embodiments in which the embodiments may be practiced. The advantages and features of the application are of a representative sample of embodiments only, and are not exhaustive and/or exclusive. Rather, they are presented to assist in understanding and teach the embodiments, and are not representative of all embodiments. As such, certain aspects of the disclosure have not been discussed herein. That alternate embodiments may not have been presented for a specific portion of the innovations or that further undescribed alternate embodiments may be available for a portion is not to be considered to exclude such alternate embodiments from the scope of the disclosure. It will be appreciated that many of those undescribed embodiments incorporate the same principles of the innovations and others are equivalent. Thus, it is to be understood that other embodiments may be utilized and functional, logical, operational, organizational, structural and/or topological modifications may be made without departing from the scope and/or spirit of the disclosure. As such, all examples and/or embodiments are deemed to be non-limiting throughout this disclosure.

Also, no inference should be drawn regarding those embodiments discussed herein relative to those not discussed herein other than it is as such for purposes of reducing space and repetition. For instance, it is to be understood that the logical and/or topological structure of any combination of any program components (a component collection), other components and/or any present feature sets as described in the figures and/or throughout are not limited to a fixed operating order and/or arrangement, but rather, any disclosed order is exemplary and all equivalents, regardless of order, are contemplated by the disclosure.

Various concepts may be embodied as one or more methods, of which at least one example has been provided. The acts performed as part of the method may be ordered in any suitable way. Accordingly, embodiments may be constructed in which acts are performed in an order different than illustrated, which may include performing some acts simultaneously, even though shown as sequential acts in illustrative embodiments. Put differently, it is to be understood that such features may not necessarily be limited to a particular order of execution, but rather, any number of threads, processes, services, servers, and/or the like that may execute serially, asynchronously, concurrently, in parallel, simultaneously, synchronously, and/or the like in a manner consistent with the disclosure. As such, some of these features may be mutually contradictory, in that they cannot be simultaneously present in a single embodiment. Similarly, some features are applicable to one aspect of the innovations, and inapplicable to others.

In addition, the disclosure may include other innovations not presently described. Applicant reserves all rights in such innovations, including the right to embodiment such innovations, file additional applications, continuations, continuations-in-part, divisionals, and/or the like thereof. As such, it should be understood that advantages, embodiments, examples, functional, features, logical, operational, organizational, structural, topological, and/or other aspects of the disclosure are not to be considered limitations on the disclosure as defined by the embodiments or limitations on equivalents to the embodiments. Depending on the particular desires and/or characteristics of an individual and/or enterprise user, database configuration and/or relational model, data type, data transmission and/or network framework, syntax structure, and/or the like, various embodiments of the technology disclosed herein may be implemented in a manner that enables a great deal of flexibility and customization as described herein.

All definitions, as defined and used herein, should be understood to control over dictionary definitions, definitions in documents incorporated by reference, and/or ordinary meanings of the defined terms.

As used herein, in particular embodiments, the terms "about" or "approximately" when preceding a numerical value indicates the value plus or minus a range of 10%. Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the disclosure. That the upper and lower limits of these smaller ranges can independently be included in the smaller ranges is also encompassed within the disclosure, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the disclosure.

The indefinite articles "a" and "an," as used herein in the specification and in the embodiments, unless clearly indicated to the contrary, should be understood to mean "at least one."

The phrase "and/or," as used herein in the specification and in the embodiments, should be understood to mean "either or both" of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunc-

tively present in other cases. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, a reference to "A and/or B", when used in conjunction with open-ended language such as "comprising" can refer, in one embodiment, to A only (optionally including elements other than B); in another embodiment, to B only (optionally including elements other than A); in yet another embodiment, to both A and B (optionally including other elements); etc.

As used herein in the specification and in the embodiments, "or" should be understood to have the same meaning as "and/or" as defined above. For example, when separating items in a list, "or" or "and/or" shall be interpreted as being inclusive, i.e., the inclusion of at least one, but also including more than one, of a number or list of elements, and, optionally, additional unlisted items. Only terms clearly indicated to the contrary, such as "only one of" or "exactly one of," or, when used in the embodiments, "consisting of," will refer to the inclusion of exactly one element of a number or list of elements. In general, the term "or" as used herein shall only be interpreted as indicating exclusive alternatives (i.e. "one or the other but not both") when preceded by terms of exclusivity, such as "either," "one of," "only one of," or "exactly one of." "Consisting essentially of," when used in the embodiments, shall have its ordinary meaning as used in the field of patent law.

As used herein in the specification and in the embodiments, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, "at least one of A and B" (or, equivalently, "at least one of A or B," or, equivalently "at least one of A and/or B") can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements); etc.

In the embodiments, as well as in the specification above, all transitional phrases such as "comprising," "including," "carrying," "having," "containing," "involving," "holding," "composed of," and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases "consisting of" and "consisting essentially of" shall be closed or semi-closed transitional phrases, respectively, as set forth in the United States Patent Office Manual of Patent Examining Procedures, Section 2111.03.

Some embodiments and/or methods described herein can be performed by software (executed on hardware), hardware, or a combination thereof. Hardware modules may include, for example, a processor, a field programmable gate array (FPGA), and/or an application specific integrated circuit (ASIC). Software modules (executed on hardware) can include instructions stored in a memory that is operably coupled to a processor, and can be expressed in a variety of software languages (e.g., computer code), including C, C++, Java™ Ruby, Visual Basic™, and/or other object-oriented, procedural, or other programming language and development tools. Examples of computer code include, but are not limited to, micro-code or micro-instructions, machine instructions, such as produced by a compiler, code used to produce a web service, and files containing higher-level instructions that are executed by a computer using an interpreter. For example, embodiments may be implemented using imperative programming languages (e.g., C, Fortran, etc.), functional programming languages (Haskell, Erlang, etc.), logical programming languages (e.g., Prolog), object-oriented programming languages (e.g., Java, C++, etc.) or other suitable programming languages and/or development tools. Additional examples of computer code include, but are not limited to, control signals, encrypted code, and compressed code.

The term "processor" should be interpreted broadly to encompass a general purpose processor, a central processing unit (CPU), a microprocessor, a digital signal processor (DSP), a controller, a microcontroller, a state machine and so forth. Under some circumstances, a "processor" may refer to an application specific integrated circuit (ASIC), a programmable logic device (PLD), a field programmable gate array (FPGA), etc. The term "processor" may refer to a combination of processing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core or any other such configuration.

The term "memory" should be interpreted broadly to encompass any electronic component capable of storing electronic information. The term memory may refer to various types of processor-readable media such as random access memory (RAM), read-only memory (ROM), non-volatile random access memory (NVRAM), programmable read-only memory (PROM), erasable programmable read only memory (EPROM), electrically erasable PROM (EEPROM), flash memory, magnetic or optical data storage, registers, etc. Memory is said to be in electronic communication with a processor if the processor can read information from and/or write information to the memory. Memory that is integral to a processor is in electronic communication with the processor.

The terms "instructions" and "code" should be interpreted broadly to include any type of computer-readable statement(s). For example, the terms "instructions" and "code" may refer to one or more programs, routines, sub-routines, functions, procedures, etc. "Instructions" and "code" may comprise a single computer-readable statement or many computer-readable statements.

While specific embodiments of the present disclosure have been outlined above, many alternatives, modifications, and variations will be apparent to those skilled in the art. Accordingly, the embodiments set forth herein are intended to be illustrative, not limiting. Various changes may be made without departing from the spirit and scope of the disclosure.

What is claimed is:

1. A computer-implemented method comprising:

receiving sensor data from one or more sensors of a vehicle having a right side and a left side, the one or more sensors including at least one of a camera, a radar, and a lidar, the sensor data including a representation of a surrounding of the vehicle;

determining whether at least one tire of the vehicle is faulty based on the sensor data;

determining at least one side of the vehicle and a particular axle of a plurality of axles associated with the at least one tire in response to determining that the at least one tire is faulty;

determining a set of weights associated with the plurality of axles in response to determining that the at least one tire of the vehicle is faulty;

selecting at least one remedial action to be performed by the vehicle, wherein selection of the at least one remedial action is based on the sensor data, the at least one side, and the at least one axle, wherein a predetermined maneuver is prohibited for the at least one side and the at least one axle associated with the at least one tire determined to be faulty, and the at least one remedial action is selected that does not cause the vehicle to perform the predetermined maneuver; and

performing the at least one remedial action by adjusting operation of the vehicle.

2. The computer-implemented method of claim **1**, wherein:

the at least one remedial action includes inhibiting the vehicle from operating in an autonomous driving mode.

3. The computer-implemented method of claim **2**, wherein:

the at least one remedial action includes automatically slowing the vehicle and alerting a passenger of the vehicle that the at least one tire is faulty before inhibiting the vehicle from operating in the autonomous driving mode.

4. The computer-implemented method of claim **1**, wherein:

the vehicle includes a steering column;

the one or more sensors includes at least one of an inertial measurement unit (IMU) and a gyroscope; and

the sensor data includes sensor data collected by the at least one of an IMU and a gyroscope that indicates at least one of an acceleration of the vehicle, a roll of the vehicle, a pitch of the vehicle, a yaw of the vehicle, and a torque associated with the steering column.

5. The computer-implemented method of claim **4**, wherein determining whether at least one tire of the vehicle is faulty comprises:

analyzing at least two of the acceleration, the roll, the pitch, the yaw, and the torque for a predetermined relationship; and

determining that the at least one tire is faulty when the predetermined relationship is detected.

6. The computer-implemented method of claim **1**, wherein:

the vehicle is a first vehicle; and

the sensor data indicates at least one of:

(1) behavior of at least one second vehicle near the first vehicle, and

(2) attributes associated with debris caused by the first vehicle.

7. The computer-implemented method of claim **1**, wherein:

the one or more sensors includes a microphone;

the sensor data includes a representation of sound collected by the microphone; and

determining whether at least one tire of the vehicle is faulty comprises:

analyzing the representation of sound for a predetermined pattern, and

determining that at least one tire of the vehicle is faulty when the predetermined pattern is detected.

8. The computer-implemented method of claim **1**, wherein the determining whether at least one tire of the vehicle is faulty comprises:

generating a confidence metric indicating a likelihood that the at least one tire is faulty based on the sensor data; and

determining that the at least one tire of the vehicle is faulty when the confidence metric is within a predetermined range.

9. The computer-implemented method of claim **1**,

wherein selecting at least one remedial action is based on the set of weights.

10. The computer-implemented method of claim **1**, wherein the vehicle includes a truck and a trailer coupled to the truck, the one or more sensors are included in the truck, the at least one tire is included in the trailer, and the trailer does not include sensors configured to measure attributes associated with the at least one tire.

11. The computer-implemented method of claim **1**, wherein when the predetermined maneuver that is prohibited is a turn to the at least one side.

12. A non-transitory, computer-readable storage medium including instructions that, when executed by at least one processor of a computing system, cause the system to perform operations comprising:

receiving sensor data from one or more sensors of a vehicle having a right side and a left side, the one or more sensors including at least one of a camera, a radar, and a lidar, the sensor data including a representation of a surrounding of the vehicle;

determining whether at least one tire of the vehicle is faulty based on the sensor data;

determining at least one side of the vehicle and a particular axle of a plurality of axles associated with the at least one tire in response to determining that the at least one tire is faulty;

determining a set of weights associated with the plurality of axles in response to determining that the at least one tire of the vehicle is faulty;

selecting at least one remedial action to be performed by the vehicle, wherein selection of the at least one remedial action is based on the sensor data, the at least one side, and the at least one axle, wherein a predetermined maneuver is prohibited for the at least one side and the at least one axle associated with the at least one tire determined to be faulty, and the at least one remedial action is selected that does not cause the vehicle to perform the predetermined maneuver; and

performing the at least one remedial action by adjusting operation of the vehicle.

13. The non-transitory, computer-readable storage medium of claim **12**, wherein:

the at least one remedial action includes inhibiting the vehicle from operating in an autonomous driving mode.

14. The non-transitory, computer-readable storage medium of claim **13**, wherein:

the at least one remedial action includes automatically slowing the vehicle and alerting a passenger of the vehicle that the at least one tire is faulty before inhibiting the vehicle from operating in the autonomous driving mode.

15. The non-transitory, computer-readable storage medium of claim 11, wherein:

the vehicle includes a steering column;

the one or more sensors includes at least one of an inertial measurement unit (IMU) and a gyroscope; and

the sensor data includes sensor data collected by the at least one of an IMU and a gyroscope that indicates at least one of an acceleration of the vehicle, a roll of the vehicle, a pitch of the vehicle, a yaw of the vehicle, and a torque associated with the steering column.

16. The non-transitory, computer-readable storage medium of claim 14, wherein determining whether at least one tire of the vehicle is faulty comprises:

analyzing at least two of the acceleration, the roll, the pitch, the yaw, and the torque for a predetermined relationship; and

determining that the at least one tire is faulty when the predetermined relationship is detected.

17. A system, comprising:

at least one processor; and

a memory operably coupled to the at least one processor and storing instructions to cause the system to perform operations comprising:

receiving sensor data from one or more sensors of a vehicle having a right side and a left side, the one or more sensors including at least one of a camera, a radar, and a lidar, the sensor data including a representation of a surrounding of the vehicle,

determining whether at least one tire of the vehicle is faulty based on the sensor data,

determining at least one side of the vehicle and a particular axle of a plurality of axles associated with the at least one tire in response to determining that the at least one tire is faulty,

determining a set of weights associated with the plurality of axles in response to determining that the at least one tire of the vehicle is faulty;

selecting at least one remedial action to be performed by the vehicle, wherein selection of the at least one remedial action is based on the sensor data, the at least one side, and the at least one axle, wherein a predetermined maneuver is prohibited for the at least one side and the at least one axle associated with the at least one tire determined to be faulty, and the at least one remedial action is selected that does not cause the vehicle to perform the predetermined maneuver; and

performing the at least one remedial action by adjusting operation of the vehicle.

18. The system of claim 17, wherein:

the at least one remedial action includes inhibiting the vehicle from operating in an autonomous driving mode.

19. The system of claim 18, wherein:

the at least one remedial action includes automatically slowing the vehicle and alerting a passenger of the vehicle that the at least one tire is faulty before inhibiting the vehicle from operating in the autonomous driving mode.

20. The system of claim 17, wherein:

the vehicle includes a steering column;

the one or more sensors includes at least one of an inertial measurement unit (IMU) and a gyroscope; and

the sensor data includes sensor data collected by the at least one of an IMU and a gyroscope that indicates at least one of an acceleration of the vehicle, a roll of the vehicle, a pitch of the vehicle, a yaw of the vehicle, and a torque associated with the steering column.

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