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**Binion et al.**

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(54) **SYNCHRONIZATION OF VEHICLE SENSOR INFORMATION**

(58) **Field of Classification Search**  
None

See application file for complete search history.

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(57) **ABSTRACT**

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**Related U.S. Application Data**

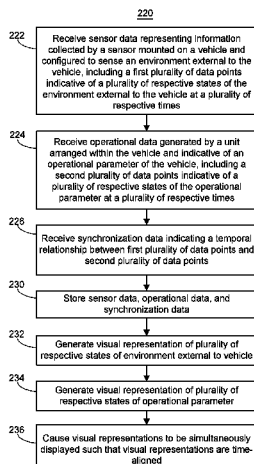
(63) Continuation of application No. 14/057,435, filed on Oct. 18, 2013, now Pat. No. 9,361,650.

A method includes receiving and storing operational data including a first plurality of data points indicative of a plurality of respective states of an operational parameter of the vehicle at a plurality of respective times, external data including a second plurality of data points indicative of a plurality of respective states of an environment external to the vehicle at a plurality of respective times, and synchronization data. The method also includes generating a virtual model of an event involving the vehicle using the stored data, at least by generating a first visual representation of the plurality of respective states of the operational parameter, generating a second visual representation of the plurality of respective states of the external environment, and using the synchronization data to cause the first visual representation to be displayed simultaneously with, and in a time-aligned manner with, the second visual representation.

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**G07C 5/08** (2006.01)  
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CPC ..... **G08G 1/162** (2013.01); **B60R 21/00** (2013.01); **B60W 40/10** (2013.01); **G06Q 40/08** (2013.01); **G07C 5/008** (2013.01); **G07C 5/0858** (2013.01); **G07C 5/0866** (2013.01); **G07C 5/12** (2013.01); **G08G 1/166** (2013.01);  
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**20 Claims, 12 Drawing Sheets**



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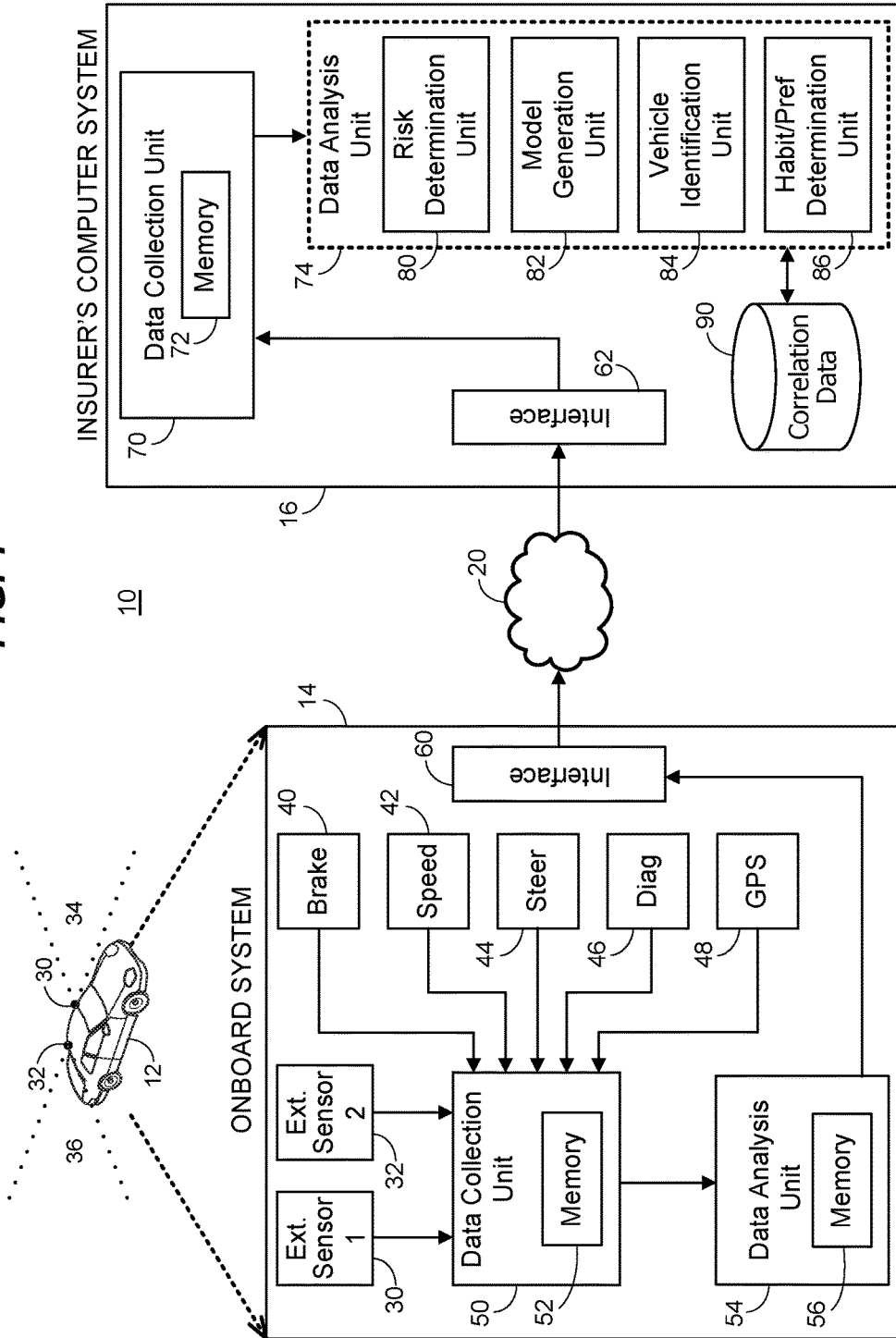
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FIG. 1



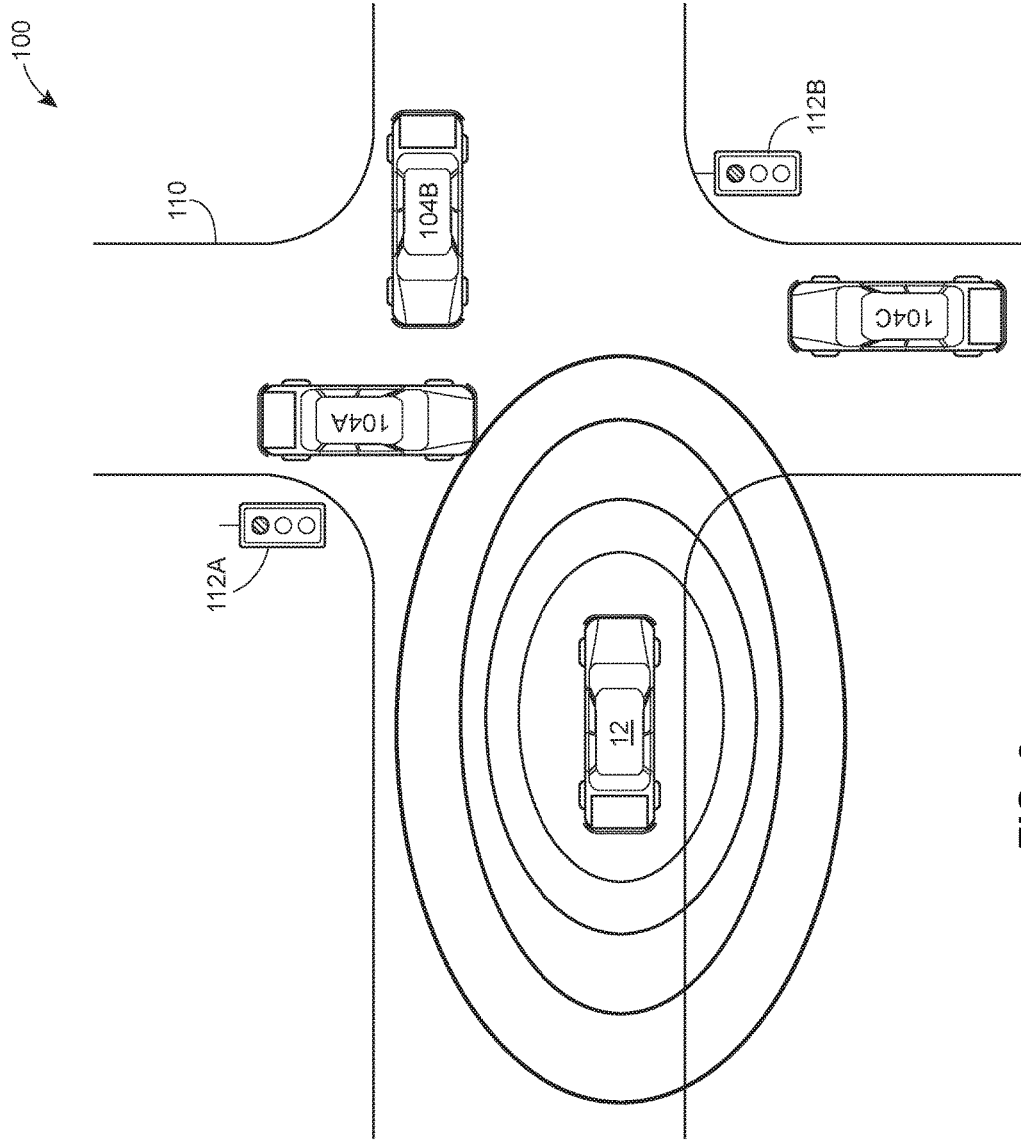


FIG. 2

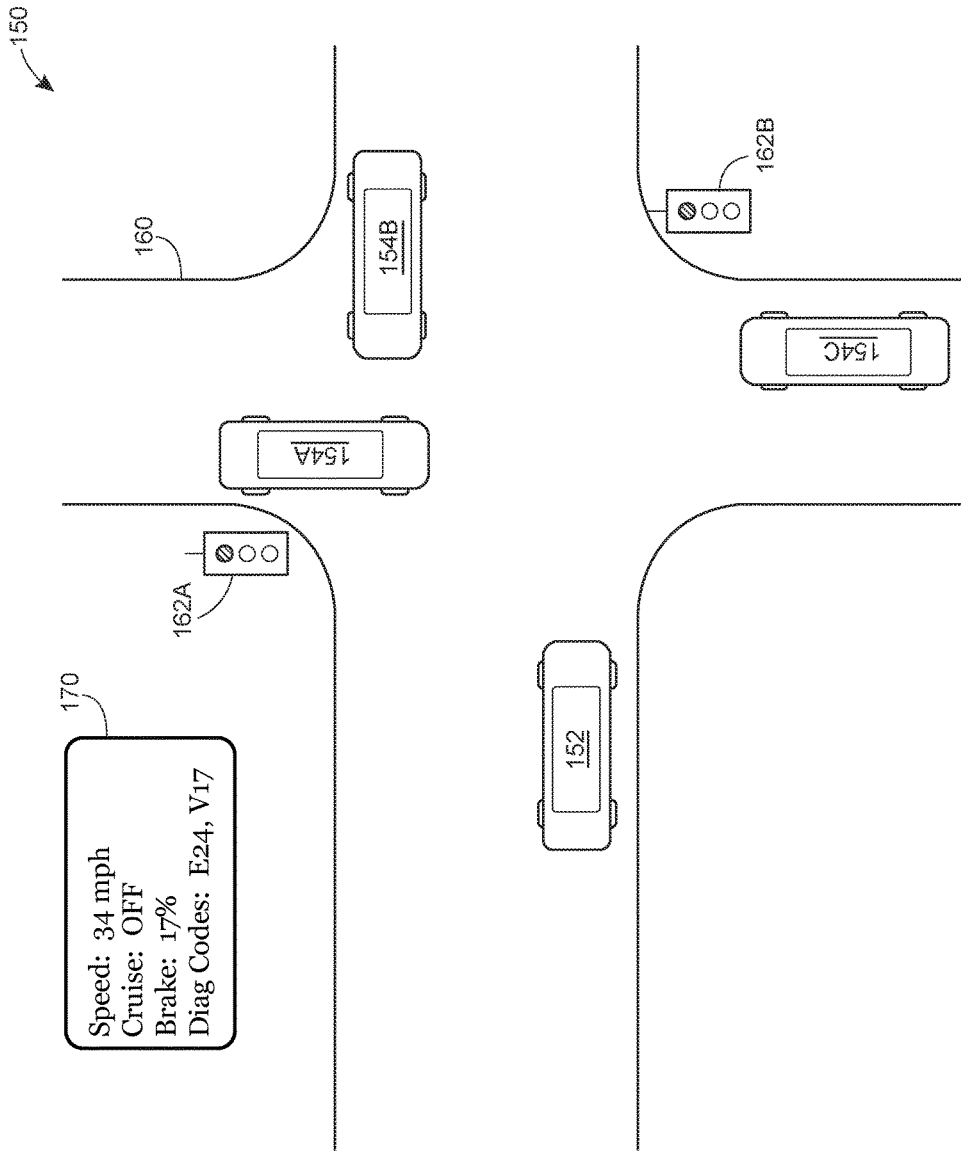
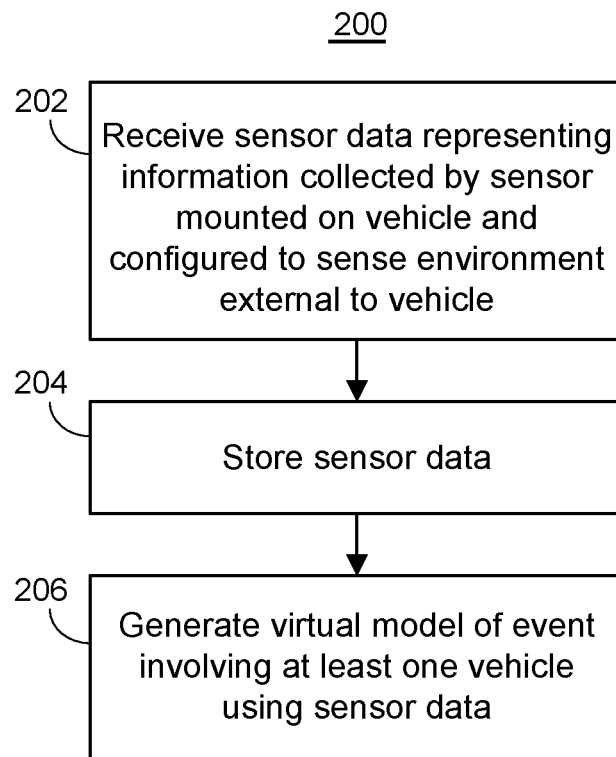
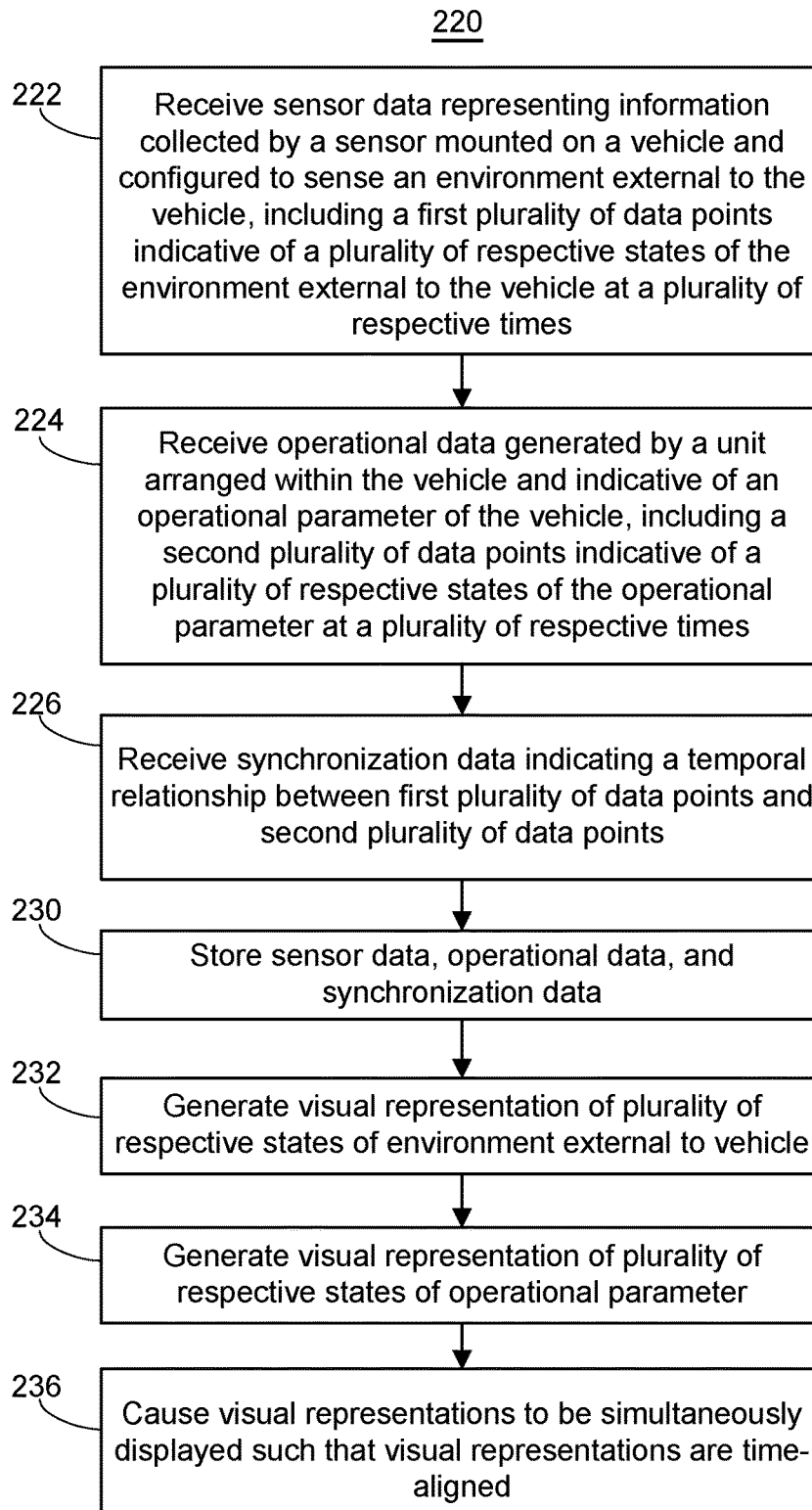


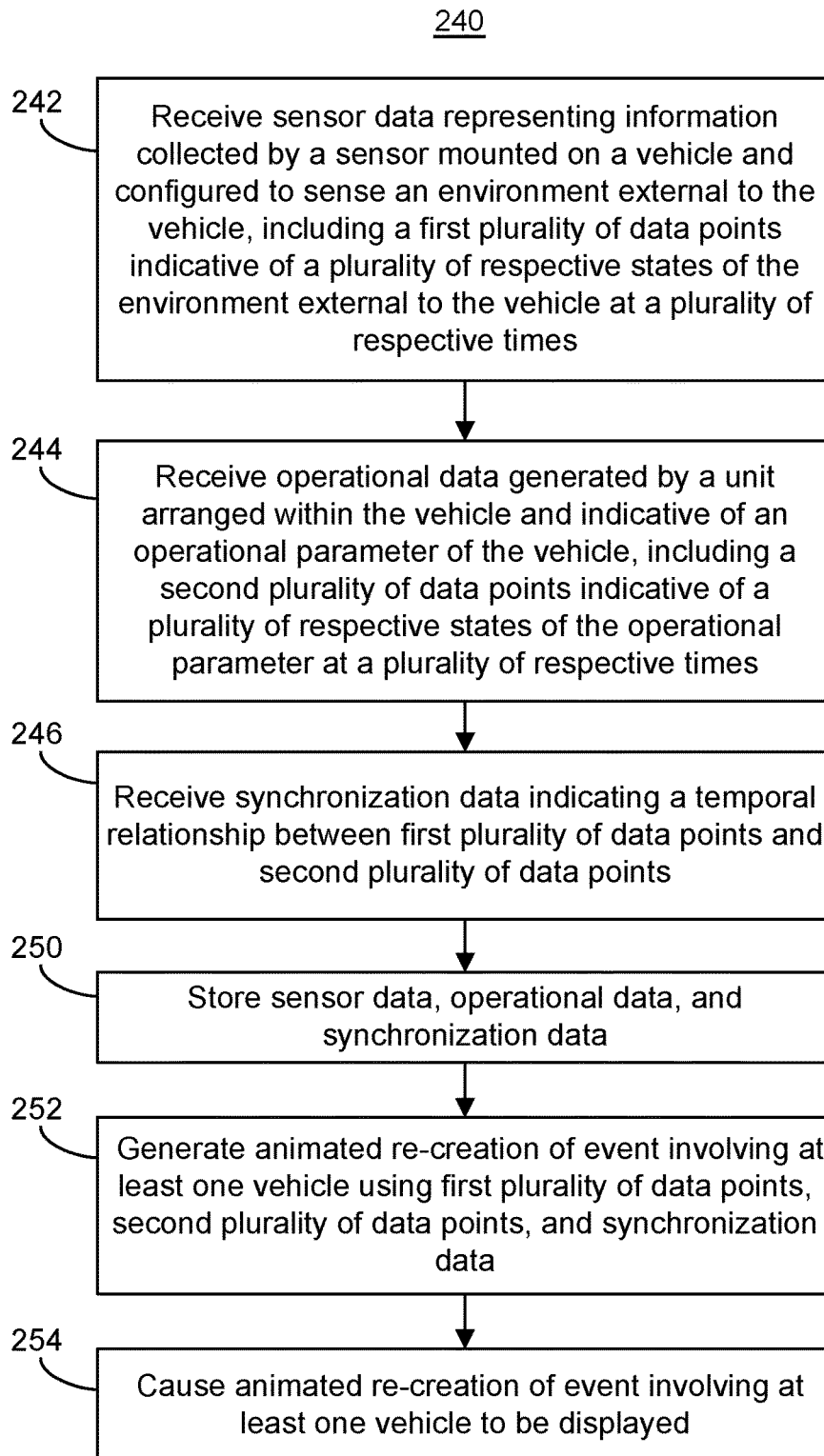
FIG. 3



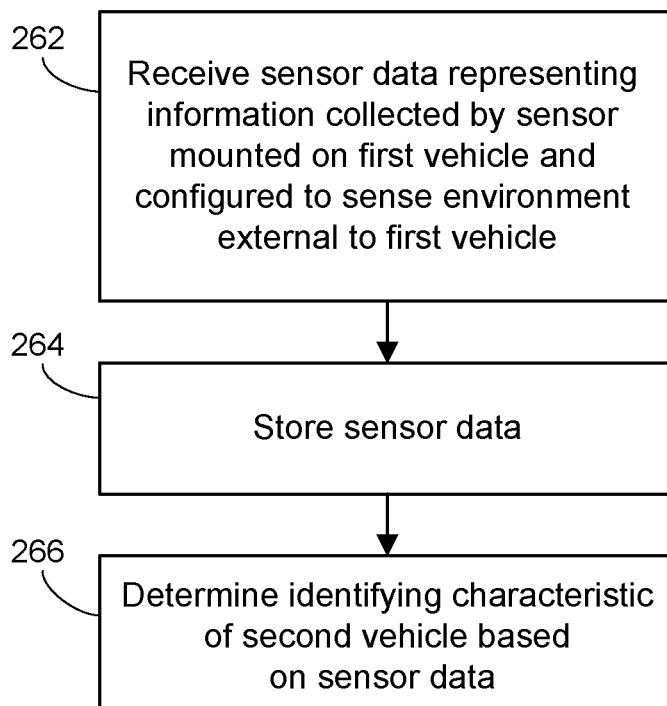
**FIG. 4**

**FIG. 5**



**FIG. 6**

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**FIG. 7**

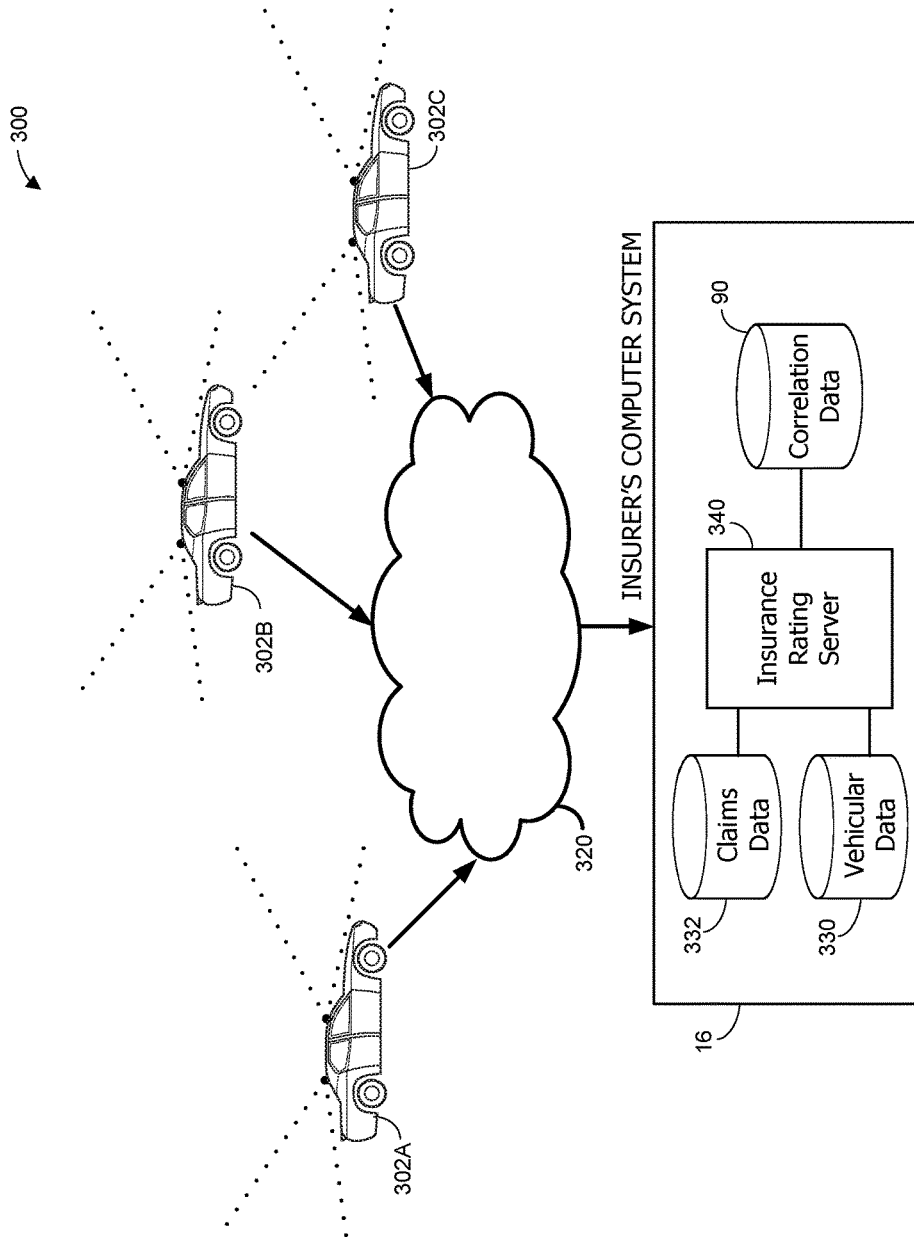
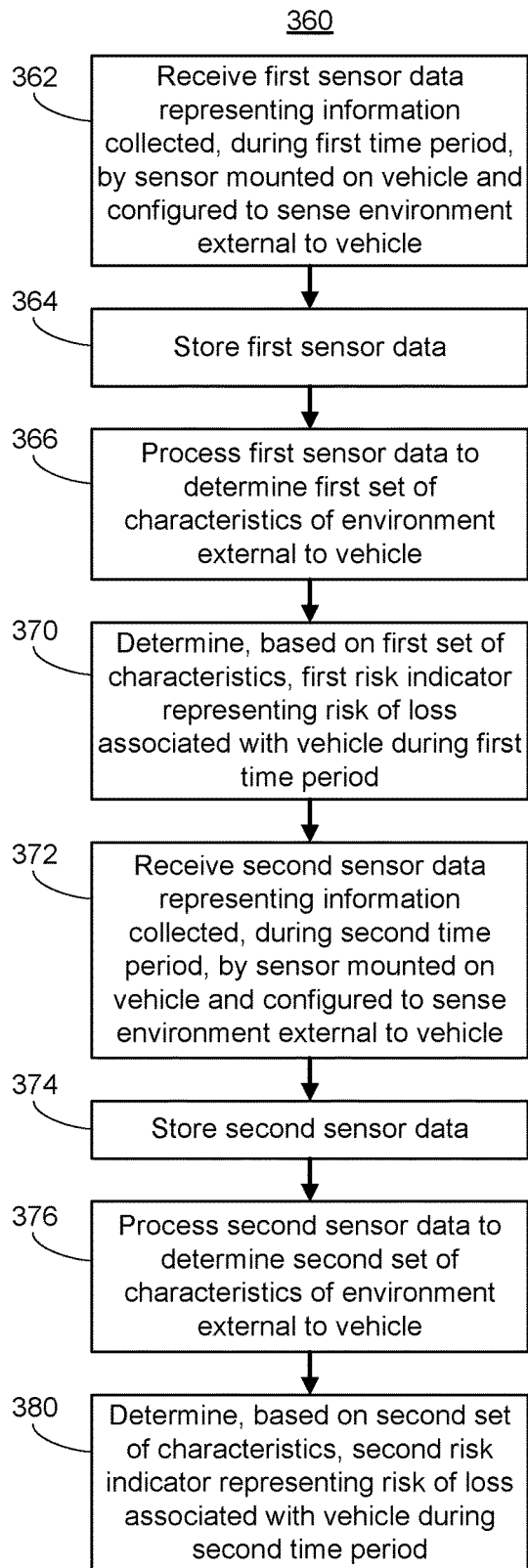
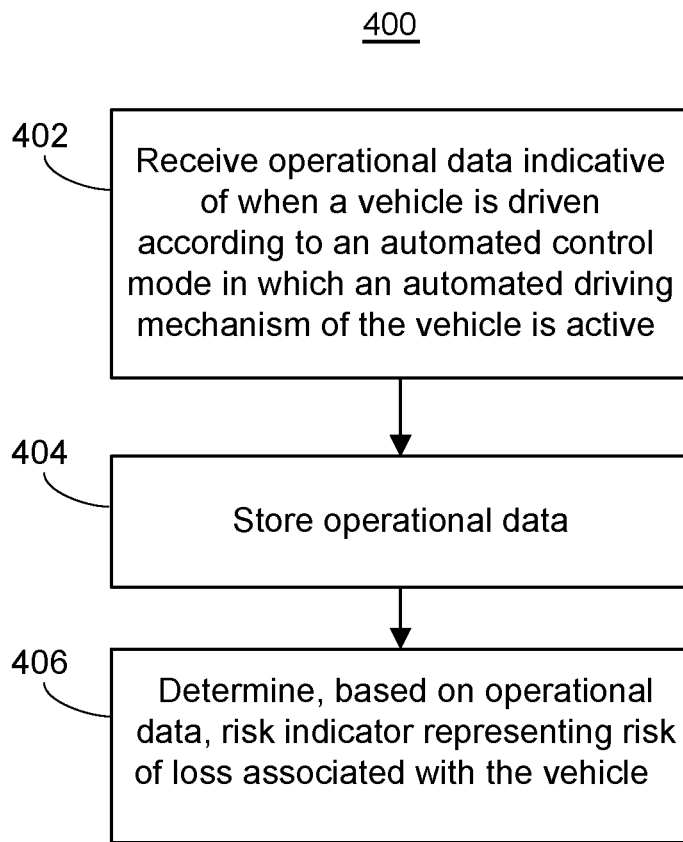


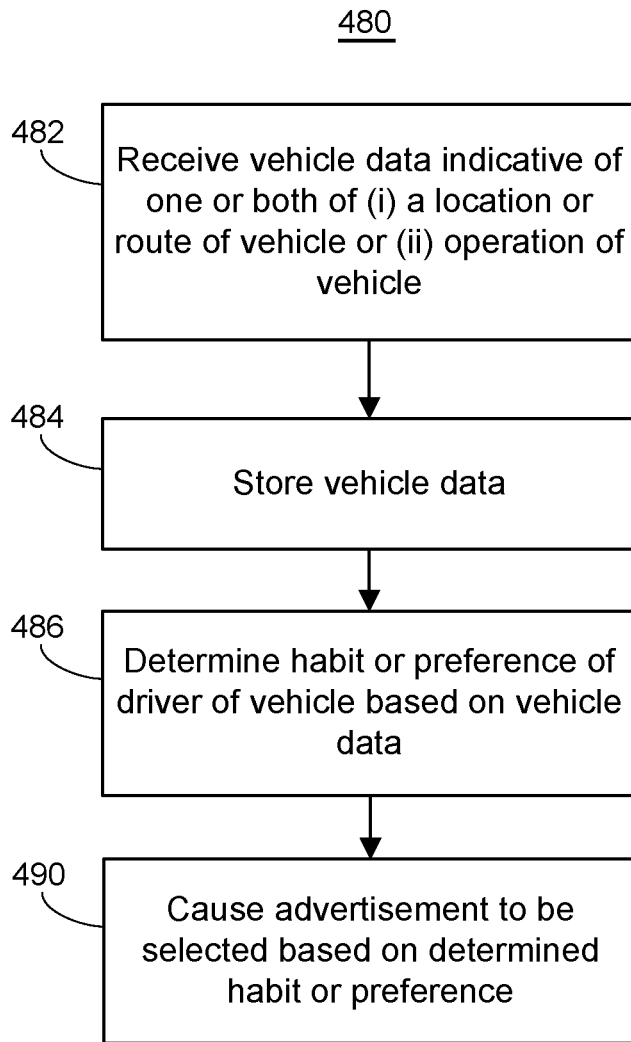
FIG. 8



**FIG. 9**



**FIG. 10**



**FIG. 11**

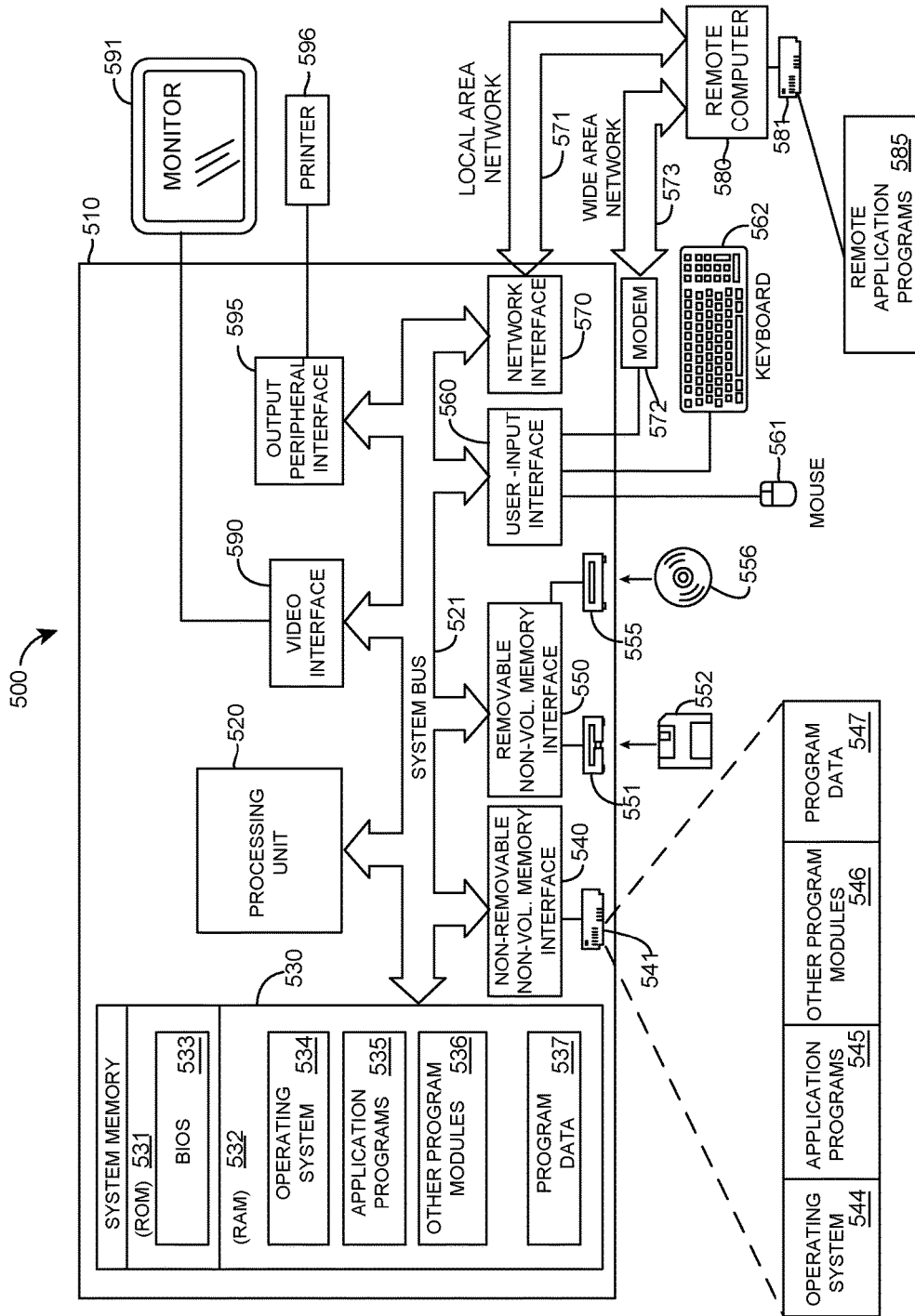


FIG. 12

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## SYNCHRONIZATION OF VEHICLE SENSOR INFORMATION

### CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation of U.S. patent application Ser. No. 14/057,435, entitled "Synchronization of Vehicle Sensor Information" and filed on Oct. 18, 2013, the entire disclosure of which is hereby incorporated herein by reference.

### TECHNICAL FIELD

The present application relates generally to vehicular sensor information and, more specifically, to systems and methods for collecting and processing sensor data to visualize an accident or other event involving a vehicle.

### BACKGROUND

When processing an accident claim, auto insurance providers seek to accurately ascertain the facts pertaining to the accident in order to determine fault and assess damages. With respect to fault, the provider typically must resort to first- or second-hand eyewitness reports (e.g., police reports). Unfortunately, eyewitness reports are often inaccurate and/or biased, and can only be obtained after considerable delay. Moreover, other types of evidence typically used to corroborate or supplement eyewitness reports, such as analyses of the damage resulting from the accident or photographs of the scene of the accident long after the accident occurred, tend to provide a very limited amount of additional information and, like the eyewitness reports, only become known to the insurance provider after a long delay. As a result, the insurance provider may incorrectly identify which party is at fault for an accident, and may be unable to form even a rough estimate of fault or damages until long after the accident occurred. Inaccurate assessments of fault may lead to unfairness and inefficiencies in the insurance marketplace, and lengthy delays may prevent insurance providers from quickly resolving claims, or taking other actions designed to benefit the policyholder.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an example system for collecting and processing data obtained from a vehicle for various insurance-related or other purposes.

FIG. 2 is a diagram illustrating an example scenario in which an external vehicle sensor is used to collect information to be processed by the system of FIG. 1.

FIG. 3 is a diagram of an example virtual model, generated by the system of FIG. 1 in order to re-create the scenario of FIG. 2.

FIG. 4 is a flow diagram of an example method of utilizing external vehicle sensor data to generate a virtual model of an event involving at least one vehicle.

FIG. 5 is a flow diagram of an example method of utilizing external vehicle sensor data, operational data, and synchronization data to generate a synchronized virtual model of an event involving the vehicle.

FIG. 6 is a flow diagram of another example method of utilizing external vehicle sensor data, operational data, and synchronization data to generate a synchronized virtual model of an event involving a vehicle.

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FIG. 7 is a flow diagram of an example method of utilizing external vehicle sensor data to determine identifying characteristics of another vehicle.

FIG. 8 is a block diagram of an example system for identifying correlations between data obtained from external vehicle sensors and probabilities of incurring losses recognizable under an insurance policy.

FIG. 9 is a flow diagram of an example method of utilizing external vehicle sensor data to determine an indication of risk over time.

FIG. 10 is a flow diagram of an example method of utilizing an indication of automated versus human driving to determine risk for insurance rating purposes.

FIG. 11 is a flow diagram of an example method of utilizing data indicative of location, route, and/or operation of a vehicle is used for targeted advertising purposes.

FIG. 12 is a block diagram of an example computer system on which an example method may operate in accordance with any of the described embodiments.

### DETAILED DESCRIPTION

The disclosed system collects data from one or more sensors and/or subsystems onboard a vehicle, and analyzes the collected data for any of various purposes according to different embodiments. The onboard vehicular data may reflect information generated by any of various devices or subsystems of a vehicle, such as devices that sense physical characteristics of the environment external to the vehicle (e.g., still image cameras, video cameras, lidar, radar, etc.), devices that monitor and/or control operational parameters of the vehicle (e.g., speed, braking, whether a conventional cruise control or other automated driving system is activated, etc.), navigational devices (e.g., dedicated global positioning system (GPS) devices, smartphones with applications that locate the smartphone using GPS or cell tower triangulation, etc.), diagnostic systems, etc.

In some embodiments, the onboard vehicular data is collected and processed remotely from the vehicle. In one embodiment, for example, data representing information collected by an external sensor, such as a video camera or lidar device, is provided to an insurer's computer system, where the data is processed to generate a virtual model of an event (e.g., an accident involving the vehicle and/or a different vehicle). Once the virtual model is generated, it may be displayed to a user of the system in order to ascertain fault or estimate damages, for example. Operational data from the vehicle (e.g., data indicative of speed, braking, electronic warnings, etc.) may also be provided to the insurer's computer system for processing in order to enhance the virtual model, by providing an information overlay (e.g. a speed indicator on the displayed virtual model), greater detail in the virtual model, and/or greater accuracy of the virtual model. Moreover, synchronization data such as time stamps may be provided to the insurer's computer system so that the virtual model may accurately reflect which portions of the external sensor data correspond, in time, with the different portions of the operational data.

Alternatively, external sensor data from a first vehicle may be provided to an insurer's computer system for processing in order to identify characteristics of a different, second vehicle in the vicinity of the first vehicle (i.e., within the sensor range). The insurer's computer system may then use the identifying characteristics of the second vehicle for various purposes, such as determining whether the second vehicle is currently insured, identifying a party that is responsible for an accident, and/or assessing risk for the



driver of the second vehicle. As another alternative, sensor data or operational data from a vehicle may be provided to an insurer's computer system (or another entity's computer system) for processing in order to determine a habit or preference of the driver, which may in turn be used to select an advertisement specifically targeted to the driver.

In other embodiments, the onboard vehicular data is collected and processed at the vehicle. In some of these embodiments, external sensor data is collected and processed at the vehicle substantially in real-time. For example, onboard processing of external sensor data may be used to determine risk indicators reflecting how safely the operator of the vehicle is driving during different time periods. The risk indicators may then be provided to the insurer's computer system at a later time in order to determine different premiums for the driver that correspond to the different time periods. The risk indicators may be based in whole or in part on operational data indicating when the vehicle is driven with an active automated driving system, such as a conventional cruise control system or a fully automated (i.e., full machine control) driving system, for example. In other embodiments, onboard processing of external sensor data may be used to identify particular types of events, such as accidents, with onboard data only being sent to the insurer's computer system when such an event is detected. In this manner, the volume of data sent to the insurance provider can be greatly reduced, thereby reducing the length and/or bandwidth of data transmissions, and/or reducing storage and processing requirements for the insurer's computer system.

FIG. 1 is a block diagram of an example system 10 for collecting and processing data obtained from a vehicle 12 for various insurance-related or other purposes. While FIG. 1 depicts vehicle 12 as an automobile, vehicle 12 may instead be a truck, motorcycle, or any other type of land-based vehicle capable of carrying at least one human passenger (including the driver). Vehicle 12 includes an onboard system 14, which comprises various different subsystems arranged within and/or on the exterior of vehicle 12. The onboard system 14 is in communication with an insurer's computer system 16 via a network 20. The network 20 may be a single network, or may include multiple networks of one or more types (e.g., a cellular telephone network, a wireless local area network (WLAN), the Internet, etc.).

The onboard system 14 includes a first external sensor 30 and a second external sensor 32. Each of external sensors 30, 32 is a device configured to sense an environment external to vehicle 12 (i.e., to sense physical characteristics of the environment external to vehicle 12), such as a still image or video camera device, a lidar (laser remote sensing) device, a radar device, or a sonar device, for example. Each of the external sensors 30, 32 may be located on or inside vehicle 12. For example, one or both of the external sensors 30, 32 may be permanently affixed to vehicle 12 (e.g., on the exterior or interior of the frame, on the dashboard, on the inner or outer surface of a windshield, etc.), or may be temporarily affixed to, or simply placed on or in, some portion of the vehicle 12 (e.g., placed on top of the dashboard, or in a device holder affixed to the windshield, etc.). External sensor 30 and/or external sensor 32 may be included in a general purpose computing device (e.g., as a software application and associated hardware of a smartphone or other portable computer device), or may be a dedicated sensor device. In the example system 10 shown in FIG. 1, external sensor 30 is located on or inside vehicle 34, while external sensor 32 is located on or inside vehicle

32 such that it senses the environment in a rear-facing range 36. In some embodiments, the external sensor 30 and external sensor 32 combine to provide a 360 degree sensing range. In other embodiments, however, the external sensor 30 and external sensor 32 are redundant sensors (of the same type, or of different type) that each provide a 360 degree sensing range. In still other embodiments, external sensor 32 is omitted, or the onboard system 14 includes more than two external sensors.

Each of external sensors 30, 32 generates data, or analog information, that is indicative of the sensed external environment. In an embodiment where external sensor 30 is a digital video camera device, for example, external sensor 30 generates data corresponding to frames of captured digital video. As another example, in an embodiment where external sensor 30 is an analog camera device, external sensor 30 generates analog signals corresponding to frames of captured analog video. As yet another example, in an embodiment where external sensor 30 is a digital lidar device, external sensor 30 generates data corresponding to frames of captured digital lidar information.

The onboard system 14 also includes hardware, firmware and/or software subsystems that monitor and/or control various operational parameters of vehicle 12. In the example system 10 of FIG. 1, a braking subsystem 40 generates data indicative of how the brakes of vehicle 12 are applied (e.g., an absolute or relative measure of applied braking force, or a binary indicator of whether the brakes are being applied at all, etc.), a speed subsystem 42 generates data indicative of how fast the vehicle 12 is being driven (e.g., corresponding to a speedometer reading, or corresponding to a driver input such as depression of a gas pedal, etc.), a steering subsystem 44 generates data indicative of how the vehicle 12 is being steered (e.g., based on the driver's manipulation of a steering wheel, or based on automated steering control data, etc.), and a diagnostics subsystem 46 generates other information pertaining to the operation of vehicle 12, such as warning information to indicate dangerous or improper operation, and/or error codes to indicate software and/or hardware malfunctions within vehicle 12. The example system 10 also includes a GPS subsystem 48 that generates data indicative of a current location of vehicle 12. In other embodiments, the subsystem 48 uses other positioning techniques instead of GPS, such as cell tower triangulation, for example.

In some embodiments, the braking subsystem 40, speed subsystem 42, steering subsystem 44, diagnostics subsystem 46, and/or a different subsystem not shown in FIG. 1 also generate(s) data indicating whether one or more automated driving systems are currently activated for vehicle 12. For example, the speed subsystem 42 may generate data indicating whether a conventional cruise control system is currently activated, and/or the braking subsystem 40 or steering subsystem 44 may generate data indicating whether assisted steering and/or assisted braking systems are currently activated. As other examples, a unit of onboard system 14 (e.g., diagnostics subsystem 46, or another unit not shown in FIG. 1) may generate data indicating whether vehicle 12 is in an automated transmission mode or a manual transmission mode, or whether the driving of vehicle 12 is currently subject to complete automated/machine control rather than manual (human) control, etc. In yet another example, a unit of onboard system 14 not shown in FIG. 1 (or a combination of units, such as a combination that includes subsystems 40 and 42) may generate data indicative of motion of the vehicle 12 relative to all six degrees of freedom (i.e., forward/backward, up/down, left/right, pitch, yaw, and roll). For example, the generated data may indicate

translational and rotational G-forces (e.g., using accelerometers), which can be used to deduce directional speed and acceleration with respect to each degree of freedom.

In some embodiments, the onboard system **14** does not include one or more of the subsystems **40**, **42**, **44**, **46** and **48**, and/or the onboard system **14** includes additional devices or subsystems not shown in FIG. 1. Moreover, one or more subsystems in onboard system **14** may be included in a general purpose computing device such as a smartphone. For example, the GPS subsystem **48** may include a software application running on a smartphone that includes the appropriate hardware (e.g., an antenna and receiver).

The onboard system **14** also includes a data collection unit **50** configured to receive data and/or analog signals from the external sensors **30**, **32** and from subsystems **40**, **42**, **44**, **46** and **48**. The data collection unit **50** may collect the data and/or analog signals substantially in real time, and in any of various different ways, according to different embodiments. In some embodiments, for example, the data collection unit **50** periodically samples data and/or analog signals from the various external sensors **30**, **32** and subsystems **40**, **42**, **44**, **46** and **48**, or is notified by the respective sensors or subsystems when new data is available, etc. In some embodiments, the data collection unit **50** also ensures that data from the various external sensors **30**, **32** and subsystems **40**, **42**, **44**, **46** and **48** can be synchronized, e.g., by generating a time stamp for each sampled data point, or by storing in memory **52** time stamps that are received from the external sensors **30**, **32** and/or subsystems **40**, **42**, **44**, **46** and **48** along with the corresponding data points.

In some embodiments, the data collection unit **50** receives data from one or more of the external sensors **30**, **32** and/or subsystems **40**, **42**, **44**, **46** and **48** via a wireless link, such as a Bluetooth link. Alternatively, one or more of subsystems **40**, **42**, **44**, **46** and **48**, and/or external sensors **30** and/or **32**, may provide data to data collection unit **50** via messages placed on a controller area network (CAN) bus (not shown in FIG. 1) or other suitable bus type. In still other embodiments, one or more of subsystems **40**, **42**, **44**, **46** and **48** provide data to data collection unit **50** via an onboard diagnostics (OBD) system (also not shown in FIG. 1). For example, the data collection unit **50** may collect information from diagnostics subsystem **46** (and/or from one or more of subsystems **40**, **42** and **44**) via one or more OBD ports. In some embodiments, the data collection unit **50** collects data using a mix of interface and/or bus types (e.g., a Bluetooth interface to receive data from sensors **30**, **32**, an OBD port to receive data from diagnostics subsystem **46**, and a CAN bus to receive data from subsystems **40**, **42**, **44**).

In some embodiments where one or more of external sensors **30**, **32** and/or one or more of subsystems **40**, **42**, **44**, **46** and **48** generate analog signals, either the respective sensors/subsystems or the data collection unit **50** converts the analog information to a digital format. Moreover, the data collection unit **50** may convert data received from one or more of external sensors **30**, **32**, and/or one or more of subsystems **40**, **42**, **44**, **46** and **48**, to different digital formats or protocols. After collecting (and possibly converting) the data from the various sensors/subsystems, the data collection unit **50** stores the data in a memory **52**. The memory **52** may be any suitable type of data storage, such as a random access memory (RAM), a flash memory, or a hard drive memory, for example.

In some embodiments, the data collection unit **50** also, or instead, collects information directly by detecting a manual input by an operator of the vehicle **12**. For example, the data collection unit **50** may directly detect when a human driver

has performed a particular operation, such as applying the brakes, turning the steering wheel, pressing a button or toggling a switch to turn on a fully automated/machine driving mode, etc. In such embodiments, the mechanisms or circuits that allow detection of the manual inputs may be viewed as portions of one or more of subsystems **40**, **42**, **44**, **46** and/or **48**. For example, a physical button or switch having a state that indicates whether an operator has turned on a conventional cruise control system may be viewed as a part of speed subsystem **42**. Thus, it is understood that references below to data, signals, or other information provided by subsystems **40**, **42**, **44**, **46** and/or **48** may encompass, in some embodiments, direct indicators of operations performed manually by a human driver. Similarly, in some embodiments and/or scenarios where the operation of vehicle **12** is fully or partially machine-controlled, references below to information provided by subsystems **40**, **42**, **44**, **46** and/or **48** may encompass direct indicators of operations performed automatically by the machine controller.

In some embodiments, data collection unit **50** also takes advantage of other sources, external to the vehicle **12**, to collect information about the environment. The use of such sources allows the data collection unit **50** to collect information that may be hidden from sensors **30**, **32** (e.g., information about distant objects or conditions outside the range of sensors **30**, **32**, or information about objects or conditions that are not in a line-of-sight path of sensors **30**, **32**), and/or to collect information that may be used to confirm (or contradict) information obtained by sensors **30**, **32**. For example, onboard system **14** may include one or more interfaces and antennas (not shown in FIG. 1), such as Dedicated Short Range Communications (DSRC) interfaces and antennas, that are configured to receive wireless signals using one or more “V2X” technologies, such as vehicle-to-vehicle (“V2V”), vehicle-to-infrastructure (“V2I”) and/or vehicle-to-pedestrian (“V2P”) technologies. In an embodiment in which onboard system **14** is configured to receive wireless signals from other vehicles using V2V, for example, the data collection unit **50** may receive data sensed by one or more external sensors (e.g., similar to external sensors **30**, **32**) of one or more other vehicles, such as data indicating the configuration of a street, or the presence and/or state of a traffic control indicator, etc. In an example embodiment in which onboard system **14** is configured to receive wireless signals from infrastructure using V2I, the data collection unit **50** may receive data provided by infrastructure elements having wireless capability, such as dedicated roadside stations or “smart” traffic control indicators (e.g., speed limit postings, traffic lights, etc.), for example. The V2I data may be indicative of traffic control information (e.g., speed limits, traffic light states, etc.), objects or conditions sensed by the stations, or may provide any other suitable type of information (e.g., weather conditions, traffic density, etc.). In an example embodiment in which onboard system **14** is configured to receive wireless signals from pedestrians using V2P (or from a cyclist using similar technology), the data collection unit **50** may receive data sent from a smartphone, such as the location of the smartphone (and thus, the location of the person carrying the smartphone), objects or conditions sensed by the smartphone, or any other suitable type of information. The onboard system **14** may receive V2X data simply by listening/scanning for the data, or may receive the data in response to a wireless request sent by the onboard system **14**, for example. More generally, the onboard system **14** may be configured to receive information about external objects and/or conditions via wireless signals sent by any

capable type of external object or entity, such as a pedestrian, cyclist or driver operating a smartphone, another vehicle, an infrastructure element (e.g., a roadside wireless station), a commercial or residential location (e.g., a locale maintaining a WiFi access point), etc.

The onboard system **14** also includes a data analysis unit **54** that is coupled to the data collection unit **50**. The data analysis unit **54** may include one or more processors, and is configured to process the data collected by data collection unit **50** and stored in memory **52** for various purposes according to different embodiments, as discussed further below. The data analysis unit **54** includes a memory **56** for storing outputs of the data analysis, which may be any suitable type of data storage, such as a RAM, a flash memory, or a hard drive memory, for example.

The data analysis unit **54** is coupled to an interface **60**, which transmits the data received from data analysis unit **54** to the insurer's computer system **16** via the network **20**. The interface **60** may include a transmitter and one or more antennas, for example. In one embodiment, the interface **60** is included in a general purpose computing device such as a smartphone. For example, the data analysis unit **54** may be coupled to interface **60** via a Bluetooth link to a smartphone device. In an alternative embodiment, the interface **60** is instead an interface to a portable memory device, such as a portable hard drive or flash memory device. In this embodiment, the portable memory device may be used to download data from memory **56** of data analysis unit **54**, and may be manually carried to the insurer's computer system **16** without utilizing network **20**. Alternatively, the portable memory device, or a Bluetooth link, may be used to download data from memory **56** to a field agent's computer device (e.g., laptop or smartphone), which may in turn be used to transmit the data to the insurer's computer system **16** via network **20**.

Data analysis unit **54** and data collection unit **50** may jointly operate to perform various different functions according to different embodiments. In one embodiment, data collection unit **50** buffers a certain amount of real-time data collected from external sensors **30**, **32** and subsystems **40**, **42**, **44**, **46** and **48** (e.g., data collected over the previous two minutes, or the previous ten seconds, etc.) by storing the data in memory **52**, and data analysis unit **54** sends all or a portion of the buffered data to interface **60** when detecting a particular event such as an accident. Data analysis unit **54** may detect the accident or other event by processing the sensor and/or subsystem data. In one embodiment, for example, data analysis unit **54** detects an accident by processing data from speed subsystem **42** to identify a very sudden change in velocity of vehicle **12**, and/or by implementing image/video processing of data from external sensors **30**, **32** to identify a collision with another vehicle or object, etc. Once the buffered data is transmitted to the insurer's computer system **16**, further processing of the data may be performed (e.g., to generate a virtual model of the accident or other event), as discussed further below. In an embodiment, data indicating that the accident or other event was detected is sent to interface **60** (and the insurer's computer system **16**) along with the buffered data.

Additionally, or alternatively, data analysis unit **54** may process data collected by data collection unit **50** and stored in memory **52**, and store results relating to that processing in memory **56**. In one such embodiment, data analysis unit **54** processes external sensor data and/or subsystem data substantially in real-time (e.g., as the data is collected by data collection unit **50**) in order to generate risk indicators reflecting the level of risk associated with the conditions or environment in which the vehicle is driven, and/or the

operation of the vehicle, during different time periods. Examples of ways in which risk indicators may be determined, and of the types of correlation models/data that may be used to determine the risk indicators, are discussed below in connection with the insurer's computer system **16**. Once each risk indicator is generated for a particular time period, the risk indicator may be stored in memory **56**, and the data in memory **52** that corresponds to that same time period may be erased to make room for new data. In this manner, storage requirements of memory **52** may be reduced, which may be useful in view of the large volume of data that may be generated by external sensors **30**, **32** and subsystems **40**, **42**, **44**, **46** and **48**, and/or received from external sources via wireless technologies such as V2X. Memory **52** and memory **56** may be separate memories, or parts of a single memory, according to different embodiments.

In some embodiments, the data generated by data analysis unit **54** and stored in memory **56** (e.g., data reflecting risk indicators corresponding to respective time periods) is automatically sent to interface **60** for transmission to the insurer's computer system **16**. For example, the data may be sent to interface **60** at regular time intervals (e.g., once per day, once per insurance billing cycle, etc.). In other embodiments, the data is sent to the insurer's computer system **16** in response to a query from the insurer's computer system **16** that is received via network **20**, or in any other suitable manner. Once the data is provided to the insurer's computer system **16**, the data may be subject to further processing (e.g., to determine an insurance rating and/or premium based on risk indicators generated by data analysis unit **54**), as discussed further below.

As noted above, one or more of subsystems **40**, **42**, **44**, **46** and **48**, and/or one or both of external sensor **30**, **32**, may provide data to data collection unit **50** via a bus, such as a CAN bus. In some embodiments, however, other components within onboard system **14** are also connected to the bus. For example, sensors **30**, **32**, subsystems **40**, **42**, **44**, **46** and **48**, data collection unit **50**, data analysis unit **54**, and interface **60** may all communicate via CAN bus messages.

The insurer's computer system **16** is an electronic processing system capable of performing various functions, and includes an interface **62** configured to receive data from the onboard system **14** of vehicle **12** via network **20**. Interface **62** may be similar to interface **60** of the onboard system **14**, for example. In embodiments where a portable memory device (rather than network **20**) is used to transfer data from the onboard system **14** to the insurer's computer system **16**, interface **62** is an interface to a portable memory device, such as a portable hard drive or flash memory device, for example.

The insurer's computer system **16** also includes a data collection unit **70** coupled to interface **62**. The data collection unit **70** is configured to receive/collect the data received by interface **62**, and to store the collected data in a memory **72**. The memory **72** may be any suitable type of data storage, such as a RAM, a flash memory, or a hard drive memory, for example. The data collection unit **70** is coupled to a data analysis unit **74**. Data analysis unit **74** may include one or more processors, and is configured to process the data collected by data collection unit **70** and stored in memory **72** for various purposes according to different embodiments, as discussed further below.

In the example system **10** of FIG. **1**, the data analysis unit **74** includes a risk determination unit **80**, a model generation unit **82**, a vehicle identification unit **84**, and a habit/preference determination unit **86**. In other embodiments, data analysis unit **74** does not include one or more of units **80**, **82**,

**84** and **86**, and/or includes additional processing units not shown in FIG. 1. In one embodiment where risk indicators are only generated by data analysis unit **54** of the onboard system **14**, for example, risk determination unit **80** is omitted from data analysis unit **74**. In one embodiment, each of units **80**, **82**, **84** and **86** includes a set of instructions stored on a tangible, nontransitory computer-readable medium and capable of being executed by the processor(s) of data analysis unit **74** to perform the functions described below. In another embodiment, each of units **80**, **82**, **84** and **86** includes a set of one or more processors configured to execute instructions stored on a tangible, nontransitory computer-readable medium to perform the functions described below. In an embodiment, data analysis unit **74** includes a memory (not shown in FIG. 1) for storing outputs of the analysis performed by data analysis unit **74**.

In some embodiments, the risk determination unit **80** is configured to generate risk indicators based on data from external sensors **30**, **32** and/or subsystems **40**, **42**, **44** and/or **46**, and/or based on data received from an external source by onboard system **14** (e.g., using V2X technology). For example, the risk determination unit **80** may generate risk indicators in an alternative embodiment where data analysis unit **54** is omitted or otherwise does not determine the risk indicators. Alternatively, in one embodiment where data analysis unit **54** of the onboard system **14** does determine risk indicators, risk determination unit **80** processes data representing the risk indicators in order to generate other indicia of risk (e.g., to generate monthly risk indicators based on per-minute or per-day risk indicators that are provided by onboard system **14**). In one embodiment where data analysis unit **54** determines risk indicators, risk determination unit **80** is not included in data analysis unit **74**.

Risk indicators may be determined using predictive modeling, which may use data reflecting information collected from external sensors **30**, **32**, subsystems **40**, **42**, **44** and/or **46**, and/or V2X communications, as well as correlation data **90** stored in the insurer's computer system **16**. The correlation data **90** can be accessed by the risk determination unit **80**, and/or other units within data analysis unit **74**. In other embodiments (e.g., some embodiments where data analysis unit **54** generates risk indicators, as discussed above), similar correlation data is instead stored, or is in part stored, in the onboard system **14** (e.g., in memory **52** or memory **56**). In some of these latter embodiments, correlation data similar to correlation data **90** is stored in the memory of onboard system **14** at the time of installation in vehicle **12**, and/or the correlation data stored in the memory of onboard system **14** is updated on a regular or irregular basis (e.g., via wireless communications, or by field agents transferring data to the onboard system **14** via a portable memory device, etc.).

The correlation data **90** may be generated based on historical data associated with other vehicles. In some embodiments, correlation data **90** includes data modeling correlations between (a) patterns relating to external conditions sensed by external vehicle sensors and/or indicated by V2X signals received by vehicle **12**, and/or patterns relating to vehicle operation as represented by external sensor data, operational data, and/or received V2X signals, and (b) likelihoods of incurring recognizable losses under a vehicle insurance policy. The correlation data/models stored in correlation data **90** may be based on manually entered information, or may be learned by the insurer's computer system **16** (or another computer system not shown in FIG. 1) based on vehicle data and claims data of a plurality of other vehicles, e.g., as described in more detail below in connection with FIG. 8.

The risk determination unit **80** may be configured to analyze the vehicle data stored in memory **72** using one or more of these correlation models in order to determine one or more risk indicators. As an example in which a relatively simple correlation model is used, the risk determination unit **80** may compare the percentage of time, within a particular time period, that the vehicle **12** was operated in a fully automated/machine driving mode (e.g., as determined based on data generated by one or more of subsystems **40**, **42**, **44** and **46** of FIG. 1) with one or more percentage ranges identified by the correlation data (e.g., 0-10 percent, 11-25 percent, etc.), and determine, for that time period, the risk indicator that corresponds to the matching percentage range. The correlation data **90** may include a relational database, for example, with each percentage range corresponding to a different indicator of a loss likelihood. As another example utilizing a slightly more complex correlation model, the risk determination unit **80** may process data from speed subsystem **42** and data from external sensor **30** to determine the average speed of vehicle **12**, and the average following distance between vehicle **12** and vehicles ahead of vehicle **12**, over a particular time period. Once average speed and average following distance are determined, risk determination unit **80** may compare those quantities with speed/following distance models represented by the correlation data, and identify, for that time period, a risk indicator that corresponds to the average speed/following distance of vehicle **12**.

More generally, risk determination unit **80** may process data collected from external sensor **30** and/or external sensor **32** (alone, in conjunction with data collected from one or more of subsystems **40**, **42**, **44**, **46** and **48**, and/or in conjunction with information provided by V2X or other wireless signals received by vehicle **12**) to determine when vehicle **12** crossed lane markers, was not operated in conformance with traffic lights or traffic signs, was driven at erratic speeds, was driven with excessive braking, or was otherwise driven in any other manner that has previously been determined (e.g., by the insurance provider) to correspond to a higher (or lower) risk of accident/loss, or to determine when vehicle **12** was driven in low-visibility conditions (e.g., rainy or snowy weather), in a high-traffic environment, on streets in disrepair (e.g., bumpy, full of pot holes, etc.), or in any other conditions external to vehicle **12** that have previously been determined to correspond to a higher (or lower) risk of accident/loss. Determination of risk indicators such as those generated by data analysis unit **54** and/or risk determination unit **80**, and the determination of correlation models such as those that may be stored within correlation data **90**, are discussed further below in connection with FIGS. 8-10.

Once the risk indicators are determined by data analysis unit **54** and/or risk determination unit **80**, the insurer's computer system **16** may provide the risk indicators to an insurance rating unit (not shown in FIG. 1), within the insurer's computer system **16** or another computer system, that is configured to determine an insurance rating for a driver of vehicle **12** based on the risk indicators. For example, in an embodiment where data analysis unit **54** and/or risk determination unit **80** generate periodic (e.g., weekly, monthly, etc.) risk indicators, the insurance rating unit may determine an insurance rating corresponding to one or more of the risk indicators (e.g., a monthly insurance rating corresponding to a monthly risk indicator, a monthly insurance rating corresponding to a set of tens or hundreds of hourly risk indicators, an annual insurance rating corresponding to a set of 52 weekly risk indicators, etc.). The

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insurance ratings may in turn be provided to a billing unit (also not shown in FIG. 1), within the insurer's computer system 16 or another computer system, that is configured to determine premiums for an insurance policy of the driver of vehicle 12 based on the insurance ratings (or, alternatively, based directly on the risk indicators). As just one example, in an embodiment where data analysis unit 54 and/or risk determination unit 80 generate monthly risk indicators, and where an insurance rating unit determines corresponding monthly insurance ratings, the billing unit may determine a monthly insurance premium corresponding to each monthly insurance rating.

Each risk indicator may include a single value or code, or a plurality of risk indices. In one embodiment, for example, a monthly risk indicator includes risk indices that are generated each hour (or each hour when vehicle 12 is operated, etc.), and a monthly rating and premium are determined based on all of the hourly risk indices generated for the respective month. The hourly risk indices may be weighted (e.g., according to the amount of time that vehicle was driven during that hour), or raw risk indices may be used to determine the rating and premium. In some embodiments and scenarios, vehicle 12 is driven by an individual not yet insured by the insurance provider, and the risk indicators are used to determine an insurance rating and corresponding premium to be offered to the driver of vehicle 12.

The model generation unit 82 is configured to process data from external sensor 30 and/or external sensor 32 in order to generate a virtual model. The virtual model can be used to visually re-create an accident or other event involving vehicle 12, or an accident or other event that does not involve vehicle 12, but is sensed by one or both of the external sensors 30, 32 of vehicle 12. As discussed above, for example, the onboard system 14 may detect when an accident involving vehicle 12 has occurred, and send buffered data to the insurer's computer system 16 in response to detecting the accident.

In one example embodiment, the virtual model generated by model generation unit 82 is an animated re-creation of the event. For example, the model generation unit 82 may process the external sensor data to render a three-dimensional temporal model of the environment of vehicle 12, which may depict the conditions, over time, of an accident that involved or occurred near vehicle 12 (e.g., configuration of a street on which vehicle 12 is driving, other vehicles in the vicinity of vehicle 12, traffic signs or lights near vehicle 12, weather conditions around vehicle 12, etc.). In some embodiments, operational data from one or more of subsystems 40, 42, 44 and/or 46, and/or information obtained by vehicle 12 from external sources, is/are also processed by model generation unit 82. For example, the operational data (e.g., braking data from braking subsystem 40, velocity data from speed subsystem 42, etc.) and/or external source information (e.g., V2X information indicating locations of pedestrians, cyclists and/or vehicles, state of a traffic light, etc.) may be used in order to improve or confirm the accuracy of the animated re-creation. Accuracy may be improved, for example, by using the operational data and/or external source information to fill in gaps or provide greater confidence in the data provided by external sensors 30, 32. In one such embodiment and scenario, information that vehicle 12 had obtained from external sources (e.g., using V2X technology) is utilized to generate portions of the animated re-creation that cannot be determined by data from external sensors 30, 32 (e.g., due to the corresponding geographic areas being out of the range or line of sight of external sensors 30, 32).

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Alternatively, or additionally, the model generation unit 82 may generate an animated re-creation of the event that distinctly displays (e.g., in a graphic overlaying the animated re-creation) one or more parameters represented by the operational data and/or external source information. For example, the model generation unit 82 may generate a virtual model such that an animated re-creation of the event can be displayed with an indicator of speed (and/or other operational parameters) of vehicle 12 overlaid on the animated re-creation, or with an indicator of current weather (or other environmental) conditions overlaid on the animated recreation, etc.

In another example embodiment, the virtual model generated by model generation unit 82 comprises data representing the raw sequence of frames produced by the external sensor(s), and therefore provides the same perspective as the external sensor(s) that captured the frame data. In an embodiment where external sensor 30 is a video camera device situated such that it captures the driver's field of vision, for example, the virtual model may be a temporal model that depicts the nearly ground-level perspective of the driver of vehicle 12 while the accident or other event is occurring and/or about to occur. As another example, the virtual model may be a temporal model that depicts a panoramic view taken by knitting together frames captured by external sensor 30 and frames captured by external sensor 32 while the accident or other event is occurring and/or about to occur. The model generation unit 82 may also process operational data from one or more of subsystems 40, 42, 44 and/or 46, and/or data received by vehicle 12 from one or more external sources (e.g., using V2X technology), to generate a virtual model such that the frames are displayed together with indicators of one or more operational parameters (e.g., speed) of vehicle 12, and/or one or more other indicators (e.g., weather conditions or visibility) overlaid on the frames.

In embodiments where indicators of operational parameters (and/or other information) are displayed along with captured frames or an animated re-creation, or where operational data and/or external source (e.g., V2X) information is used to increase the accuracy of an animated re-creation, the model generation unit 82 may use synchronization data received from onboard system 14 (e.g., time stamps that were initially received and/or generated by data collection unit 50) to ensure that the operational parameters and/or other information are properly synchronized to the captured frames or the animated re-creation. An example of a virtual model that provides an animated re-creation of an accident is discussed below in connection with FIGS. 2 and 3, and various methods of utilizing external vehicle sensor data to generate a virtual model of an event are discussed further below in connection with FIGS. 4-6.

Once a virtual model is generated by model generation unit 82, the virtual model (e.g., captured frames with operational parameters or other information overlaid, or an animated re-creation with or without overlaid information, etc.) may be displayed to a user of the insurer's computer system 16 (or other computer system not shown in FIG. 1), who may then study the displayed virtual model in order to help determine fault for the accident, determine an initial estimate of damages resulting from the accident, or take other action (e.g., attempt to contact medical assistance, and/or the driver's cell phone, after determining that the vehicle 12 was involved in a crash).

In the example system 10, the insurer's computer system 16 is also configured to utilize information obtained by one or both of external sensors 30, 32 of vehicle 12 to determine

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information pertaining to a different, second vehicle within sensor range **34** and/or **36**. While various different kinds of information relating to the second vehicle may be collected by the insurer's computer system **16** (e.g., how the second vehicle is being driven, the conditions in which the second vehicle is driven, etc.), that information may be of limited value unless the second vehicle, and therefore the owner and/or driver of the second vehicle, can be identified. For example, a risk level associated with a driver of the second vehicle (e.g., as determined based on driving conditions and/or habits captured by external sensors **30**, **32**) may be of limited use unless an insurance company can identify an owner/driver of the second vehicle (e.g., in order to update an insurance rating for the owner/driver of the second vehicle, etc.). Further, some applications may more directly rely on identification of the second vehicle. For example, it may be useful to identify a party at fault for an accident (e.g., in a scenario where, based on a visualization of an accident provided by model generation unit **82**, a user of the insurer's computer system **16** has determined that the driver of the second vehicle caused the accident), or to determine whether an owner/driver of the second vehicle is insured (e.g., based on identification of a license plate number of the second vehicle).

To determine identifying characteristics of a second vehicle within range **34** of external sensor **30** and/or range **36** of external sensor **32**, the vehicle identification unit **84** processes data from external sensor **30** and/or external sensor **32**. For example, vehicle identification unit **84** may utilize image processing of images/frames captured by a still image camera, video camera, or lidar device, located on or inside vehicle **12** in order to determine a license plate number for the other vehicle, and/or other identifying characteristics such as state where the vehicle is registered (e.g., as printed on the license plate), or the color, year, make and/or model of the vehicle. In some embodiments, vehicle identification unit **84** (or another unit within or outside of the insurer's computer system **16**) makes one or more additional determinations based on the initially determined information. For example, vehicle identification unit **84** (or another unit) may determine a selection of possible license plate numbers that each correspond to an identified color, make, model and/or year of a vehicle. To this end, vehicle identification unit **84** (or another unit) may access correlation data **90**, or another local or remote database not shown in FIG. **1**, which may correlate various types of identifying information with other information (e.g., license plate numbers to color, make, model and/or year). A method of utilizing external vehicle sensor data to determine identifying characteristics of another vehicle is discussed further below in connection with FIG. **7**.

In the example system **10**, the insurer's computer system **16** is also configured to determine habits or preferences of a driver of vehicle **12**, which may be useful for selecting advertisements specifically targeted to the driver. To determine habits or preferences of the driver, the habit/preferences determination unit **86** may process data from external sensor **30** and/or external sensor **32**, data from one or more of subsystems **40**, **42**, **44**, **46** and **48**, and/or data received by vehicle **12** from external sources (e.g., using V2X technology). For example, habit/preferences determination unit **86** may process location data from GPS subsystem **48**, sensor data from external sensor **30** and/or **32**, and/or external source information in order to learn specific locations, or types of locations, frequently visited by the driver of vehicle **12** (e.g., stores, restaurants, etc.), and/or routes (e.g., to or from work) frequently taken by the driver. As another

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example, habit/preferences determination unit **86** may process any other data from vehicle **12**, such as braking information from braking subsystem **40**, velocity information speed subsystem **42**, steering information from steering subsystem **44**, automated versus human driving information from any of subsystems **40**, **42**, **44** and/or **46**, and/or information obtained by vehicle **12** from external sources in order to determine other habits or preferences of the driver (e.g., habitual or preferred speeds relative to posted speed limits, tendency to drive in areas with dense concentrations of pedestrians and/or cyclists, or any other driving preferences or habits such as heavy use of the brake pedal, etc.).

Once habit/preferences determination unit **86** determines a driver habit or preference, habit/preferences determination unit **86** may send data representing the habit or preference to another unit or entity, such as a computer system at a vendor or advertising agency, where an advertisement specifically targeted to the driver of vehicle **12** may be selected for delivery to the driver. For example, the advertisement may be played over internet radio, or emailed to the driver for viewing at a later time. As one specific example, an advertisement for "Restaurant A" may be selected based on data (e.g., data generated by GPS subsystem **48**) suggesting that vehicle **12** has often parked at locations known to correspond to restaurants of the same type as Restaurant A. Other examples are discussed below in connection with FIG. **11**. In an alternative embodiment, the insurer's computer system **16** itself includes an advertisement selection unit (not shown in FIG. **1**) that selects an advertisement targeted to the driver of vehicle **12** based on the determined habit or preference (e.g., for selecting an advertisement for an insurance product or service). For example, an advertisement for a particular insurance service or product may be selected based on data (e.g., data generated by external sensors **30**, **32**, data generated by subsystems **40**, **42**, **44**, and/or **46**, and/or data received by vehicle **12** from external sources using V2X technology) suggesting that the driver of vehicle **12** is a particularly safe, or particularly unsafe, driver.

In some embodiments, data analysis unit **74** not only accesses correlation data **90** (e.g., for purposes of risk determination unit **80** and/or vehicle identification unit **84**), but also stores information in correlation data **90**. For example, data analysis unit **74** (or interface **62**) may send data received from onboard system **14** to correlation data **90** in order to further develop existing correlation models and increase the accuracy of predictive modeling.

The functionality of various portions/units of system **10** are now described in more detail. In particular, FIGS. **2-6** relate to the generation of a virtual model of an accident or other event using external sensor and/or operational data of a vehicle, FIG. **7** relates to identifying characteristics of a first vehicle using external sensor data of a second vehicle, FIGS. **8-10** relate to the determination of risk based on external sensor and/or operational data of a vehicle, and FIG. **11** relates to the determination of driver habits or preferences and advertisement selection based on external sensor data and/or operational data of a vehicle.

FIG. **2** is a diagram illustrating an example scenario **100** in which an external vehicle sensor is used to collect information to be processed by the system **10** of FIG. **1**. In the example scenario **100**, vehicle **12** (i.e., vehicle **12** of FIG. **1**) carries at least one external sensor (in this example, external sensors **30** and **32** of FIG. **1**), in order to sense the external environment of vehicle **12** in substantially a 360 degree range. As discussed above with reference to FIG. **1**, the sensors may be a camera, lidar, or other type of sensor, and in other embodiments may include only a single sensor

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or more than two sensors. Also in the example scenario **100**, vehicle **12** is traveling in the vicinity of three other vehicles **104A-104C**, at a street intersection **110** with two traffic lights **112A**, **112B**. In the example scenario **100**, the positions and orientations of each of the vehicles **104A-104C**, the configuration of the street intersection **110**, and the positions and state (i.e., light color) of each of the traffic lights **112A**, **112B** is within the sensing range/capabilities of the external sensor(s) of vehicle **12**.

The example scenario **100** represents a snapshot in time shortly before an accident, such as vehicle **104B** impacting vehicle **104A**, and/or vehicle **104B** impacting vehicles **12** and **104C**. The onboard system **14** of vehicle **12** may store data from external sensors **30** and/or **32** (and, in some embodiments, operational data from one or more of subsystems **40**, **42**, **44** and/or **46**, and/or V2X or other data provided by sources external to vehicle **12**) for a particular amount of time leading up to and/or during the accident, which may be sent to the insurer's computer system **16** of FIG. **1**. At the insurer's computer system **16**, model generation unit **82** may then process the data to generate a virtual model that re-creates the accident of scenario **100**.

FIG. **3** is a diagram of an example virtual model **150**, generated by the system **10** of FIG. **1** in order to re-create the scenario **100** of FIG. **2**, and corresponds to an embodiment in which the virtual model **150** provides an animated re-creation of the accident. In the virtual model **150**, vehicle model **152** represents the real-life vehicle **12**, vehicle models **154A-154C** represent the real-life vehicles **104A-104C**, respectively, street intersection model **160** represents the real-life street intersection **110**, and traffic light models **162A** and **162B** represent the real-life traffic lights **112A** and **112B**, respectively. The virtual model **150** may be generated based solely on external sensor data from one or both of external sensors **30**, **32** of vehicle **12**, or may be generated using operational data from one or more of subsystems **40**, **42**, **44** and **46** (or other subsystems) in vehicle **12**, and/or data reflecting information received by vehicle **12** from external sources (e.g., using V2X technology), in addition to the external sensor data. For example, to determine the location and/or orientation of vehicle **104B** at times when vehicle **154B** was not in the line of sight of any external sensors on vehicle **12** (e.g., due to vehicle **104A** blocking vehicle **104B**), the position and/or orientation of vehicle model **154B** within the virtual model **150** may be determined based on data that vehicle **12** received from vehicle **104B** (e.g., using V2V technology). Moreover, in some embodiments and scenarios, different temporal segments of the virtual model **150** may be generated using different types of data. For example, a first segment of the virtual model **150** may re-create a first time period leading up to a crash involving vehicle **12**, and may be constructed solely or primarily using data from external sensors **30**, **32**, while a second segment of the virtual model **150** may represent a second time period during the crash (e.g., a period of time that starts at or shortly after impact), and may be constructed using data from one or more subsystems of vehicle **12** that indicates G-forces on vehicle **12** relative to all six degrees of freedom.

In the embodiment of FIG. **3**, the virtual model **150** also includes indicators **170** of various operational parameters displayed in conjunction with the animated re-creation of the accident, including indicators of speed of vehicle **12**, whether a conventional cruise control system is activated for vehicle **12**, a percentage of maximum braking pressure or force applied in vehicle **12**, and various diagnostic codes associated with vehicle **12**. As just one example, the code "E24" may indicate that engine temperatures are higher than

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normal for vehicle **12**, and the code "V17" may indicate that a rear, left-side taillight is disabled for vehicle **12**. In other embodiments, the indicators **170** include additional operational parameters not shown in FIG. **3** (e.g., an indicator of whether a fully automated driving system is activated for vehicle **12**, etc.), omit some of the operational parameters that are shown in FIG. **3**, and/or are displayed in a different manner than shown in FIG. **3** (e.g., on a different display window entirely, or superimposed on vehicle model **152**, etc.). The indicators **170** are generally time-aligned with the animation provided by virtual model **150**, so that a person viewing the animated re-creation can determine how the various operational parameters relate, in time, to the changing positions of the vehicles **12** and **104A-104C**, and to the changing states of the traffic lights **112A**, **112B**, etc.

In some embodiments, the virtual model **150** also either graphically depicts weather/visibility conditions (e.g., rain, fog, snow, night versus day, etc.), or includes text describing the weather/visibility conditions within indicator **170**. Additionally, or alternatively, the virtual model **150** may either graphically depict street conditions (e.g., wet, icy, bumpy, etc.), or include text describing the street conditions within indicator **170**. The weather/visibility and/or street conditions (and/or any other environmental conditions) may be determined by model generation unit **82** based on data from external sensor **30** and/or external sensor **32**, and/or based on data received from vehicle **12** receives from external sources (e.g., via V2X communications), for example.

While the virtual model **150** provides a "bird's eye" perspective of an accident, in other embodiments the virtual model **150** provides a different perspective. In one embodiment where the external sensor **30** of FIG. **1** is a video camera device, for example, the virtual model **150** provides raw frames as captured by the video camera device, and the indicators **170** overlay the sequence of video frames, or are displayed next to the sequence of video frames. Moreover, in some embodiments, the virtual model **150** allows an individual (e.g., at the insurer's computer system **16** of FIG. **1**) to selectively change the perspective in order to gain a more complete understanding of the accident.

By viewing a display (or multiple displays with different perspectives) of the virtual model **150**, an individual may be able to make important determinations regarding the facts of the actual scenario **100**. For example, the viewer may be able to determine that the driver of vehicle **104A** was entirely at fault for the accident because, according to virtual model **150**, the driver of vehicle **104A** attempted to pass through intersection **110** while the traffic light **112A** was red. Alternatively, if the vehicle **12** is also involved in the accident of scenario **100**, the viewer may be able to determine that the driver of vehicle **12** was also partially at fault for the accident based on the speed of vehicle **12** as shown by indicators **170**. The viewer may also be able to make other assessments, such as roughly estimating an amount of damage to vehicle **12** (and/or other vehicles) due to the accident (e.g., based on speed and angle of impact). In some scenarios and embodiments, the external sensor(s) **30**, **32** of vehicle **12** may directly capture images portraying body damage to one or more vehicles, thereby further facilitating the initial damage assessment.

FIG. **4** is a flow diagram of an example method **200** of utilizing external vehicle sensor data to generate a virtual model of an event involving at least one vehicle. In an embodiment, the method **200** is implemented in whole or in part by the insurer's computer system **16** of FIG. **1**. Alter-



natively, or additionally, in an embodiment, the method **200** is implemented at least in part by the onboard system **14** of FIG. **1**.

The method **200** receives sensor data representing information collected by a sensor located on or inside a vehicle and configured to sense an environment external to the vehicle (block **202**). The sensor may be a camera device, lidar device, radar device, or sonar device, for example. The sensor may be permanently or removably affixed to an exterior or interior (e.g., passenger cabin) portion of the vehicle, or simply placed on or in a portion of the vehicle (e.g., on a dashboard). In some embodiments, the sensor is included in a general purpose computing device, such as a smartphone having sensor hardware and running a sensor application. In other embodiments, the sensor includes only dedicated hardware and/or software. The sensor data may be data that was directly generated by the sensor, or data that was converted from other information (e.g., other data or analog signals) generated by the sensor, for example.

In some embodiments, the sensor data is received at a server remote from the vehicle via a wireless communication network, such as a wireless communication network of network **20** in FIG. **1**. In other embodiments, the sensor data is received at a server remote from the vehicle via a portable memory device, such as a portable hard drive or flash device. For example, a portable memory device may be plugged into a hardware interface at the vehicle, used to download sensor data from the vehicle, and physically carried to a remote server (e.g., in insurer's computer system **16**) so that the sensor data may be received by the server. In another example embodiment, the sensor data is transferred to a field agent's computing device (e.g., laptop or smartphone) via a short-range wireless link (e.g., Bluetooth link), USB or other cable connection, or portable memory device (e.g., flash drive), and then transmitted to the remote server in a wired or wireless manner.

The method **200** also stores the sensor data received at block **202** to a memory (block **204**). The memory may be similar to memory **72** of FIG. **1**, for example. The method **200** then retrieves the sensor data from the memory, and uses the sensor data to generate a virtual model of an event involving at least one vehicle (block **206**). The event may be an accident involving the vehicle on or in which the sensor is located, for example, and/or involving one or more other vehicles. Alternatively, the event may be another type of incident, other than an accident, involving a vehicle. In each instance, however, the event is one that, when occurring, is at least partially sensed by the sensor located on or in the vehicle.

In some embodiments, the virtual model includes an animated re-creation of the event. The animated re-creation may depict various factors or circumstances relating to the event, such as an orientation of the vehicle with respect to a second vehicle or other object, a closing speed between the vehicle and a second vehicle or other object, a configuration of and/or condition of a driving surface (e.g., the street(s) on which the event occurs), visibility conditions external to the vehicle (e.g., weather conditions, darkness, etc.), a traffic control indicator external to the vehicle (e.g., a traffic light, speed limit sign, stop sign, etc.), a state of a traffic control indicator external to the vehicle (e.g., whether a traffic light is red, yellow or green), etc. When displayed, the animated re-creation may look similar to the example virtual model **150** of FIG. **3** (with or without indicators **170**), for example.

In alternative embodiments, the method **200** also includes additional blocks not shown in FIG. **4**. For example, in an embodiment where the event re-created by the virtual model

is an accident involving the vehicle and/or other vehicles, the method **200** also causes the virtual model to be displayed (e.g., to a user of an electronic processing system implementing the method **200**), causes data representing the virtual model to be sent to an electronic claims processing system, and/or determines, based on the virtual model, fault for the accident and/or damages resulting from the accident. Fault and/or damages may be determined by a user viewing a display of the virtual model, or automatically determined based on various processing algorithms, for example.

As another example, in some embodiments, the virtual model is generated using data from external sensors of at least two different vehicles (e.g., in order to re-create an accident or other event involving both vehicles). For example, the method **200** may also receive additional sensor data that represents information collected by a different, second sensor, where the second sensor is located on or in a different, second vehicle and configured to sense an environment external to the second vehicle. The second sensor may be of the same type as the sensor of the first vehicle, or of a different type, and may be received in the same or a similar manner. For example, the sensor data of the second vehicle may be received, at a server, directly from the second vehicle (e.g., via a wireless network and/or portable memory device), or may be received from the first vehicle (e.g., if the first vehicle first obtains the data from the second vehicle via V2V communications). In these embodiments, the method **200** also stores the additional sensor data in the memory, and the method **200** generates the virtual model at block **204** not only based on the sensor data corresponding to the first sensor, but also based on the additional sensor data corresponding to the second sensor.

As another example, in some embodiments, the virtual model is generated using not only external sensor data of a vehicle, but also operational data of the vehicle. For example, the method **200** may also receive operational data indicative of operation of the vehicle on or in which the sensor is located, and store the operational data in the memory. The operational data may be indicative of velocity of the vehicle, acceleration of the vehicle, braking of the vehicle, status of an automated driving system of the vehicle (e.g., whether an automated driving system such as a conventional cruise control system, or a completely automated/machine driving system, is activated), and/or diagnostics information associated with the vehicle (e.g., whether a software or hardware subsystem within the vehicle has failed or is otherwise operating incorrectly), for example. In some embodiments, the operational data is indicative of movement of the vehicle relative to any or all of the six degrees of freedom (e.g., by specifying G-forces with respect to each degree of freedom). The operational data may be data that was directly generated by one or more subsystems of the vehicle, data that was converted from other information (e.g., other data or analog signals) that was generated by one or more subsystems of the vehicle, and/or data that was generated in response to the direct detection of one or more manual or machine inputs that control operation of the vehicle, for example. In this embodiment, the method **200** generates the virtual model (block **204**) not only based on the sensor data, but also based on the operational data. The accuracy and/or detail of the virtual model may be improved as a result of the operational data, and/or the virtual model may provide indicators of operational parameters (e.g., speed, error codes, etc., as determined based on the operational data) in conjunction with an animated re-creation of the event or in conjunction with captured frames showing the event.



As yet another example, in some embodiments, the virtual model is generated using not only external sensor data of a vehicle, but also data representing information that was received by the vehicle from one or more external sources via one or more wireless signals (e.g., V2V, V2I and/or V2P signals). For example, the method **200** may also receive data representing information that was included in wireless signals received by the vehicle, and store the data in the memory. The data may be indicative of any object and/or environmental condition in the vicinity of the vehicle, such as weather conditions, street configurations, vehicle cyclist or pedestrian locations, or traffic control indicators or status, for example. The data may be data that was included in the wireless (e.g., V2X) signals, or data that was converted from data included in the wireless signals, for example. In these embodiments, the method **200** generates the virtual model (block **204**) not only based on the sensor data, but also based on the data representing information that the vehicle had received from the external source(s). The accuracy and/or detail of the virtual model may be improved using the information provided by the external source(s), and/or the virtual model may provide indicators of the information provided by the external source(s) in conjunction with an animated re-creation of the event, or in conjunction with captured frames showing the event.

Preferably, in embodiments where a virtual model of an event is generated using both external sensor data and operational data, the sensor data and operational data is synchronized such that the virtual model provides an accurate temporal representation of the event. FIGS. **5** and **6** show example methods of utilizing external vehicle sensor data, operational data, and synchronization data to generate a synchronized virtual model of an event involving a vehicle. Specifically, FIG. **5** relates to an embodiment in which sensor data and operational data are each used to generate respective visual representations that are displayed simultaneously to provide visualization of an event involving a vehicle, and FIG. **6** relates to an embodiment in which sensor data and operational data are jointly used to generate an animated re-creation to provide visualization of an event involving a vehicle.

Referring first to FIG. **5**, a method **220** is implemented in whole or in part by the insurer's computer system **16** of FIG. **1**. Alternatively, or additionally, in an embodiment, the method **220** is implemented at least in part by the onboard system **14** of FIG. **1**. The method **220** receives sensor data representing information collected by a sensor configured to sense an environment external to a vehicle (block **222**). The sensor is located on or in the vehicle, and may be a device similar to that discussed above in connection with block **202** of method **200** (e.g., a camera device, a lidar device, etc.), for example. The received sensor data includes a first plurality of data points indicative of a plurality of respective states of the environment external to the vehicle at a plurality of respective times. For example, each data point may correspond to a different frame captured by a video camera or lidar device. The sensor data may be received in a manner similar to that described above in connection with block **202** of method **200** (e.g., at a server remote from the vehicle, etc.), for example.

The method **220** also receives operational data generated by a unit that is arranged within the vehicle and indicative of an operational parameter of the vehicle (block **224**). The unit may be hardware and/or software that is configured to monitor and/or control the operational parameter. The operational data may be indicative of velocity of the vehicle, acceleration of the vehicle, braking of the vehicle, status of

an automated driving system of the vehicle (e.g., whether an automated driving system such as a cruise control mode, or a completely automated/machine driving mode, is activated), and/or diagnostics information associated with the vehicle (e.g., whether a software or hardware system within the vehicle has failed or is otherwise operating incorrectly), for example. In some embodiments, the operational data is indicative of movement of the vehicle relative to any of the six degrees of freedom (e.g., by indicating G-forces with respect to each degree of freedom). The received operational data includes a second plurality of data points indicative of a plurality of respective states of the operational parameter at a plurality of respective times. For example, each data point may correspond to a state/value of the operational parameter at the respective time (e.g., the speed at the respective time, the degree a steering wheel is turned in a particular direction at the respective time, the degree of pressure on a brake pedal at the respective time, etc.). The operational data may be received in a manner similar to that described above (for sensor data) in connection with block **202** of method **200** (e.g., at a server remote from the vehicle, etc.), for example.

The method **220** also receives synchronization data indicating a temporal relationship between first plurality of data points received at block **222** and the second plurality of data points received at block **224** (block **226**). The synchronization data may be received in a manner similar to that described above (for sensor data) in connection with block **202** of method **200** (e.g., at a server remote from the vehicle, etc.), for example. In one embodiment, the synchronization data includes data indicating which of the first plurality of data points (in the sensor data) corresponds to which of the second plurality of data points (in the operational data). For example, a data collection unit at the vehicle may sample data points of sensor data and data points of operational data at the same times, and store each pair of data points in a relational database that links each pair of data points together to indicate that those data points correspond to a same time. With reference to FIG. **1**, for example, data collection unit **50** may, at the same time, sample a data point of sensor data from external sensor **30** or **32**, and a data point of operational data from one of subsystems **40**, **42**, **44** or **46**, and store the pair of sampled data points in a relational database in memory **52**.

In another embodiment, the synchronization data includes a first plurality of time stamps that each correspond to a respective one of the first plurality of data points, and a second plurality of time stamps that each correspond to a respective one of the second plurality of data points. For example, each sensor that generates sensor data at the vehicle, and each subsystem that generates operational data at the vehicle, may generate and provide time stamps that indicate which sets of data (i.e., which data points) correspond to which times. Referring again to FIG. **1**, for example, external sensors **30**, **32** and one or more of subsystems **40**, **42**, **44** and **46** may generate time stamps for each data point generated by the sensor or subsystem, provide those time stamps to data collection unit **50** for storage (along with the data points themselves) in memory **52**.

The method **220** also stores the sensor data received at block **222**, the operational data received at block **224**, and the synchronization data received at block **226** in a memory (block **230**). The sensor data, operational data, and synchronization data may be stored in memory **72** of FIG. **1**, for example.

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The method **220** retrieves the stored sensor data, operational data, and synchronization data from memory, and uses the retrieved data to generate a virtual model of an event involving the vehicle (blocks **232**, **234** and **236**). More specifically, the method **220** uses the first plurality of data points to generate a visual representation of the plurality of respective states of the environment external to the vehicle (block **232**), uses the second plurality of data points to generate a visual representation of the plurality of respective states of the operational parameter (block **234**), and uses the synchronization data to cause the visual representations generated at blocks **232** and **234** to be simultaneously displayed such that the two visual representations are time-aligned (block **236**).

The visual representation of the plurality of respective states of the environment external to the vehicle (block **232**) generally provides a visualization of the event (e.g., accident) being re-created. In one straightforward example where the sensor data is data from a video camera, lidar, or other sensor device located on or in the vehicle, the visual representation of the states of the external environment may simply be the captured frames (e.g., video frames), with each frame being generated using a single data point of the first plurality of data points. In another example embodiment, the visual representation is instead an animated recreation having a perspective that need not align with the perspective of the sensor that captured the data (e.g., a perspective from above the event, the perspective of a driver of the vehicle on or in which the sensor is located, etc.).

The visual representation of the plurality of respective states of the operational parameter (block **234**) generally provides a visual indication (e.g., a number, word, alphanumeric code, bar graph, etc.) of the status of the operational parameter at the times corresponding to each of the second plurality of data points. In one embodiment where the operational data was provided by a subsystem that controls or monitors speed of the vehicle (e.g., speed subsystem **42** of FIG. **1**), for example, the visual representation of the states of the operational parameter may be a number, a needle position on a virtual speedometer, or another indicator, with each value/position of the visual indicator being generated using a single data point of the second plurality of data points.

Using the synchronization data to cause the visual representations generated at blocks **232** and **234** to be simultaneously displayed such that the two visual representations are time-aligned involves different techniques in different embodiments. In one embodiment where the synchronization data includes time stamps for each of the first plurality of data points and for each of the second plurality of data points, for example, the method **220** reads the time stamp values to align the corresponding frames of the visual representation generated at block **232** with the operational parameter states/values of the visual representation generated at block **234**. In embodiments and scenarios where the time stamp values of the first plurality of data points do not exactly match the time stamp values of the second plurality of data points, any suitable algorithm or rule may be used to determine a “best match” between data points, such as associating those data points that are closest in time.

In another embodiment, where the synchronization data includes data (e.g., data associated with a relational database) that links pairs of data points that were sampled at substantially the same time, the method **220** uses the linkage data to determine which frames of the visual representation generated at block **232** are to be displayed with which of the

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operational parameter states/values of the visual representation generated at block **234**.

The visual representations may be displayed to a user of an electronic processing system implementing the method **220** (e.g., the insurer’s computer system **16** of FIG. **1**) on a monitor or smartphone touchscreen, for example. The method **220** may cause the visual representations to be displayed in any of various different ways. In one embodiment, for example, the method **220** causes the visual representations to be displayed by sending video data to a video processing card (or other video processing unit) coupled to a monitor or screen. In another embodiment, the method **220** causes the visual representations to be displayed by sending a command to another unit or processing system, either automatically or in response to a user input.

One example of the simultaneous display of the first and second visual representations is provided above with reference to FIGS. **2** and **3**. In the example of FIG. **3**, the first visual representation of method **220** is an animated recreation that includes the representation of the vehicles **152** and **154A-154C**, the intersection **160**, and the traffic lights **162A**, **162B**, while the second visual representation of method **220** includes the representation of the speed (“34 mph”) in the indicators **170**. Synchronized displays of this sort may allow a viewer to visualize an event such as an accident, while also viewing precise metrics (e.g., vehicle speed, vehicle warning codes, etc.) that provide a more complete understanding of how the event occurred (e.g., who was at fault) and/or the likely outcome of the event (e.g., an amount of damage or injury).

In some embodiments, the blocks of method **220** are performed in an order different than that shown in FIG. **5**. For example, blocks **222**, **224** and/or **226** may occur in a different order, or may occur at least in part simultaneously. As another example, blocks **232** and **234** may be performed at least in part simultaneously with block **236** (e.g., as parts of a single software operation as executed by a processor). Further, in some embodiments, the method **220** includes additional blocks. In one embodiment where the visualized event is an accident, for example, the method **220** also determines fault for the accident based on the virtual model, and/or determines damages resulting from the accident based on the virtual model (e.g., as determined by a user viewing a display of the virtual model, or as determined automatically based on various processing algorithms).

As another example, in an alternative embodiment, the method **220** also receives, and stores in the memory, additional operational data that is generated by another unit arranged within the same vehicle, where the additional operational data is indicative of a different operational parameter of the vehicle. The additional operational data may include a third plurality of data points indicative of a plurality of respective states of the additional operational parameter at a plurality of respective times, for example. In this embodiment, the synchronization data received at block **226** may indicate a temporal relationship between the first, second and third plurality of data points, and the method **220** may further generate a third visual representation that is a representation of the plurality of respective states of the additional operational parameter (e.g., a visual indication of braking pressure, a visual indication that a conventional cruise control system is active or not active, a visual indication that a fully automated/machine driving system is active or not active, etc.). The synchronization data may then be used to cause the first, second and third visual representations to be simultaneously displayed such that all three visual representations are time-aligned. In FIG. **3**, for

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example, the first visual representation includes the representation of the vehicles **152** and **154A-154C**, the intersection **160**, and the traffic lights **162A**, **162B**, the second visual representation includes the representation of the speed (“34 mph”) in the indicators **170**, and the third visual representation includes the representation of whether the cruise control system is activated (“OFF”) in the indicators **170**.

Referring next to FIG. 6, an example method **240** is implemented in whole or in part by the insurer’s computer system **16** of FIG. 1. Alternatively, or additionally, in an embodiment, the method **240** is implemented at least in part by the onboard system **14** of FIG. 1.

Like method **220** of FIG. 5, the method **240** receives sensor data representing information collected by a sensor located on or in a vehicle and configured to sense an environment external to the vehicle (block **242**), operational data generated by a unit that is arranged within the vehicle and indicative of an operational parameter of the vehicle (block **244**), and synchronization data indicating a temporal relationship between the first plurality of data points received at block **242** and the second plurality of data points received at block **244** (block **246**), and stores the sensor data, operational data and synchronization data in a memory (block **250**). Blocks **242**, **244**, **246** and **250** are the same as blocks **202**, **204**, **206** and **210**, respectively, of method **220**, in an embodiment.

The method **240** retrieves the first plurality of data points, the second plurality of data points, and the synchronization data from memory, and uses that data to generate an animated re-creation of an event involving at least one vehicle (block **252**). The event may be an accident, for example, and may involve the vehicle on or in which the sensor is located, and/or one or more other vehicles. Whereas the method **220** of FIG. 5 relates to an embodiment where sensor data and operational data are used to generate visually distinct representations (e.g., captured frames or an animated re-creation as generated from the sensor data, versus an indicator of an operational parameter as generated from the operational data), the method **240** jointly uses the first plurality of data points, the second plurality of data points, and the synchronization data to generate an animated re-creation. In one embodiment, for example, data representing an operational parameter such as vehicle speed or steering is used to fill gaps in the information provided by the sensor data. In one scenario where an external sensor experiences an outage (e.g., is temporarily blocked or disabled), for example, speed, braking and/or steering data may be used to estimate where the vehicle is in relation to other vehicles or objects during the outage. In another embodiment, data representing an operational parameter is instead (or additionally) used to confirm features of the animated re-creation that are initially determined based on the sensor data. In one scenario where an external sensor provides sensor data that indicates a particular closing speed between the vehicle and another vehicle with less than 100% certainty, for example, speed data may be used to confirm the initial estimate of the closing speed, or to refine the initial estimate of the closing speed.

As with the method **220**, the synchronization data (e.g., time stamps, or data pertaining to a relational database, etc.) is used to ensure that the first plurality of data points (sensor data) and second plurality of data points (operational data) are time-aligned. In this manner, misalignment issues in the animated re-creation, such as instances where the sensor data suggests a sequence of vehicle positions that conflicts with the sequence of vehicle positions suggested by one or more operational parameters, may be avoided.

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The method **240** also causes the animated re-creation of the event to be displayed (block **254**). The animated re-creation may be displayed to a user of an electronic processing system implementing the method **240** (e.g., the insurer’s computer system **16** of FIG. 1) on a monitor or smartphone touchscreen, for example. The method **240** may cause the animated re-creation to be displayed in any of various different ways. In one embodiment, for example, the method **240** causes the animated re-creation to be displayed by sending video data to a video processing card (or other video processing unit) coupled to a monitor or screen. In another embodiment, the method **240** causes the animated re-creation to be displayed by sending a command to another unit or processing system, either automatically or in response to a user input.

In some embodiments, the blocks of method **240** are performed in an order different than that shown in FIG. 6. For example, blocks **242**, **244** and/or **246** may occur in a different order, or may occur at least in part simultaneously. Further, in some embodiments, the method **240** includes additional blocks. In one embodiment where the visualized event is an accident, for example, the method **240** also determines fault for the accident based on the animated re-creation, and/or determines damages resulting from the accident based on the animated re-creation (e.g., as determined by a user viewing a display of the animated re-creation, or as determined automatically based on various processing algorithms).

While the methods **220** and **240** of FIGS. 5 and 6, respectively, have been described with respect to synchronization of sensor data and operational data, in other embodiments the sensor data is instead synchronized with (or is also synchronized with) data representing information that the vehicle received from an external source via a wireless link (e.g., using V2V, V2I, V2P or other similar technologies). With respect to method **220**, for example, the data representing the external source information may be received at block **224**, stored at block **230**, and used to generate a visual representation of a plurality of states (e.g., current weather/visibility conditions, current locations, current speed limits, etc.) at block **234**, with the visual representations being simultaneously displayed with the other visual representations (corresponding to external sensor data) at block **236** in the manner described above. With respect to method **240**, the data representing the external source information may be received at block **244**, stored at block **250**, and used (with the external sensor data and synchronization data) to generate the animated re-creation of the event at block **252** in the manner described above.

As discussed above in connection with FIG. 1, in some embodiments, external sensors of a first vehicle may be used to gather information about a different, second vehicle. In order to be useful to the insurance provider, however, information of that sort may generally include information that serves to identify the second vehicle. Accordingly, FIG. 7 is a flow diagram of an example method **260** of utilizing external vehicle sensor data to determine an identifying characteristic of another vehicle. In an embodiment, the method **260** is implemented in whole or in part by the insurer’s computer system **16** of FIG. 1. Alternatively, or additionally, in an embodiment, the method **260** is implemented at least in part by the onboard system **14** of FIG. 1.

The method **260** receives sensor data representing information collected by a sensor located on or in a first vehicle and configured to sense an environment external to the first vehicle (block **262**). Block **262** may be similar to block **202** of method **200**, for example. The method **260** also stores the

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sensor data received at block 262 in a memory (block 264). Block 264 may be similar to block 204 of method 200, for example.

The method 260 retrieves the sensor data from memory, and uses the sensor data to determine an identifying characteristic of the second vehicle (block 266). The identifying characteristic is a fixed or semi-fixed physical property of the second vehicle, rather than a transient condition such as current vehicle speed or location. In one embodiment, for example, a license plate number of the second vehicle is determined. Alternatively, or additionally, a make, model, year, and/or color of the second vehicle may be determined, and/or the state in which the second vehicle is registered may be determined. In an embodiment where the sensor located on or in the first vehicle is a camera (e.g., video camera), for example, the method 260 may utilize image processing to determine the identifying characteristic (e.g., by reading the number and/or state from a license plate of the second vehicle, etc.).

In some embodiments, the method 260 includes additional blocks. In one embodiment, for example, the method 260 also accesses a memory to determine, based on the identifying characteristic determined at block 266, whether the second vehicle is an insured vehicle, and/or whether a particular insurer provides insurance for the second vehicle (e.g., to help the insurer target its advertising to those in need of insurance). In another example embodiment, the method 260 generates a virtual model of an accident involving the second vehicle (and possibly the first vehicle and/or one or more other vehicles) using the sensor data stored at block 264. The virtual model may be generated in accordance with any of method 200, 220 and/or 240, for example. The method 260 may then further determine, based on the virtual model, fault for the accident and/or damages resulting from the accident (e.g., as determined by a user viewing a display of the virtual model, or as determined automatically based on various processing algorithms), and/or may cause the virtual model to be displayed (e.g., by sending data representing the virtual model to a video processing card, or sending a command to another unit or computing system, etc.). If the driver of the second vehicle is determined to be at fault for an accident, identifying characteristics of the second vehicle determined at block 266 may be used to help identify the responsible party. In still another embodiment, the method 260 causes data representing the identifying characteristic of the second vehicle to be sent to an electronic claims processing system (e.g., by providing the data to a network interface card, etc.).

As discussed above in connection with FIG. 1, risk level for a driver of a vehicle is determined in some embodiments, which may involve the use of predictive models. The predictive models may utilize correlations between data obtained from external vehicle sensors (in conjunction with operational data from the vehicles, in some embodiments) and probabilities of incurring losses recognizable under an insurance policy. FIG. 8 is a block diagram of an example system 300 for identifying such correlations. FIG. 8 depicts the same correlation data 90 as shown in FIG. 1, as well as portions of the insurer's computer system 16 not shown in FIG. 1.

In the example system 300, each of vehicles 302A-302C is equipped with one or more external sensors and, in some embodiments, with one or more subsystems for controlling and/or monitoring operational parameters of the respective vehicle. Each of vehicles 302A-302C may carry an onboard system similar to onboard system 14 of FIG. 1, for example. While FIG. 8 shows the collection of data from only three

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vehicles, other scenarios may involve collecting data from a very large number of vehicles (e.g., thousands or millions of vehicles).

Vehicle data from the vehicles 302A-302C (e.g., data from sensors similar to external sensors 30, 32 and/or subsystems 40, 42, 44, 46, 48) is sent to the insurer's computer system 16 via a network 320, which may be similar to (or include) the network 20 of FIG. 1. In some embodiments, the vehicle data also includes data representing information that one or more of the vehicles 302A-302C received from external sources via wireless signals (e.g., using V2X technology). In various embodiments and/or scenarios, the vehicle data from vehicles 302A-302C is uploaded to the insurer's computer system 16 at times corresponding to particular events (e.g., in response to onboard systems of vehicles 302A-302C detecting accidents involving the respective vehicles), on a regular basis (e.g., once per day, month, billing cycle, etc.), on a substantially real-time basis (e.g., as data is collected by sensors and/or subsystems of vehicles 302A-302C), etc. In an alternative embodiment, data from one or more of vehicles 302A-302B is carried to the insurer's computer system 16 via portable memory devices, or via a combination of portable memory devices and wireless networks (e.g., in embodiments where field agents use portable memory devices to download vehicle data to a portable computer that transmits the data to the insurer's computer system 16).

The insurer's computer system 16 stores the vehicle data from vehicles 302A-302C in a memory 330. The insurer's computer system 16 also has access to claims data of policy holders associated with the vehicles 302A-302C, which is stored in a memory 332 and corresponds to at least some of the same time periods as the vehicle data in memory 330. The claims data in memory 332 indicates actual instances of past losses under the various insurance policies of the policy holders, along with associated information such as the date of the loss, the type of loss, amounts paid to the policy holders due to the loss, etc. An insurance rating server 340 in the insurer's computer system 16 may retrieve the claims data from the memory 332 and the collected vehicle data from the memory 330, and utilize the retrieved data to identify particular patterns in the vehicle data that exhibit strong correlations with contemporaneous losses identified in the claims data, and/or particular patterns in the vehicle data that exhibit strong correlations with an absence of losses (or only minor losses, etc.). For example, the insurance rating server 340 may determine that losses are more frequent and/or larger for vehicles that are often driven in rainy or snowy weather (e.g., as detected by external sensor data), or for vehicles that are often driven at high speeds with only a small forward distance to another vehicle (e.g., as detected by a combination of external sensor data and speed data), etc. As another example, the insurance rating server 340 may determine that losses are less frequent and/or smaller for vehicles that are often driven in an automated/machine driving mode.

The insurance rating server 340 may generate correlation models based on the identified patterns and correlations, which may then be used with the vehicle data of an individual policy holder in order to determine a risk indicator for the policy holder (e.g., to be used in determining an insurance rating and/or premium for the policy holder), as discussed above in connection with FIG. 1. Generally, the correlation models may serve as a more reliable predictor of losses when vehicle data is collected from a larger number of vehicles 302 and/or over a longer period of time. In an embodiment, however, vehicle data is only collected from a

particular vehicle if a policy holder associated with that vehicle has opted in to a program. For example, the insurance rating server **340** may only collect vehicle data (or, alternatively, only use previously collected vehicle data) from the vehicles of those policy holders who have opted into a premium discount program. In an embodiment, the correlation data omits any user-identifiable data in order to help preserve anonymity.

As discussed above in connection with FIG. 1, risk indicators may be generated over time in order to adjust a premium of an existing/current policy holder, in some embodiments. FIG. 9 is a flow diagram of an example method **360** of utilizing external vehicle sensor data to determine risk indicators that may vary over time. In an embodiment, the method **360** is implemented at least in part by the onboard system **14** of FIG. 1. Alternatively, or additionally, in an embodiment, the method **360** is implemented in whole or in part by the insurer's computer system **16** of FIG. 1.

The method **360** receives first sensor data representing information that was collected, during a first time period, by a sensor configured to sense an environment external to the vehicle (block **362**). The sensor is located on or in a vehicle associated with an existing insurance policy, and may be a device similar to that discussed above in connection with block **202** of method **200** (e.g., camera device, lidar device, etc.), for example. The first time period may be any suitable time period, such as one minute, one hour, one day, one week, one month, one quarter, one year, one billing cycle, etc. The first sensor data may be received by a unit within the vehicle (e.g., data collection unit **50** of FIG. 1), or in a manner similar to that described above in connection with block **202** of method **200** (e.g., at a server remote from the vehicle, etc.), for example. Moreover, the first sensor data may be data that was converted from other information generated by the sensor (e.g., as described above in connection with block **202** of method **200**). In some embodiments where the first sensor data is received by a unit within the vehicle (or by a portable device that removably couples to the vehicle), the first sensor data may be received via a CAN bus. For example, the first sensor data may be included in a CAN bus message that was generated by a sensor device or sensor controller. In an embodiment, the first sensor data is received substantially in real-time (e.g., substantially as the data is generated by the sensor).

The method **360** also stores the first sensor data received at block **362** in a memory (block **364**). Block **364** may be similar to block **204** of method **200**, for example. The method **360** then retrieves the first sensor data from memory, and processes the first sensor data to determine a first set of one or more characteristics of the environment external to the vehicle (block **366**). In some embodiments where the first sensor data is received substantially in real-time at block **362**, the first set of characteristics is also determined substantially in real-time. The first set of characteristics corresponds to the first time period, i.e., the characteristics correspond to the external environment as sensed by the sensor during the first time period. For example, the determined characteristics may include an orientation of the vehicle with respect to another object (e.g., another vehicle, and/or a traffic light, stop sign or other traffic control indicator) during the first time period. As another example, the characteristics may include a closing speed between the vehicle and another object during the first time period. As another example, the characteristics may include a condition of a driving surface during the first time period. As yet another example, the characteristics may include visibility

conditions (e.g., a visibility range, or whether snowy or rainy conditions exist, etc.) during the first time period. In some embodiments, the characteristics also include temporal information, such as a duration of at least one other characteristic. For example, the first set of characteristics may include both visibility information (e.g., an indication of the severity of poor visibility conditions) and duration information associated with the visibility information (e.g., the length of time that visibility was below a particular threshold).

The method **360** also determines, based on the first set of characteristics determined at block **366**, a first risk indicator representing a risk of loss associated with the vehicle during the first time period (block **370**). For example, the first risk indicator may indicate a relatively high risk of loss if the vehicle was driven in poor visibility conditions (e.g., below a threshold visibility range) for a long amount of time (e.g., above a threshold percentage of driving time) during the first time period. As another example, the first risk indicator may indicate a relatively high risk of loss if the vehicle was driven during the first time period such that the average following distance behind other vehicles was small (e.g., below a threshold distance). As yet another example, the first risk indicator may indicate a relatively low risk of loss if the vehicle was driven only on streets in good condition (e.g., having at least a threshold degree of smoothness, as detected by processing of lidar or sonar data, etc.) during the first time period.

In some embodiments where the first sensor data is received substantially in real-time at block **362**, and the first set of characteristics is determined substantially in real-time at block **366**, the first risk indicator is also determined substantially in real-time (e.g., immediately at the end of the first time period). Moreover, the first risk indicator may include a plurality of risk indices that correspond to a plurality of respective time periods within the first time period. For example, in an embodiment where the first time period is a one-month period, the method **360** may generate risk indices every hour during that month, or every hour that the vehicle is driven during that month. In this manner, the sensor data used to determine the risk indices, and the data representing the determined environmental characteristics on which the risk indices are based, can be deleted on a regular basis, and data storage requirements (e.g., at the vehicle) may be greatly reduced.

The method **360** also receives second sensor data representing information collected, during a second time period, by the sensor (block **372**). Block **372** may be similar to block **362**, for example, except that the second time period is later than the first time period. In some embodiments, the second time period has the same length as the first time period, and/or immediately follows the first time period.

The method **360** also stores the second sensor data received at block **372** in the memory (block **374**). Block **374** may be similar to block **364**, for example. The method **360** then retrieves the second sensor data from memory, and processes the second sensor data to determine a second set of one or more characteristics of the environment external to the vehicle (block **376**). Block **376** may be similar to block **366**, for example. The second set of characteristics, however, will generally differ from the first set of characteristics, so long as the external environment of the vehicle changes between the first and second time periods.

The method **360** also determines, based on the second set of characteristics determined at block **376**, a second risk indicator representing a risk of loss associated with the vehicle during the second time period (block **380**). Block

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**380** may be similar to block **370**, for example. The second risk indicator may differ from the first risk indicator, however, depending on whether the environment in which the vehicle has been driven has changed sufficiently between the first and second time periods.

In some embodiments, some of the blocks of method **360** are performed in an order different than that shown in FIG. **9**. For example, block **366** may be performed simultaneously with block **376**, and/or block **370** may be performed simultaneously with block **380**. Further, in some embodiments, the method **360** includes additional blocks. In one embodiment where sensor data is received at an electronic processing system within the vehicle, for example, the method **360** also causes data representing the first risk indicator to be wirelessly transmitted from the vehicle to a server, and causes data representing the second risk indicator to be wirelessly transmitted from the vehicle to the server. At the server, the data representing the first risk indicator and the data representing the second risk indicator may then be used to determine a first premium and a second premium, respectively, associated with the existing insurance policy (e.g., by calculating the premiums directly from the risk indicators, or by first determining insurance ratings based on the risk indicators, etc.). The first premium may be a premium to be billed to the driver of the vehicle during a first billing cycle, and the second premium may be a premium to be billed to the driver of the vehicle during a subsequent, second billing cycle, for example. Alternatively, both the first and the second risk indicator (and possibly additional risk indicators) may be used at the server to determine a single premium associated with the existing insurance policy.

In another embodiment, the method **360** also receives operational data that is indicative of operation, during the respective time period, of the vehicle, and stores the operational data (e.g., velocity of the vehicle, acceleration of the vehicle, rotational and translational G-forces of the vehicle, status of an automated driving system of the vehicle, diagnostics information associated with the vehicle, etc.) in the memory. In this embodiment, the method **360** may determine the first set of characteristics based not only on the first sensor data, but also on operational data indicative of operation of the vehicle during the first time period. For example, one of the characteristics may be an average following distance determined using the first sensor data, and another one of the characteristics may be an average velocity of the vehicle. Similarly, the method **360** may determine the second set of characteristics based not only on the second sensor data, but also on operational data indicative of operation of the vehicle during the second time period. In some embodiments in which operational data is received by a unit within the vehicle (or by a portable device that removably couples to the vehicle), the operational data may be received via a CAN bus (e.g., in the form of one or more CAN bus messages generated by one or more vehicle subsystems), and/or via one or more OBD ports.

In another embodiment, the method **360** also receives data that represents information that the vehicle received from an external source via a wireless link (e.g., using V2X technology), and is indicative of the state or location of one or more objects (e.g., locations of pedestrians, cyclists, vehicles or other objects, traffic light states, street configurations, etc.), and/or is indicative of one or more environmental conditions (e.g., weather, visibility, etc.), during the respective time period, and stores the data in the memory. In this embodiment, the method **360** may determine the first set of characteristics based not only on the first sensor data, but also on the data representing the external source information

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corresponding to the first time period. For example, one characteristic that is determined based on the external source information may be the number and/or locations of pedestrians (and/or cyclists, etc.) in close proximity to the vehicle. Similarly, the method **360** may determine the second set of characteristics based not only on the second sensor data, but also on data representing information that the vehicle received from an external source via a wireless link (e.g., additional V2X signals) during the second time period.

While risk indicators may be based on any of various different factors, one factor that may predict risk particularly well is the degree of automated operation/driving of the vehicle. For example, fully automated/machine driving may be significantly safer than human driving, and/or partially automated driving (e.g., utilizing a conventional cruise control system) may be significantly safer, or significantly less safe, than human driving. Such correlations may be learned using the system **300** of FIG. **8**, for example. FIG. **10** is a flow diagram of an example method **400** of utilizing an indication of automated versus human driving to determine risk for insurance rating purposes. In an embodiment, the method **400** is implemented at least in part by the onboard system **14** of FIG. **1**. Alternatively, or additionally, in an embodiment, the method **400** is implemented in whole or in part by the insurer's computer system **16** of FIG. **1**.

The method **400** receives operational data indicative of when a vehicle is driven according to an automated control mode in which an automated driving system of the vehicle is active (block **402**). The operational data may be data that was directly generated by one or more subsystems of the vehicle, data that was converted from other information (e.g., other data or analog signals) generated by one or more subsystems of the vehicle, and/or data that was generated in response to the direct detection of one or more manual or machine inputs that control operation of the vehicle, for example.

The operational data may be received at a unit arranged within the vehicle, such as the data collection unit **50** or the data collection unit **70** of FIG. **1**, for example. Moreover, the operational data may be received from one or more subsystems arranged within the vehicle, such as one or more of subsystems **40**, **42**, **44** and **46** in FIG. **1**. In an alternative embodiment, the operational data is received at a server remote from the vehicle (e.g., a server configured in a manner similar to the insurer's computer system **16** of FIG. **1**) via a wireless communication network (e.g., network **20** of FIG. **1**) or a portable memory device, for example.

In an embodiment, the automated driving system is any hardware, firmware and/or software that controls, or partially controls, the velocity, braking, and/or steering of the vehicle. For example, the automated control mode may be a conventional cruise control mode in which a velocity control system is active, an assisted braking mode in which a braking control system is active, or an assisted steering mode in which a steering control system is active. The operational data may be generated by a braking subsystem such as braking subsystem **40** of FIG. **1**, a speed subsystem such as speed subsystem **42** of FIG. **1**, a steering subsystem such as steering subsystem **44** of FIG. **1**, and/or a diagnostics system such as diagnostics subsystem **46** of FIG. **1**, for example, or by a different subsystem of the vehicle. In some embodiments, the operational data additionally includes data indicative of other operational parameters of the vehicle, such as velocity and/or acceleration.

The method **400** also stores the operational data received at block **402** in a memory (block **404**), such as memory **52** or memory **72** of FIG. **1**, for example. The method **400** then

retrieves the operational data from memory and, based on the operational data, determines a risk indicator representing a risk of loss associated with the vehicle (block 406). The risk indicator may be determined based on a total length of time in which the vehicle is driven according to the automated control mode, and/or based on a percentage of time in which the vehicle is driven according to the automated control mode, for example. If the operational data is also indicative of other operational parameters of the vehicle, such as velocity and/or acceleration, the risk indicators may be determined based in part on those operational parameters as well. In some embodiments, the determined risk indicator comprises a plurality of risk indices corresponding to a plurality of respective time periods.

In some embodiments, the method 400 includes additional blocks not shown in FIG. 10. In one embodiment where the operational data is received at a unit arranged within the vehicle, for example, the method 400 also causes data representing the determined risk indicator to be wirelessly transmitted from the vehicle to a server, where the data may then be used to determine an insurance rating and/or premium associated with the vehicle. In another embodiment, the method 400 also receives sensor data representing information collected by a sensor that is located on or in the vehicle and configured to sense an environment external to the vehicle (e.g., similar to block 202 of method 200). In this embodiment, the method 400 further stores the received sensor data in a memory, and the risk indicator is determined based not only on the operational data, but also the stored sensor data (e.g., in a manner similar to that discussed above in connection with method 360 of FIG. 9).

As discussed above in connection with FIG. 1, in some embodiments, advertising is targeted to particular drivers based on the determined habits or preferences of those drivers. FIG. 11 is a flow diagram of an example method 480 of utilizing data indicative of location, route, and/or operation of a vehicle for targeted advertising purposes. In an embodiment, the method 480 is implemented in whole or in part by the insurer's computer system 16 of FIG. 1. Alternatively, or additionally, in an embodiment, the method 480 is implemented at least in part by a computer system of a different entity than the insurer, such as any entity that may wish to advertise to the driver or owner of a vehicle.

The method 480 receives vehicle data indicative of a location or route of a vehicle, and/or indicative of operation of the vehicle (block 482). The vehicle data may be received at a unit arranged within a server remote from the vehicle, such as the data collection unit 70 of FIG. 1, for example. In one embodiment, the vehicle data is received via a wireless communication network (e.g., network 20 of FIG. 1). The vehicle data may include external sensor data (e.g., data generated by external sensor 30 and/or 32 of FIG. 1), data representing one or more operational parameters (e.g., data generated by one or more of subsystems 40, 42, 44 and 46 of FIG. 1), and/or location data (e.g., data generated by GPS subsystem 48 of FIG. 1), for example. The vehicle data may be data that was directly generated by the sensor(s) and/or subsystem(s), and/or data that was converted from other information (e.g., other data or analog signals) generated by the sensor(s) and/or subsystem(s), for example. In some embodiments, the vehicle data also includes data representing information that the vehicle received from an external source (e.g., using V2X technology).

In embodiments where the vehicle data is indicative of a location or route of the vehicle, the vehicle data may reflect specific locales visited by the driver/vehicle, such as particular restaurants, bars, retail stores, entertainment facilities

(e.g., movie theaters, sports stadiums, etc.), for example. Alternatively, the vehicle data may reflect general types/categories of locales visited by the driver/vehicle, without further identifying specific locations. The vehicle data may indicate the location or route in various different ways, according to different embodiments. In one embodiment where the vehicle data is location data generated by a GPS device located on or in the vehicle (e.g., GPS subsystem 48 in FIG. 1), for example, the location data may be used in conjunction with other map/directory information to match locations of the vehicle to particular known locations. In another example embodiment, where the vehicle data was generated by a camera or other external sensor device located on or in the vehicle (e.g., external sensor 30 in FIG. 1), the images provided by the data of the camera or other sensor may be processed to identify particular known locations.

In embodiments where the vehicle data is instead (or additionally) indicative of operation of the vehicle, the vehicle data may reflect any operational parameter of the vehicle, such as velocity, steering, diagnostics information, or whether an automated driving system is active, for example. The vehicle data may be data that was generated by one or more operational subsystems of the vehicle (e.g., subsystems 40, 42, 44 and/or 46 in FIG. 1), for example. In embodiments where the vehicle data instead (or additionally) includes data representing information that the vehicle had received from an external source (e.g., using V2X technology), the vehicle data may reflect the identity, type, status or location of any object(s) or locale(s) in the vicinity of the vehicle, or any environmental condition (e.g., weather, visibility, etc.), for example.

The method 480 also stores the vehicle data received at block 482 in a memory (block 484), which may be similar to memory 72 of FIG. 1, for example. The method 480 then retrieves the vehicle data from memory, and determines a habit or preference of the driver of the vehicle based on the vehicle data (block 486). In one embodiment where the vehicle data received at block 482 is indicative of routes taken by the vehicle, for example, the driver's habit or preference may be determined to be a preferred route that has been followed repeatedly by the vehicle (e.g., on a commute to or from work), a length of that route (e.g., in miles or minutes), a time at which that route is usually traveled, etc. As another example, in one embodiment where the vehicle data received at block 482 is indicative of locations of the vehicle, the driver's habit or preference may be determined to be a particular locale or type of locale that is repeatedly visited by the driver, a time at which the driver tends to visit that locale or type of locale, an amount of time spent at that locale or type of locale, etc. As yet another example, in one embodiment where the vehicle data received at block 482 is indicative of operation of the vehicle, the driver's habit or preference may be determined to be a habit or preference of the driver with respect to operation of the vehicle, such as a speed that the driver likes to drive, the manner in which the driver tends to steer or operate the brakes, how closely the driver tends to follow other vehicles, etc.

The method 480 also causes an advertisement to be selected based on the habit or preference determined at block 486 (block 490). The method 480 may cause the advertisement to be selected in various different ways according to different embodiments. In one embodiment, for example, the method 480 causes an indication of the habit or preference determined at block 486 to be sent to an advertising entity (e.g., an entity that desires to advertise its

service or product). The indication may be an email or other electronic message that describes the habit or preference, or that provides a code representing a particular class of habits or preferences, for example. In another example embodiment, the method **480** causes an indication of the habit or preference determined at block **486** to be provided to a computer system (e.g., a computer system owned by the insurer) that is configured to automatically select an advertisement based on the habit or preference.

Advertisement selection criteria may generally be determined based on previous market studies or correlation analyses. For example, it may become known that drivers who often take routes that avoid more congested traffic (e.g., on their daily commute to or from work), even at the expense of a longer commute time, tend to like or dislike certain types of products or services, and that drivers who instead take routes that result in a shorter commute time, even at the expense of more congestion, tend to like or dislike other products or services. As another, more intuitive example, it may be known that drivers who often stop at convenience stores tend to be more receptive to advertisements for other, nearby convenience stores, regardless of whether those particular convenience stores have been visited previously by the drivers. As yet another example, it may be known that drivers who have a particular driving style (e.g., heavy brake usage, frequently driving at a relatively high or low speed, etc.) tend to be more or less receptive to certain advertising styles. In this latter case, a single advertisement may be selected from a plurality of advertisements that are all directed to the same product or service.

In some embodiments, the method **480** includes additional blocks not shown in FIG. **11**. In one embodiment, for example, the method **480** also selects the advertisement based on the habit or preference determined at block **486**. In an embodiment where the method **480** is entirely performed within the insurer's computer system **16** of FIG. **1**, for example, the method **480** may select an advertisement for an insurance product or service based on the determined habit or preference. In some embodiments, the method **480** also causes the selected advertisement to be provided to the driver. For example, the method **480** may cause the advertisement to be provided to the driver while still driving in the vehicle (e.g., via internet radio), or via email for later viewing, etc.

FIG. **12** is a block diagram of an example computer system **500** on which a method may operate in accordance with any of the embodiments described above. The computer system **500** of FIG. **12** includes a computing device in the form of a computer **510**. Components of the computer **510** may include, but are not limited to, a processing unit **520**, a system memory **530**, and a system bus **521** that couples various system components including the system memory to the processing unit **520**. The system bus **521** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. By way of example, and not limitation, such architectures include the Industry Standard Architecture (ISA) bus, Micro Channel Architecture (MCA) bus, Enhanced ISA (EISA) bus, Video Electronics Standards Association (VESA) local bus, and Peripheral Component Interconnect (PCI) bus (also known as Mezzanine bus).

Computer **510** typically includes a variety of computer-readable media. Computer-readable media can be any available media that can be accessed by computer **510** and includes both volatile and nonvolatile media, and both removable and non-removable media. By way of example,

and not limitation, computer-readable media may comprise computer storage media and communication media. Computer storage media includes volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Computer storage media includes, but is not limited to, RAM, read only memory (ROM), EEPROM, FLASH memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical disk storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by computer **510**. Communication media typically embodies computer-readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism and includes any information delivery media. The term "modulated data signal" means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media includes wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, radio frequency (RF), infrared and other wireless media. Combinations of any of the above are also included within the scope of computer-readable media.

The system memory **530** includes computer storage media in the form of volatile and/or nonvolatile memory such as ROM **531** and RAM **532**. A basic input/output system (BIOS) **533**, containing the basic routines that help to transfer information between elements within computer **510**, such as during start-up, is typically stored in ROM **531**. RAM **532** typically contains data and/or program modules that are immediately accessible to, and/or presently being operated on by, processing unit **520**. By way of example, and not limitation, FIG. **12** illustrates operating system **534**, application programs **535**, other program modules **536**, and program data **537**.

The computer **510** may also include other removable/non-removable, volatile/nonvolatile computer storage media. By way of example only, FIG. **12** illustrates a hard disk drive **541** that reads from or writes to non-removable, nonvolatile magnetic media, a magnetic disk drive **551** that reads from or writes to a removable, nonvolatile magnetic disk **552**, and an optical disk drive **555** that reads from or writes to a removable, nonvolatile optical disk **556** such as a CD ROM or other optical media. Other removable/non-removable, volatile/nonvolatile computer storage media that can be used in the exemplary operating environment include, but are not limited to, magnetic tape cassettes, flash memory cards, digital versatile disks, digital video tape, solid state RAM, solid state ROM, and the like. The hard disk drive **541** is typically connected to the system bus **521** through a non-removable memory interface such as interface **540**, and magnetic disk drive **551** and optical disk drive **555** are typically connected to the system bus **521** by a removable memory interface, such as interface **550**.

The drives and their associated computer storage media discussed above and illustrated in FIG. **12** provide storage of computer-readable instructions, data structures, program modules and other data for the computer **510**. In FIG. **12**, for example, hard disk drive **541** is illustrated as storing operating system **544**, application programs **545**, other program modules **546**, and program data **547**. Note that these components can either be the same as or different from operating system **534**, application programs **535**, other program mod-



ules 536, and program data 537. Operating system 544, application programs 545, other program modules 546, and program data 547 are given different reference numbers in FIG. 12 to illustrate that, at a minimum, they are different copies. A user may enter commands and information into the computer 510 through input devices such as a keyboard 562 and cursor control device 561, commonly referred to as a mouse, trackball or touch pad. A monitor 591 or other type of display device is also connected to the system bus 521 via an interface, such as a graphics controller 590. In addition to the monitor 591, computers may also include other peripheral output devices such as printer 596, which may be connected through an output peripheral interface 595.

The computer 510 may operate in a networked environment using logical connections to one or more remote computers, such as a remote computer 580. The remote computer 580 may be a personal computer, a server, a router, a network PC, a peer device or other common network node, and typically includes many or all of the elements described above relative to the computer 510, although only a memory storage device 581 has been illustrated in FIG. 12. The logical connections depicted in FIG. 12 include a local area network (LAN) 571 and a wide area network (WAN) 573, but may also include other networks. Such networking environments are commonplace in hospitals, offices, enterprise-wide computer networks, intranets and the Internet.

When used in a LAN networking environment, the computer 510 is connected to the LAN 571 through a network interface or adapter 570. When used in a WAN networking environment, the computer 510 typically includes a modem 572 or other means for establishing communications over the WAN 573, such as the Internet. The modem 572, which may be internal or external, may be connected to the system bus 521 via the input interface 560, or via another appropriate mechanism. In a networked environment, program modules depicted relative to the computer 510, or portions thereof, may be stored in the remote memory storage device 581. By way of example, and not limitation, FIG. 12 illustrates remote application programs 585 as residing on memory device 581.

The communications connections 570, 572 allow the device to communicate with other devices. The communications connections 570, 572 are an example of communication media, as discussed above.

The methods of any of the embodiments described above (e.g., methods 200, 220, 240, 260, 360, 400, and/or 480) may be implemented wholly or in part using one or more computer systems such as the computer system 500 illustrated in FIG. 12. Referring generally to the embodiments of FIG. 1, for example, the computer 510 may be used as the insurer's computer system 16, with the various units 80, 82, 84 and 86 being instructions that are a part of application programs 535 stored in RAM 532 and/or application programs 545 stored in hard disk drive 541. For example, data from onboard system 14 may be received via a modem similar to the modem 572, which may in turn be coupled to a network similar to network 20 of FIG. 1. As another example, risk indicators generated by the risk determination unit 80 of FIG. 1 may be sent to a remote insurance rating system and/or remote billing system similar to the remote computer 580, where the data is stored on a memory device such as the memory storage device 581. As another example, the correlation data 90 may be provided to the insurer's computer system 16 of FIG. 1 as a removable memory source such as the nonvolatile magnetic disk 552 or the nonvolatile optical disk 556.

Some or all calculations performed in the embodiments described above (e.g., calculations for determining risk indicators, calculations for determining habits or preferences of a driver, etc.) may be performed by a computer such as the computer 510, and more specifically may be performed by a processor such as the processing unit 520, for example. In some embodiments, some calculations may be performed by a first computer such as the computer 510 while other calculations may be performed by one or more other computers such as the remote computer 580. The calculations may be performed according to instructions that are part of a program such as the application programs 535, the application programs 545 and/or the remote application programs 585, for example.

A computer such as the computer 510 may also cause any of the virtual models described in the above embodiments, such as animated re-creations of accidents involving vehicles, to be displayed to a user of the computer 510. For example, data may be sent over a video interface such as the video interface 590 in order to display the virtual model on an output device such as the monitor 591.

We claim:

1. A method in an electronic processing system comprising a memory and one or more processors, the method comprising:

receiving, at the electronic processing system, first operational data (i) generated by a first unit arranged within a vehicle and (ii) indicative of a first operational parameter of the vehicle, wherein receiving first operational data includes receiving a first plurality of data points indicative of a plurality of respective states of the first operational parameter at a plurality of respective times;

receiving, at the electronic processing system, external data that (i) was received by the vehicle from a mobile communication device of a pedestrian external to the vehicle via a wireless link and (ii) is indicative of objects sensed by the mobile communication device, wherein receiving external data includes receiving a second plurality of data points indicative of a plurality of respective states of an environment external to the vehicle at a plurality of respective times;

receiving, at the electronic processing system, synchronization data indicating a temporal relationship between the first plurality of data points and the second plurality of data points;

storing the received first operational data, the received external data, and the received synchronization data in the memory; and

generating, via the one or more processors, a virtual model of an event involving the vehicle using the stored first operational data, the stored external data, and the stored synchronization data, wherein generating the virtual model includes

generating, using the first plurality of data points, a first visual representation of the plurality of respective states of the first operational parameter,

generating, using the second plurality of data points, a second visual representation of the plurality of respective states of the environment external to the vehicle, and

using the synchronization data to cause the first visual representation to be displayed simultaneously with the second visual representation such that the first visual representation is time-aligned with the second visual representation.

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2. The method of claim 1, wherein receiving synchronization data includes receiving data indicating which of the first plurality of data points corresponds to which of the second plurality of data points.

3. The method of claim 1, wherein receiving synchronization data includes receiving:

- a first plurality of time stamps each corresponding to a respective one of the first plurality of data points; and
- a second plurality of time stamps each corresponding to a respective one of the second plurality of data points.

4. The method of claim 1, wherein receiving first operational data indicative of the first operational parameter of the vehicle includes receiving first operational data indicative of:

- velocity of the vehicle;
- acceleration of the vehicle;
- braking of the vehicle; or
- steering of the vehicle.

5. The method of claim 1, wherein receiving first operational data indicative of the first operational parameter of the vehicle includes receiving first operational data indicative of motion of the vehicle with respect to six degrees of freedom.

6. The method of claim 1, wherein receiving first operational data indicative of the first operational parameter of the vehicle includes receiving first operational data indicative of status of an automated driving system of the vehicle.

7. The method of claim 1, wherein receiving first operational data indicative of the first operational parameter of the vehicle includes receiving diagnostics information associated with the vehicle.

8. The method of claim 1, wherein generating the virtual model of an event involving the vehicle includes generating a virtual model of an accident involving the vehicle.

9. The method of claim 8, further comprising at least one of:

- determining fault for the accident based on the virtual model of the accident involving the vehicle; or
- determining damages resulting from the accident based on the virtual model of the accident involving the vehicle.

10. The method of claim 1, wherein:

the method further comprises

- receiving, at the electronic processing system, second operational data (i) generated by a second unit arranged within the vehicle and (ii) indicative of a second operational parameter of the vehicle, wherein receiving second operational data includes receiving a third plurality of data points indicative of a plurality of respective states of the second operational parameter at a plurality of respective times, and
- storing the received second operational data in the memory;

receiving synchronization data includes receiving synchronization data indicating a temporal relationship between the first plurality of data points, the second plurality of data points, and the third plurality of data points;

generating the virtual model of an event involving the vehicle further includes generating a third visual representation of the plurality of respective states of the second operational parameter; and

using the synchronization data to cause the first visual representation to be displayed simultaneously with the second visual representation includes using the synchronization data to cause the first visual representation

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to be displayed simultaneously with both the second visual representation and the third visual representation, such that the first visual representation is time-aligned with both the second visual representation and the third visual representation.

11. The method of claim 1, wherein receiving first operational data includes receiving first operational data at a server remote from the vehicle via one of (i) a wireless communication network, or (ii) a portable memory device.

12. An electronic processing system comprising:

a memory;

a data collection unit configured to

- receive first operational data (i) generated by a first unit arranged within a vehicle and (ii) indicative of a first operational parameter of the vehicle, wherein receiving first operational data includes receiving a first plurality of data points indicative of a plurality of respective states of the first operational parameter at a plurality of respective times,

receive external data that (i) was received by the vehicle from a mobile communication device of a pedestrian external to the vehicle via a wireless link and (ii) is indicative of objects sensed by the mobile communication device, wherein receiving external data includes receiving a second plurality of data points indicative of a plurality of respective states of an environment external to the vehicle at a plurality of respective times,

receive synchronization data indicating a temporal relationship between the first plurality of data points and the second plurality of data points, and

store the received first operational data, the received external data, and the received synchronization data in the memory; and

a model generation unit coupled to the data collection unit and configured to generate a virtual model of an event involving the vehicle using the stored first operational data, the stored external data, and the stored synchronization data, wherein generating the virtual model includes:

generating, using the first plurality of data points, a first visual representation of the plurality of respective states of the first operational parameter,

generating, using the second plurality of data points, a second visual representation of the plurality of respective states of the environment external to the vehicle, and

using the synchronization data to cause the first visual representation to be displayed simultaneously with the second visual representation such that the first visual representation is time-aligned with the second visual representation.

13. The electronic processing system of claim 12, wherein the synchronization data includes data indicating which of the first plurality of data points corresponds to which of the second plurality of data points.

14. The electronic processing system of claim 12, wherein the synchronization data includes both (i) a first plurality of time stamps each corresponding to a respective one of the first plurality of data points, and (ii) a second plurality of time stamps each corresponding to a respective one of the second plurality of data points.

15. The electronic processing system of claim 12, wherein the data collection unit is configured to receive first operational data indicative of:

- velocity of the vehicle;
- acceleration of the vehicle;

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braking of the vehicle;  
steering of the vehicle;  
diagnostics information associated with the vehicle; or  
status of an automated driving system of the vehicle.

16. A tangible, non-transitory, computer-readable medium 5  
storing instructions that, when executed by one or more  
processors, cause the one or more processors to:

store operational data, external data, and synchronization  
data in a memory, wherein

the operational data (i) was generated by a first unit 10  
arranged within a vehicle and (ii) is indicative of a  
first operational parameter of the vehicle, the opera-  
tional data including a first plurality of data points  
indicative of a plurality of respective states of the  
first operational parameter at a plurality of respective 15  
times,

the external data (i) was received by the vehicle from  
a mobile communication device of a pedestrian  
external to the vehicle via a wireless link and (ii) is 20  
indicative of objects sensed by the mobile commu-  
nication device, the external data including a second  
plurality of data points indicative of a plurality of  
respective states of an environment external to the  
vehicle at a plurality of respective times, and  
the synchronization data indicates a temporal relation- 25  
ship between the first plurality of data points and the  
second plurality of data points, and

generate a virtual model of an event involving the vehicle  
using the stored operational data, the stored external  
data, and the stored synchronization data, wherein  
generating the virtual model includes:

generating, using the first plurality of data points, a first  
visual representation of the plurality of respective  
states of the first operational parameter,

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generating, using the second plurality of data points, a  
second visual representation of the plurality of  
respective states of the environment external to the  
vehicle, and

using the synchronization data to cause the first visual  
representation to be displayed simultaneously with  
the second visual representation such that the first  
visual representation is time-aligned with the second  
visual representation.

17. The tangible, non-transitory, computer-readable  
medium of claim 16, wherein the synchronization data  
includes data indicating which of the first plurality of data  
points corresponds to which of the second plurality of data  
points.

18. The tangible, non-transitory, computer-readable  
medium of claim 16, wherein the synchronization data  
includes (i) a first plurality of time stamps each correspond-  
ing to a respective one of the first plurality of data points,  
and (ii) a second plurality of time stamps each correspond-  
ing to a respective one of the second plurality of data points.

19. The tangible, non-transitory, computer-readable  
medium of claim 16, wherein the operational data includes  
data indicative of:

velocity of the vehicle;  
acceleration of the vehicle;  
braking of the vehicle;  
steering of the vehicle;  
diagnostics information associated with the vehicle; or  
status of an automated driving system of the vehicle.

20. The tangible, non-transitory, computer-readable  
medium of claim 16, wherein the operational data includes  
data received at a server remote from the vehicle via one of  
(i) a wireless communication network, or (ii) a portable  
memory device.

\* \* \* \* \*