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Inventor(s)

Ancrum; Derek Beaulieu et al.

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### IDENTIFYING ROADWAY SAFETY EVENTS IN REMOTE VEHICLES

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#### Abstract

According to several aspects, a method for identifying roadway safety events may include performing a measurement of one or more target vehicles using a sensor. The method further may include identifying a safety event based at least in part on the measurement of the of one or more target vehicles. The method further may include performing an action based at least in part on the safety event.

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**Inventors:** Ancrum; Derek Beaulieu (Whitby, CA), Grimm; Donald K. (Utica, MI), Granda; Shawn F. (Warren, MI)

**Applicant:** GM Global Technology Operations LLC (Detroit, MI)

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#### Background/Summary

## INTRODUCTION

[0001] The present disclosure relates to systems and methods for identifying roadway safety events for a vehicle.

[0002] To increase occupant awareness and convenience, vehicles may be equipped with sensing and communication systems allowing for communication between vehicles on a roadway. Communication systems may be used to transmit information between vehicles, such as, for example, location, heading, velocity, and/or the like. Such information may be used to identify roadway safety events, such as, for example, heavy braking or near collisions. Vehicles may also be equipped with advanced driver assistance systems (ADAS) which enable the vehicle to notify the occupant and/or take action based on information related to roadway safety events. However, some vehicles may not be equipped with communication systems and thus may not have the capability to transmit information to other vehicles. Without information about remote vehicle location, heading, velocity and/or the like, performance and/or feature availability of the ADAS system may be reduced.

[0003] Thus, while sensing and communication systems and methods achieve their intended purpose, there is a need for a new and improved system and method for identifying roadway safety events for a vehicle.

## SUMMARY

[0004] According to several aspects, a method for identifying roadway safety events is provided. The method may include performing a measurement of one or more target vehicles using a sensor. The method further may include identifying a safety event based at least in part on the measurement of the one or more target vehicles. The method further may include performing an action based at least in part on the safety event.

[0005] In another aspect of the present disclosure, performing the measurement further may include performing the measurement of the one or more target vehicles. The sensor includes at least one of: a host vehicle sensor of a host vehicle, a mobile device, and a roadside unit (RSU). The measurement of the one or more target vehicles includes at least a target vehicle location of each of the one or more target vehicles and a target vehicle velocity of each of the one or more target vehicles.

[0006] In another aspect of the present disclosure, performing the measurement further may include performing the measurement of the one or more target vehicles. The sensor is the host vehicle sensor of the host vehicle.

[0007] In another aspect of the present disclosure, performing the measurement further may include extrapolating at least one of: the target vehicle location and the target vehicle velocity of a first target vehicle of the one or more target vehicles in response to determining that the first target vehicle is outside of a field of view of the sensor. The at least one of: the target vehicle location and the target vehicle velocity of the first target vehicle is extrapolated based at least in part on one or more past measurements of the first target vehicle.

[0008] In another aspect of the present disclosure, identifying the safety event further may include evaluating the measurement of the one or more target vehicles to identify a target-to-infrastructure safety event. Identifying the safety event further may include evaluating the measurement of the one or more target vehicles to identify a target-to-target safety event. Identifying the safety event further may include evaluating the measurement of the one or more target vehicles to identify an erratic driving safety event. Identifying the safety event further may include evaluating the measurement of the one or more target vehicles to identify an unobserved safety event.

[0009] In another aspect of the present disclosure, evaluating the measurement of the one or more target vehicles to identify the target-to-infrastructure safety event further may include evaluating the measurement of the one or more target vehicles based at least in part on one or more traffic regulations. Evaluating the measurement of the one or more target vehicles to identify the target-to-

infrastructure safety event further may include identifying the target-to-infrastructure safety event in response to determining that at least one of the one or more target vehicles is in violation of the one or more traffic regulations.

[0010] In another aspect of the present disclosure, evaluating the measurement of the one or more target vehicles to identify the target-to-infrastructure safety event further may include calculating a time-to-collision between a first target vehicle and a second target vehicle of the one or more target vehicles based at least in part on the measurement of the one or more target vehicles. Evaluating the measurement of the one or more target vehicles to identify the target-to-infrastructure safety event further may include identifying the target-to-target safety event in response to determining that the time-to-collision is less than or equal to a predetermined time-to-collision threshold.

[0011] In another aspect of the present disclosure, evaluating the measurement of the one or more target vehicles to identify the erratic driving safety event further may include executing an erratic driving identification machine learning model. The erratic driving identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the erratic driving safety event based at least in part on the measurement of the one or more target vehicles.

[0012] In another aspect of the present disclosure, evaluating the measurement of the one or more target vehicles to identify the unobserved safety event further may include executing an unobserved safety event identification machine learning model. The unobserved safety event identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the unobserved safety event based at least in part on the measurement of the one or more target vehicles. The unobserved safety event occurs outside of a field of view of the sensor.

[0013] In another aspect of the present disclosure, performing the action based at least in part on the safety event further may include providing an in-vehicle warning to an occupant. Performing the action based at least in part on the safety event further may include providing a navigation suggestion based at least in part on a quantity of safety events within a particular geographical area.

[0014] According to several aspects, a system for identifying roadway safety events for a host vehicle is provided. The system may include a remote server system including a server communication system. The system further may include a server controller in electrical communication with the server communication system. The server controller is programmed to receive a measurement of one or more target vehicles using the server communication system. The server controller is further programmed to identify a safety event based at least in part on the measurement of the one or more target vehicles. The server controller is further programmed to perform an action based at least in part on the safety event.

[0015] In another aspect of the present disclosure, to identify the safety event, the server controller is further programmed to evaluate the measurement of the one or more target vehicles to identify a target-to-infrastructure safety event. To identify the safety event, the server controller is further programmed to evaluate the measurement of the one or more target vehicles to identify a target-to-target safety event. To identify the safety event, the server controller is further programmed to evaluate the measurement of the one or more target vehicles to identify an erratic driving safety event. To identify the safety event, the server controller is further programmed to evaluate the measurement of the one or more target vehicles to identify an unobserved safety event.

[0016] In another aspect of the present disclosure, to identify the safety event, the server controller is further programmed to evaluate the measurement of the one or more target vehicles based at least in part on one or more traffic regulations. To identify the safety event, the server controller is further programmed to calculate a time-to-collision between a first target vehicle and a second target vehicle of the one or more target vehicles based at least in part on the measurement of the one or more target vehicles. To identify the safety event, the server controller is further programmed to identify the target-to-infrastructure safety event in response to determining that at

least one of the one or more target vehicles is in violation of the one or more traffic regulations. To identify the safety event, the server controller is further programmed to identify the target-to-target safety event in response to determining that the time-to-collision is less than or equal to a predetermined time-to-collision threshold.

[0017] In another aspect of the present disclosure, to evaluate the measurement of the one or more target vehicles to identify the erratic driving safety event, the server controller is further programmed to execute an erratic driving identification machine learning model. The erratic driving identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the erratic driving safety event based at least in part on the measurement of the one or more target vehicles.

[0018] In another aspect of the present disclosure, to evaluate the measurement of the one or more target vehicles to identify the unobserved safety event, the server controller is further programmed to execute an unobserved safety event identification machine learning model. The unobserved safety event identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the unobserved safety event based at least in part on the measurement of the one or more target vehicles.

[0019] In another aspect of the present disclosure, the system further includes a host vehicle system including a host vehicle communication system. The host vehicle system further includes a host vehicle sensor. The host vehicle system further includes a host vehicle controller in electrical communication with the host vehicle communication system and the host vehicle sensor. The host vehicle controller is programmed to perform a measurement of one or more target vehicles using the host vehicle sensor. The one or more target vehicles are remote from the host vehicle. The host vehicle controller is further programmed to transmit the measurement of the one or more target vehicles to the remote server system using the host vehicle communication system.

[0020] In another aspect of the present disclosure, to perform the action based at least in part on the safety event, the server controller is further programmed to transmit a safety event message to the host vehicle using the server communication system. The safety event message includes information regarding the safety event. The host vehicle system further may include a host vehicle display in electrical communication with the host vehicle controller. To perform the action based at least in part on the safety event, the host vehicle controller is further programmed to receive the safety event message from the remote server system using the host vehicle communication system. To perform the action based at least in part on the safety event, the host vehicle controller is further programmed to provide an in-vehicle warning to an occupant of the host vehicle using the host vehicle display based at least in part on the safety event message.

[0021] According to several aspects, a method for identifying roadway safety events is provided. The method may include performing a measurement of one or more target vehicles using a sensor. The sensor is remote from the one or more target vehicles. The sensor includes at least one of: a host vehicle sensor of a host vehicle, a mobile device, and a roadside unit (RSU). The measurement of the one or more target vehicles includes at least a target vehicle location of each of the one or more target vehicles and a target vehicle velocity of each of the one or more target vehicles. The method further may include identifying a safety event based at least in part on the measurement of the of one or more target vehicles. The safety event includes at least one of: a target-to-infrastructure safety event, a target-to-target safety event, an erratic driving safety event, and an unobserved safety event. The method further may include performing an action based at least in part on the safety event.

[0022] In another aspect of the present disclosure, performing the measurement further may include extrapolating at least one of: the target vehicle location and the target vehicle velocity of a first target vehicle of the one or more target vehicles in response to determining that the first target vehicle is outside of a field of view of the sensor. The at least one of: the target vehicle location and the target vehicle velocity of the first target vehicle is extrapolated based at least in part on one or

more past measurements of the first target vehicle.

[0023] In another aspect of the present disclosure, identifying the safety event further may include evaluating the measurement of the one or more target vehicles based at least in part on one or more traffic regulations. Identifying the safety event further may include identifying the target-to-infrastructure safety event in response to determining that the first target vehicle is in violation of the one or more traffic regulations. Identifying the safety event further may include calculating a time-to-collision between the first target vehicle and a second target vehicle based at least in part on the measurement of the one or more target vehicles. Identifying the safety event further may include identifying the target-to-target safety event in response to determining that the time-to-collision is less than or equal to a predetermined time-to-collision threshold. Identifying the safety event further may include executing an erratic driving identification machine learning model. The erratic driving identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the erratic driving safety event based at least in part on the measurement of the one or more target vehicles. Identifying the safety event further may include executing an unobserved safety event identification machine learning model. The unobserved safety event identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the unobserved safety event based at least in part on the measurement of the one or more target vehicles. The unobserved safety event occurs outside of the field of view of the sensor.

[0024] Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

[0026] FIG. 1 is a schematic diagram of a system for identifying roadway safety events, according to an exemplary embodiment;

[0027] FIG. 2 is a schematic diagram of a host vehicle system, according to an exemplary embodiment;

[0028] FIG. 3 is a flowchart of a method for identifying roadway safety events, according to an exemplary embodiment; and

[0029] FIG. 4 is a flowchart of a method for performing a measurement, according to an exemplary embodiment.

### DETAILED DESCRIPTION

[0030] The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

[0031] In aspects of the present disclosure, it is advantageous to collect data about vehicles on the roadway (e.g., location, heading, velocity, and/or the like). In some aspects, it is possible to retrieve such data directly from vehicles using wireless communications systems. However, in aspects of the present disclosure, some vehicles may not be equipped with the sensing and/or communication capabilities necessary to facilitate data collection. Therefore, the present disclosure provides a new and improved system and method for identifying roadway safety events by enabling collection of data about remote vehicles.

[0032] Referring to FIG. 1, a system for identifying roadway safety events is illustrated and generally indicated by reference number **10**. The system **10** generally includes a remote server system **12** and a host vehicle system **14** in a host vehicle **16**. The system **10** is shown in the

exemplary context of a roadway **18** including one or more target vehicles **20**. It should be understood that the roadway **18** may include any open way for passage and transportation of vehicles (e.g., roads, streets, highways, expressways, freeways, boulevards, avenues, parkways, alleys, bridges, tunnels, and/or the like). In the exemplary embodiment shown in FIG. **1**, the one or more target vehicles **20** includes a first target vehicle **20a** and a second target vehicle **20b**. It should be understood that the one or more target vehicles **20** may include any number of vehicles occupying the roadway **18**. The one or more target vehicles **20** may include, for example, sport utility vehicles (SUVs), sedans, compact cars, trucks, utility vehicles, and/or the like. In some examples, the one or more target vehicles may further include additional roadway users, such as, for example, pedestrians, bicycles, and/or the like.

[0033] The remote server system **12** includes a server controller **30** in electrical communication with a server database **32** and a server communication system **34**. In a non-limiting example, the remote server system **12** is located in a server farm, datacenter, roadside unit (RSU), or the like, and is connected to the internet.

[0034] The server controller **30** is used to implement a method **100** for identifying roadway safety events, as will be described below. The server controller **30** includes at least one server processor **36** and a non-transitory computer readable storage device or server media **38**. The server processor **36** may be a custom made or commercially available processor, a central processing unit (CPU), a graphics processing unit (GPU), an auxiliary processor among several processors associated with the server controller **30**, a semiconductor-based microprocessor (in the form of a microchip or chip set), a macroprocessor, a combination thereof, or generally a device for executing instructions. The computer readable storage device or server media **38** may include volatile and nonvolatile storage in read-only memory (ROM), random-access memory (RAM), and keep-alive memory (KAM), for example. KAM is a persistent or non-volatile memory that may be used to store various operating variables while the server processor **36** is powered down. The computer-readable storage device or server media **38** may be implemented using a number of memory devices such as PROMs (programmable read-only memory), EPROMs (electrically PROM), EEPROMs (electrically erasable PROM), flash memory, or another electric, magnetic, optical, or combination memory devices capable of storing data, some of which represent executable instructions used by the server controller **30** perform the method **100**. The server controller **30** may also consist of multiple controllers which are in electrical communication with each other.

[0035] The server controller **30** is in electrical communication with the server database **32** and the server communication system **34**. In an exemplary embodiment, the electrical communication is established using, for example, a CAN network, a FLEXRAY network, a local area network (e.g., WiFi, ethernet, and the like), a serial peripheral interface (SPI) network, or the like. It should be understood that various additional wired and wireless techniques and communication protocols for communicating with the server controller **30** are within the scope of the present disclosure.

[0036] The server database **32** is used to store information about the one or more target vehicles **20**, as will be discussed in greater detail below. The server database **32** may also store detailed maps of roadways, including, for example, information about lane boundaries, road geometry, speed limits, traffic signs, and/or other relevant features. In an exemplary embodiment, the server database **32** includes one or more mass storage devices, such as, for example, hard disk drives, magnetic tape drives, magneto-optical disk drives, optical disks, solid-state drives, and/or additional devices operable to store data in a persisting and machine-readable fashion. In some examples, the one or more mass storage devices may be configured to provide redundancy in case of hardware failure and/or data corruption, using, for example, a redundant array of independent disks (RAID). In a non-limiting example, the server controller **30** may execute software such as, for example, a database management system (DBMS), allowing data stored on the one or more mass storage devices to be organized and accessed. The server database **32** is in electrical communication with the server controller **30**, as discussed above.

[0037] The server communication system **34** is used by the server controller **30** to communicate with other systems external to the remote server system **12**. For example, the server communication system **34** includes capabilities for communication with vehicles, infrastructure, other remote systems at a remote call center (e.g., ON-STAR by GENERAL MOTORS) and/or personal devices. In certain embodiments, the server communication system **34** is a wireless communication system configured to communicate via a wireless local area network (WLAN) using IEEE 802.11 standards or by using cellular data communication (e.g., using GSM standards, such as, for example, SGP.02, SGP.22, SGP.32, and the like). Accordingly, the server communication system **34** may further include an embedded universal integrated circuit card (eUICC) configured to store at least one cellular connectivity configuration profile, for example, an embedded subscriber identity module (eSIM) profile.

[0038] The server communication system **34** is further configured to communicate via a personal area network (e.g., BLUETOOTH), near-field communication (NFC), and/or any additional type of radiofrequency communication. However, additional or alternate communication methods, such as a dedicated short-range communications (DSRC) channel and/or mobile telecommunications protocols based on the 3rd Generation Partnership Project (3GPP) standards, are also considered within the scope of the present disclosure. DSRC channels refer to one-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards. The 3GPP refers to a partnership between several standards organizations which develop protocols and standards for mobile telecommunications. 3GPP standards are structured as “releases”. Thus, communication methods based on 3GPP release 30, 15, 16 and/or future 3GPP releases are considered within the scope of the present disclosure.

[0039] Accordingly, the server communication system **34** may include one or more antennas and/or communication transceivers for receiving and/or transmitting signals. The server communication system **34** is configured to wirelessly communicate information between the remote server system **12** and at least the host vehicle **16**. It should be understood that the server communication system **34** may be integrated with the server controller **30** (e.g., on a same circuit board with the server controller **30** or otherwise a part of the server controller **30**) without departing from the scope of the present disclosure. The server communication system **34** is in electrical communication with the server controller **30**, as discussed above.

[0040] Referring to FIG. 2, a schematic diagram of the host vehicle system **14** is shown. The host vehicle system **14** is shown with the exemplary host vehicle **16**. While a passenger vehicle is illustrated, it should be appreciated that the host vehicle **16** may be any type of vehicle without departing from the scope of the present disclosure. The host vehicle system **14** generally includes a host vehicle controller **50**, a host vehicle communication system **52**, a host vehicle sensor **54**, and a host vehicle display **56**.

[0041] The host vehicle controller **50** is used in conjunction with the server controller **30** to implement the method **100** for identifying roadway safety events, as will be described below. The host vehicle controller **50** includes at least one host vehicle processor **58** and a non-transitory computer readable storage device or host vehicle media **60**. The host vehicle processor **58** may be a custom made or commercially available processor, a central processing unit (CPU), a graphics processing unit (GPU), an auxiliary processor among several processors associated with the host vehicle controller **50**, a semiconductor-based microprocessor (in the form of a microchip or chip set), a macroprocessor, a combination thereof, or generally a device for executing instructions. The computer readable storage device or host vehicle media **60** may include volatile and nonvolatile storage in read-only memory (ROM), random-access memory (RAM), and keep-alive memory (KAM), for example. KAM is a persistent or non-volatile memory that may be used to store various operating variables while the host vehicle processor **58** is powered down. The computer-readable storage device or host vehicle media **60** may be implemented using a number of memory devices such as PROMs (programmable read-only memory), EPROMs (electrically PROM),

EEPROMs (electrically erasable PROM), flash memory, or another electric, magnetic, optical, or combination memory devices capable of storing data, some of which represent executable instructions, used by the host vehicle controller **50** to control various systems of the host vehicle **16**. The host vehicle controller **50** may also consist of multiple controllers which are in electrical communication with each other. The host vehicle controller **50** may be inter-connected with additional systems and/or controllers of the host vehicle **16**, allowing the host vehicle controller **50** to access data such as, for example, speed, acceleration, braking, and steering angle of the host vehicle **16**.

[0042] The host vehicle controller **50** is in electrical communication with the host vehicle communication system **52**, the host vehicle sensor **54**, and the host vehicle display **56**. In an exemplary embodiment, the electrical communication is established using, for example, a CAN network, a FLEXRAY network, a local area network (e.g., WiFi, ethernet, and the like), a serial peripheral interface (SPI) network, or the like. It should be understood that various additional wired and wireless techniques and communication protocols for communicating with the host vehicle controller **50** are within the scope of the present disclosure.

[0043] The host vehicle communication system **52** is used by the host vehicle controller **50** to communicate with other systems external to the host vehicle **16** (e.g., the remote server system **12**). For example, the host vehicle communication system **52** includes capabilities for communication with vehicles (“V2V” communication), infrastructure (“V2I” communication), remote systems at a remote call center (e.g., ON-STAR by GENERAL MOTORS) and/or personal devices. In general, the term vehicle-to-everything communication (“V2X” communication) refers to communication between the host vehicle **16** and any remote system (e.g., vehicles, infrastructure, and/or remote systems). In certain embodiments, the host vehicle communication system **52** is a wireless communication system configured to communicate via a wireless local area network (WLAN) using IEEE 802.11 standards or by using cellular data communication (e.g., using GSM standards, such as, for example, SGP.02, SGP.22, SGP.32, and the like). Accordingly, the host vehicle communication system **52** may further include an embedded universal integrated circuit card (eUICC) configured to store at least one cellular connectivity configuration profile, for example, an embedded subscriber identity module (eSIM) profile.

[0044] The host vehicle communication system **52** is further configured to communicate via a personal area network (e.g., BLUETOOTH), near-field communication (NFC), and/or any additional type of radiofrequency communication. However, additional or alternate communication methods, such as a dedicated short-range communications (DSRC) channel and/or mobile telecommunications protocols based on the 3rd Generation Partnership Project (3GPP) standards, are also considered within the scope of the present disclosure. DSRC channels refer to one-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards. The 3GPP refers to a partnership between several standards organizations which develop protocols and standards for mobile telecommunications. 3GPP standards are structured as “releases”. Thus, communication methods based on 3GPP release 50, 15, 16 and/or future 3GPP releases are considered within the scope of the present disclosure.

[0045] Accordingly, the host vehicle communication system **52** may include one or more antennas and/or communication transceivers for receiving and/or transmitting signals, such as cooperative sensing messages (CSMs). The host vehicle communication system **52** is configured to wirelessly communicate information between the host vehicle **16** and another vehicle. Further, the host vehicle communication system **52** is configured to wirelessly communicate information between the host vehicle **16** and infrastructure or other vehicles. Further, the host vehicle communication system **52** is configured to wirelessly communicate information between the host vehicle **16** and the remote server system **12**. It should be understood that the host vehicle communication system **52** may be integrated with the host vehicle controller **50** (e.g., on a same circuit board with the host



vehicle controller **50** or otherwise a part of the host vehicle controller **50**) without departing from the scope of the present disclosure.

[0046] The host vehicle sensor **54** is used to acquire information about the one or more target vehicles **20**. In an exemplary embodiment, the host vehicle sensor **54** includes at least a perception sensor **62** and a global navigation satellite system (GNSS) **64**.

[0047] The perception sensor **62** is used to perceive objects and/or measure distances in the environment surrounding the host vehicle **16**. In an exemplary embodiment, the perception sensor **62** includes at least one of: a camera **68**, a radar sensor **70**, and a light detection and ranging (LiDAR) sensor **72**.

[0048] The camera **68** is a perception sensor used to capture images and/or videos of the environment surrounding the host vehicle **16**. In an exemplary embodiment, the camera **68** includes a photo and/or video camera which is positioned to view the environment surrounding the host vehicle **16**. In a non-limiting example, the camera **68** includes a camera affixed inside of the host vehicle **16**, for example, in a headliner of the host vehicle **16**, having a view through a windscreen of the host vehicle **16**. In another non-limiting example, the camera **68** includes a camera affixed outside of the host vehicle **16**, for example, on a roof of the host vehicle **16**, having a view of the environment in front of the host vehicle **16**.

[0049] In another exemplary embodiment, the camera **68** is a surround view camera system including a plurality of cameras (also known as satellite cameras) arranged to provide a view of the environment adjacent to all sides of the host vehicle **16**. In a non-limiting example, the camera **68** includes a front-facing camera (mounted, for example, in a front grille of the host vehicle **16**), a rear-facing camera (mounted, for example, on a rear tailgate of the host vehicle **16**), and two side-facing cameras (mounted, for example, under each of two side-view mirrors of the host vehicle **16**). In another non-limiting example, the camera **68** further includes an additional rear-view camera mounted near a center high mounted stop lamp of the host vehicle **16**.

[0050] It should be understood that camera systems having additional cameras and/or additional mounting locations are within the scope of the present disclosure. It should further be understood that cameras having various sensor types including, for example, charge-coupled device (CCD) sensors, complementary metal oxide semiconductor (CMOS) sensors, and/or high dynamic range (HDR) sensors are within the scope of the present disclosure. Furthermore, cameras having various lens types including, for example, wide-angle lenses and/or narrow-angle lenses are also within the scope of the present disclosure. The camera **68** is in electrical communication with the host vehicle controller **50**, as discussed above.

[0051] The radar sensor **70** is used to detect and measure the distance, speed, and direction of objects (e.g., the one or more target vehicles **20**) by emitting radio waves and analyzing reflections of the radio waves. In an exemplary embodiment, the radar sensor **70** includes a radar transmitter, a radar antenna, a radar receiver, and a radar signal processing unit. In a non-limiting example, the radar transmitter emits radio frequency (RF) signals, which travel through space until they encounter an object. The RF signals bounce off the object's surface, return to the radar sensor **70**. The radar receiver captures the reflected signals, and the radar signal processing unit analyzes the time delay, frequency shift, and amplitude of the returned RF signals to determine the distance, speed, and direction of the detected objects. The radar sensor **70** is in electrical communication with the host vehicle controller **50**, as discussed above.

[0052] The LiDAR sensor **72** is utilized for remote sensing and environmental mapping by emitting laser pulses and measuring the time it takes for the laser pulses to return to the LiDAR sensor **72** after hitting objects. In an exemplary embodiment, the LiDAR sensor **72** includes a LiDAR laser source, a LiDAR scanner or mirror, a LiDAR photodetector, and a LiDAR time-of-flight measurement system. In a non-limiting example, the LiDAR laser source emits laser pulses that travel to the target area, and the LiDAR scanner directs these pulses in different directions. The emitted laser pulses interact with objects in the environment and their reflections are captured by

the LiDAR photodetector.

[0053] The LiDAR time-of-flight measurement system calculates the distance to the objects based on the time between emission of the laser pulses by the LiDAR laser source and reception of the reflected laser pulses by the LiDAR photodetector. The LiDAR sensor **72** is in electrical communication with the host vehicle controller **50**, as discussed above.

[0054] In another exemplary embodiment, the perception sensor **62** further includes a stereoscopic camera having distance measurement capabilities. In one example, the perception sensor **62** is affixed inside of the host vehicle **16**, for example, in a headliner of the host vehicle **16**, having a view through the windscreen of the host vehicle **16**. In another example, the perception sensor **62** is affixed outside of the host vehicle **16**, for example, on a roof of the host vehicle **16**, having a view of the environment surrounding the host vehicle **16**. It should be understood that various additional types of perception sensors, such as, for example, ultrasonic ranging sensors and/or time-of-flight sensors are within the scope of the present disclosure. The perception sensor **62** is in electrical communication with the host vehicle controller **50** as discussed above.

[0055] The GNSS **64** is used to determine a geographical location of the host vehicle **16**. In an exemplary embodiment, the GNSS **64** is a global positioning system (GPS). In a non-limiting example, the GPS includes a GPS receiver antenna (not shown) and a GPS controller (not shown) in electrical communication with the GPS receiver antenna. The GPS receiver antenna receives signals from a plurality of satellites, and the GPS controller calculates the geographical location of the host vehicle **16** based on the signals received by the GPS receiver antenna.

[0056] In an exemplary embodiment, the GNSS **64** additionally includes a map. The map includes information about infrastructure such as municipality borders, roadways, railways, sidewalks, buildings, and the like. Therefore, the geographical location of the host vehicle **16** is contextualized using the map information. In a non-limiting example, the map is retrieved from a remote source using a wireless connection. In another non-limiting example, the map is stored in a database of the GNSS **64**.

[0057] It should be understood that various additional types of satellite-based radionavigation systems, such as, for example, the Global Positioning System (GPS), Galileo, GLONASS, and the BeiDou Navigation Satellite System (BDS) are within the scope of the present disclosure. It should be understood that the GNSS **64** may be integrated with the host vehicle controller **50** (e.g., on a same circuit board with the host vehicle controller **50** or otherwise a part of the host vehicle controller **50**) without departing from the scope of the present disclosure.

[0058] In another exemplary embodiment, the host vehicle sensor **54** further includes sensors to determine performance data about the host vehicle **16**. In a non-limiting example, the host vehicle sensor **54** further includes at least one of a motor speed sensor, a motor torque sensor, an electric drive motor voltage and/or current sensor, an accelerator pedal position sensor, a brake position sensor, a coolant temperature sensor, a cooling fan speed sensor, and a transmission oil temperature sensor.

[0059] In another exemplary embodiment, the host vehicle sensor **54** further includes additional sensors to determine information about an environment within the host vehicle **16**. In a non-limiting example, the host vehicle sensor **54** further includes at least one of a seat occupancy sensor, a cabin air temperature sensor, a cabin motion detection sensor, a cabin camera, a cabin microphone, an occupant eye tracker, and/or the like.

[0060] In another exemplary embodiment, the host vehicle sensor **54** further includes additional sensors to determine information about an environment surrounding the host vehicle **16**. In a non-limiting example, the host vehicle sensor **54** further includes at least one of an ambient air temperature sensor, a barometric pressure sensor, and/or the like. The host vehicle sensor **54** is in electrical communication with the host vehicle controller **50** as discussed above.

[0061] The host vehicle display **56** is used to provide information to an occupant of the host vehicle **16**. In the scope of the present disclosure, the occupant includes a driver and/or a passenger of the

host vehicle **16**. In the exemplary embodiment depicted in FIG. 2, the host vehicle display **56** is a human-machine interface (HMI) located in view of the occupant and capable of displaying text, graphics and/or images. It is to be understood that HMI display systems including LCD displays, LED displays, and the like are within the scope of the present disclosure. Further exemplary embodiments where the host vehicle display **56** is disposed in a rearview mirror are also within the scope of the present disclosure.

[0062] In another exemplary embodiment, the host vehicle display **56** includes a head-up display (HUD) configured to provide information to the occupant by projecting text, graphics, and/or images upon the windscreen of the host vehicle **16**. The text, graphics, and/or images are reflected by the windscreen of the host vehicle **16** and are visible to the occupant without looking away from the roadway **18** ahead of the host vehicle **16**. In another exemplary embodiment, the host vehicle display **56** includes an augmented reality head-up display (AR-HUD). The AR-HUD is a type of HUD configured to augment the occupant's vision of the roadway ahead of the host vehicle **16** by overlaying text, graphics, and/or images on physical objects in the environment surrounding the host vehicle **16** within a field-of-view of the occupant. In an exemplary embodiment, the occupant may interact with the host vehicle display **56** using a human-interface device (HID), including, for example, a touchscreen, an electromechanical switch, a capacitive switch, a rotary knob, and the like. It should be understood that additional systems for displaying information to the occupant of the host vehicle **16** are also within the scope of the present disclosure. The host vehicle display **56** is in electrical communication with the host vehicle controller **50** as discussed above.

[0063] Referring to FIG. 3, a flowchart of the method **100** for identifying roadway safety events is shown. The method **100** begins at block **102** and proceeds to block **104**. At block **104**, a measurement of at least one of the one or more target vehicles **20** is performed. In an exemplary embodiment, the measurement includes a target vehicle location of each of the one or more target vehicles and a target vehicle velocity of each of the one or more target vehicles. In an exemplary embodiment, the measurement is performed using a sensor. In a non-limiting example, the sensor includes at least one of: the host vehicle sensor **54** of the host vehicle **16** (i.e., the host vehicle system **14**), a mobile device (e.g., a smartphone, a smartwatch, a tablet, and/or the like), and/or a roadside unit (RSU). Performance of the measurement will be discussed in greater detail below. After block **104**, the method **100** proceeds to block **106**.

[0064] At block **106**, the measurement is transmitted to the remote server system **12**. In an exemplary embodiment, the host vehicle controller **50** uses the host vehicle communication system **52** to transmit the measurement to the remote server system **12** via the server communication system **34**. In another exemplary embodiment, the mobile device uses a mobile device communication system to transmit the measurement to the remote server system **12** via the server communication system **34**. In another exemplary embodiment, the RSU uses an RSU communication system to transmit the measurement to the remote server system **12** via the server communication system **34**. In a non-limiting example, the server controller **30** receives the measurement using the server communication system **34** and stores the measurement in the server database **32**. After block **106**, the method **100** proceeds to blocks **108**, **110**, **112**, and **114**.

[0065] At block **108**, the server controller **30** evaluates the measurement of the one or more target vehicles **20** to identify a target-to-infrastructure safety event. In the scope of the present disclosure, the target-to-infrastructure safety event describes an event where a target vehicle **20** violates a traffic regulation involving roadway infrastructure. In a non-limiting example, the target-to-infrastructure safety event includes, for example, departing from the roadway **18** and/or a lane of travel (e.g., crossing a lane line), driving a wrong direction in a one-way lane of travel, violating a stop sign, a yield sign, a traffic signal and/or other road signs, a no turn on red violation, a passing zone violation, a speed limit violation, and/or the like.

[0066] In an exemplary embodiment, to identify the target-to-infrastructure safety event, the server controller **30** first determines one or more traffic regulations applicable on the roadway **18**. In the

scope of the present disclosure, the one or more traffic regulations include, for example, lane line location and type, lane/roadway permitted direction of travel, traffic sign location, type, and content, traffic signal location, type, and phase, speed limit, and/or the like. In an exemplary embodiment, the server controller **30** retrieves the one or more traffic regulations from the server database **32**. In another exemplary embodiment, the server controller **30** retrieves the one or more traffic regulations from an external system (e.g., the internet) using the server communication system **34**.

[0067] After determining the one or more traffic regulations applicable on the roadway **18**, the server controller **30** evaluates the measurement received at block **106** based at least in part on the one or more traffic regulations. In a non-limiting example, the server controller **30** compares the target vehicle location to a lane line location to identify a departure from the roadway **18** and/or a lane of travel. In a non-limiting example, the server controller **30** compares a direction of the target vehicle velocity to the lane/roadway permitted direction of travel to identify whether the target vehicle **20** is driving a wrong direction in a one-way lane of travel.

[0068] In a non-limiting example, the server controller **30** analyzes the target vehicle location and target vehicle velocity over time in the vicinity of one or more traffic signs/signals to identify a stop sign violation, a yield sign violation, a traffic signal violation, a passing zone violation, and/or the like. In a non-limiting example, the server controller **30** compares a magnitude of the target vehicle velocity to the speed limit of the roadway **18** to identify a speed limit violation.

[0069] It should be understood that additional analysis of the measurement may be performed to identify other types of target-to-infrastructure safety events without departing from the scope of the present disclosure. It should further be understood that the server controller **30** may utilize signal processing techniques, such as, for example, thresholding, filtering, pattern recognition, time-frequency analysis, statistical analysis, machine learning, and/or the like to identify the target-to-infrastructure safety event without departing from the scope of the present disclosure. After block **108**, the method **100** proceeds to block **116**.

[0070] At block **116**, if the target-to-infrastructure safety event is not identified at block **108**, the method **100** proceeds to enter a standby state at block **118**. If the target-to-infrastructure safety event is identified at block **108**, the method **100** proceeds to block **120**, as will be discussed in greater detail below.

[0071] At block **110**, the server controller **30** evaluates the measurement of the one or more target vehicles **20** to identify a target-to-target safety event. In the scope of the present disclosure, the target-to-target safety event describes an event where two or more target vehicles **20** are involved in an unsafe driving situation. In a non-limiting example, the target-to-target safety event includes, for example, a collision between two or more target vehicles **20**, a near collision between two or more target vehicles **20**, an aggressive maneuver (e.g., hard braking, hard acceleration, hard cornering, aggressive lane change) involving two or more target vehicles **20**, tailgating (i.e., close following distance) between two or more target vehicles **20**, and/or the like.

[0072] In an exemplary embodiment, to identify the target-to-target safety event, the server controller **30** calculates a time-to-collision (TTC) between the two or more target vehicles **20** (e.g., the first target vehicle **20a** and the second target vehicle **20b**). In the scope of the present disclosure, the time-to-collision (TTC) quantifies an estimated time it will take for the first target vehicle **20a** to collide with the second target vehicle **20b** (i.e., for the first target vehicle **20a** and the second target vehicle **20b** to reach a common point in space, based on their trajectories).

[0073] In a non-limiting example, to calculate the TTC, the server controller **30** determines a first trajectory of the first target vehicle **20a** (i.e., a future path of the first target vehicle **20a**) based at least in part on a first target vehicle velocity and a first target vehicle location of the first target vehicle **20a**. The server controller **30** further determines a second trajectory of the second target vehicle **20b** (i.e., a future path of the second target vehicle **20b**) based at least in part on a second target vehicle velocity and a second target vehicle location of the second target vehicle **20b**. The

server controller **30** then evaluates the first trajectory and the second trajectory to determine whether the first trajectory intersects with the second trajectory. If the first trajectory and the second trajectory do not intersect, the TTC is determined to be infinite.

[0074] If the first trajectory and the second trajectory do intersect, the server controller **30** determines a distance between the first target vehicle **20a** and the second target vehicle **20b** based at least in part on the first target vehicle location and the second target vehicle location. The server controller **30** then determines a relative velocity between the first target vehicle **20a** and the second target vehicle **20b** based at least in part on a magnitude of the first target vehicle velocity and a magnitude of the second target vehicle velocity.

[0075] To determine the TTC, the server controller **30** divides the distance between the first target vehicle **20a** and the second target vehicle **20b** by the relative velocity between the first target vehicle **20a** and the second target vehicle **20b**. In a non-limiting example, the target-to-target safety event is identified if the TTC is less than or equal to a predetermined time-to-collision threshold (e.g., three seconds).

[0076] It should be understood that additional analysis of the measurement may be performed to identify other types of target-to-target safety events without departing from the scope of the present disclosure. It should further be understood that the server controller **30** may utilize signal processing techniques, such as, for example, thresholding, filtering, pattern recognition, time-frequency analysis, statistical analysis, machine learning, and/or the like to identify the target-to-target safety event without departing from the scope of the present disclosure. After block **110**, the method **100** proceeds to block **122**.

[0077] At block **122**, if the target-to-target safety event is not identified at block **110**, the method **100** proceeds to enter the standby state at block **118**.

[0078] If the target-to-target safety event is identified at block **110**, the method **100** proceeds to block **120**, as will be discussed in greater detail below.

[0079] At block **112**, the server controller **30** evaluates the measurement of the one or more target vehicles **20** to identify an erratic driving safety event. In the scope of the present disclosure, the erratic driving safety event describes a situation or occurrence involving unpredictable and irregular driving behavior which poses potential risks to road users. In a non-limiting example, the erratic driving safety event includes, for example, an abrupt lane change, a sudden acceleration or deceleration, aggressive driving, and/or other erratic driving patterns. In an exemplary embodiment, the server controller **30** uses an erratic driving identification machine learning model to identify the erratic driving safety event.

[0080] In a non-limiting example, the erratic driving identification machine learning model includes multiple layers, including an input layer and an output layer, as well as one or more hidden layers. The input layer receives the measurement performed at block **104** as an input. The input is then passed on to the hidden layers. Each hidden layer applies a transformation (e.g., a non-linear transformation) to the data and passes the result to the next hidden layer until the final hidden layer. The output layer produces an erratic driving safety event classification. In the scope of the present disclosure, the erratic driving safety event classification includes, for example, a no event classification (i.e., no erratic driving behavior is identified), an abrupt lane change classification, an abrupt speed change classification, an aggressive driving classification, and/or the like.

[0081] To train the erratic driving identification machine learning model, a dataset of inputs and their corresponding erratic driving safety event classification is used. The algorithm is trained by adjusting internal weights between nodes in each hidden layer to minimize prediction error. During training, an optimization technique (e.g., gradient descent) is used to adjust the internal weights to reduce the prediction error. The training process is repeated with the entire dataset until the prediction error is minimized, and the resulting trained model is then used to classify new input data.

[0082] After sufficient training of the erratic driving identification machine learning model, the

algorithm is capable of accurately and precisely determining the erratic driving safety event classification based on the measurement performed at block **104**. By adjusting the weights between the nodes in each hidden layer during training, the algorithm “learns” to recognize patterns in the measurement data which are indicative of the erratic driving safety event classification.

[0083] It should be understood that additional analysis of the measurement may be performed to identify other types of erratic driving safety events without departing from the scope of the present disclosure. It should further be understood that the server controller **30** may utilize signal processing techniques, such as, for example, thresholding, filtering, pattern recognition, time-frequency analysis, statistical analysis, and/or the like to identify the erratic driving safety event without departing from the scope of the present disclosure. After block **112**, the method **100** proceeds to block **124**.

[0084] At block **124**, if the erratic driving safety event is not identified at block **112** (i.e., the erratic driving safety event classification is the no event classification), the method **100** proceeds to enter the standby state at block **118**. If the erratic driving safety event is identified at block **112**, the method **100** proceeds to block **120**, as will be discussed in greater detail below.

[0085] At block **114**, the server controller **30** evaluates the measurement of the one or more target vehicles **20** to identify an unobserved safety event. In the scope of the present disclosure, the unobserved safety event describes a situation or occurrence happening outside of a field of view of the sensor (e.g., the host vehicle sensor **54**) which poses potential risks to road users. In a non-limiting example, the unobserved safety event includes any of the target-to-infrastructure safety events, target-to-target safety events, and/or erratic driving safety events discussed above.

[0086] For example, a near collision far ahead of the host vehicle **16** on the roadway **18** may occur outside of the field of view of the host vehicle sensor **54**, but the host vehicle sensor **54** may observe responses of other target vehicles **20** within the field of view of the host vehicle sensor **54** to the near collision. Therefore, even without directly observing the unobserved safety event, information about the unobserved safety event may be gleaned from the measurement performed at block **104**. In an exemplary embodiment, the server controller **30** uses an unobserved safety event identification machine learning model to identify the unobserved safety event.

[0087] In a non-limiting example, the unobserved safety event identification machine learning model includes multiple layers, including an input layer and an output layer, as well as one or more hidden layers. The input layer receives the measurement performed at block **104** as an input. In an exemplary embodiment, the input further may include additional information such as, for example, telemetry data, advanced driver assistance system (ADAS) data, and/or accident data/warnings received from external sources. The input is then passed on to the hidden layers. Each hidden layer applies a transformation (e.g., a non-linear transformation) to the data and passes the result to the next hidden layer until the final hidden layer. The output layer produces an unobserved safety event classification.

[0088] In the scope of the present disclosure, the unobserved safety event classification includes, for example, a no event classification (i.e., no unobserved safety event is identified), an unobserved target-to-infrastructure classification, an unobserved target-to-target classification, an unobserved erratic driving classification, and/or the like. It should be understood that the unobserved safety event classification may include more specific classifications (e.g., an unobserved near collision classification) without departing from the scope of the present disclosure. It should further be understood that the output layer may produce additional information such as, for example, a predicted location of the unobserved safety event and/or a confidence of the unobserved safety event classification.

[0089] To train the unobserved safety event identification machine learning model, a dataset of inputs and their corresponding unobserved safety event classification is used. The algorithm is trained by adjusting internal weights between nodes in each hidden layer to minimize prediction error. During training, an optimization technique (e.g., gradient descent) is used to adjust the

internal weights to reduce the prediction error. The training process is repeated with the entire dataset until the prediction error is minimized, and the resulting trained model is then used to classify new input data.

[0090] After sufficient training of the unobserved safety event identification machine learning model, the algorithm is capable of accurately and precisely determining the unobserved safety event classification based on the measurement performed at block **104**. By adjusting the weights between the nodes in each hidden layer during training, the algorithm “learns” to recognize patterns in the measurement data which are indicative of the unobserved safety event classification.

[0091] It should be understood that additional analysis of the measurement may be performed to identify other types of unobserved safety events without departing from the scope of the present disclosure. It should further be understood that the server controller **30** may utilize signal processing techniques, such as, for example, thresholding, filtering, pattern recognition, time-frequency analysis, statistical analysis, and/or the like to identify the unobserved safety event without departing from the scope of the present disclosure. After block **114**, the method **100** proceeds to block **126**.

[0092] At block **126**, if the unobserved safety event is not identified at block **114** (i.e., the unobserved safety event classification is the no event classification), the method **100** proceeds to enter the standby state at block **118**. If the unobserved safety event is identified at block **114**, the method **100** proceeds to block **120**.

[0093] At block **120**, the server controller **30** performs a first action based at least in part on the safety event. In an exemplary embodiment, the first action includes transmitting a safety event message to the host vehicle **16**. In a non-limiting example, the safety event message includes at least one of: information about the target-to-infrastructure safety event identified at block **108** (i.e., a location, type, severity, and/or the like), information about the target-to-target safety event identified at block **110** (i.e., a location, type, severity, and/or the like), information about the erratic driving safety event classification determined at block **112** (i.e., a location, type, severity, and/or the like), and/or information about the unobserved safety event classification determined at block **114** (i.e., a location, type, severity, and/or the like). The safety event message further includes a geographical location of each of the aforementioned safety events. In an exemplary embodiment, the server controller **30** uses the server communication system **34** to transmit the safety event message. The safety event message is received by the host vehicle controller **50** using the host vehicle communication system **52**.

[0094] In another exemplary embodiment, the safety event message further includes statistical information about safety events within a particular geographical area (e.g., a one-mile radius) near the host vehicle **16**. In a non-limiting example, the statistical information includes, for example, a rate of occurrence of safety events, a quantity of safety events, a geographical density of safety events, and/or the like.

[0095] In another exemplary embodiment, at block **120**, the server controller **30** saves the safety event message in the server database **32**. In a non-limiting example, the safety event message is later retrieved for purposes of analysis to improve road infrastructure and/or road safety, creating regional road risk assessments, and/or the like. After block **120**, the method **100** proceeds to block **128**.

[0096] At block **128**, the host vehicle controller **50** performs the first action based at least in part on the safety event. In an exemplary embodiment, the first action further includes using the host vehicle communication system **52** to receive the safety event message transmitted at block **120**. In an exemplary embodiment, the host vehicle controller **50** uses the host vehicle display **56** to provide an in-vehicle warning to the occupant of the host vehicle **16** based at least in part on the safety event message. For example, the host vehicle controller **50** may use the host vehicle display **56** to display a warning including text, images, icons, and/or the like. In a non-limiting example, the warning includes text describing a type, location, severity, and/or the like of the safety event

contained in the safety event message transmitted at block **120**.

[0097] In another exemplary embodiment, the host vehicle controller **50** uses the GNSS **64** to determine a navigation suggestion based at least in part on a quantity of safety events within a particular geographical area. In a non-limiting example, the host vehicle controller **50** uses the GNSS **64** to calculate a navigation route based at least in part on the statistical information about safety events within the particular geographical area, for example, the navigation route may be configured to avoid geographical areas having a high density or rate of occurrence of safety events. After block **128**, the method **100** proceeds to enter the standby state at block **118**.

[0098] In an exemplary embodiment, the method **100** repeatedly restarts at block **102**. In a non-limiting example, the method **100** restarts on a timer, for example, every three hundred milliseconds.

[0099] Referring to FIG. **4**, a flowchart of an exemplary embodiment **104a** of block **104** (i.e., a method for performing a measurement) is shown. The exemplary embodiment **104a** begins at block **302**. As discussed above, the measurement is performed using a sensor. In a non-limiting example, the sensor includes at least one of: the host vehicle sensor **54** of the host vehicle system **14**, a mobile device (e.g., a smartphone, a smartwatch, a tablet, and/or the like), and/or a roadside unit (RSU). The exemplary embodiment **104a** will be explained in reference to an exemplary embodiment where the sensor is the host vehicle sensor **54**. It should be understood that the following method steps are also applicable to a mobile device, and/or a roadside unit (RSU).

[0100] At block **302**, the host vehicle controller **50** selects a selected target vehicle. In a non-limiting example, the selected target vehicle may be any of the target vehicles **20** (e.g., the first target vehicle **20a** or the second target vehicle **20b**). After block **302**, the exemplary embodiment **104a** proceeds to block **304**.

[0101] At block **304**, the host vehicle controller **50** determines whether the selected target vehicle is within the field of view of the host vehicle sensor **54**. For example, if the host vehicle sensor **54** includes only a front facing camera, and the selected target vehicle is behind the host vehicle **16**, the selected target vehicle is not within the field of view of the host vehicle sensor **54**. If the selected target vehicle is not within the field of view of the host vehicle sensor **54**, the exemplary embodiment **104a** proceeds to block **306**. If the selected target vehicle is within the field of view of the host vehicle sensor **54**, the exemplary embodiment **104a** proceeds to block **308**, as will be discussed in greater detail below.

[0102] At block **306**, the host vehicle controller **50** extrapolates at least one of: the target vehicle location of the selected target vehicle and the target vehicle velocity of the selected target vehicle in response to determining that the selected target vehicle is outside of the field of view of the host vehicle sensor **54**. In an exemplary embodiment, the host vehicle controller **50** uses a time-series forecasting method to predict (i.e., extrapolate) future values of the target vehicle location of the selected target vehicle and the target vehicle velocity of the selected target vehicle based on one or more past measurements of the selected target vehicle stored in the host vehicle media **60** and/or the server database **32**.

[0103] In a non-limiting example, the time-series forecasting method includes, for example, an autoregressive integrated moving average (ARIMA), exponential smoothing, and/or machine learning models for forecasting/extrapolating time-series data. In a non-limiting example, a decaying confidence value is assigned to the extrapolations of the target vehicle location of the selected target vehicle and the target vehicle velocity of the selected target vehicle based on the time elapsed since the last ground-truth measurement was received (i.e., since the selected target vehicle was last within the field of view of the host vehicle sensor **54**).

[0104] In another exemplary embodiment, the host vehicle controller **50** extrapolates the target vehicle location of the selected target vehicle and the target vehicle velocity of the selected target vehicle by assuming that a rate of change in target vehicle location and a rate of change in target vehicle velocity of the selected target vehicle remain constant. After a predetermined amount of



time since the last ground-truth measurement has elapsed, the prediction (i.e., extrapolation) of the target vehicle location of the selected target vehicle and the target vehicle velocity of the selected target vehicle is considered to be invalid and is discarded. After block **306**, the exemplary embodiment **104a** proceeds to block **310**, as will be discussed in greater detail below.

[0105] At block **308**, the host vehicle controller **50** uses the host vehicle sensor **54** to perform the measurement of the selected target vehicle (e.g., the first target vehicle **20a** or the second target vehicle **20b**) in response to determining that the selected target vehicle is within the field of view of the host vehicle sensor **54**. As discussed above, the measurement includes at least a target vehicle location and a target vehicle velocity of the selected target vehicle. After block **308**, the exemplary embodiment **104a** proceeds to block **310**.

[0106] At block **310**, the host vehicle controller **50** updates the location of the selected target vehicle in memory. In an exemplary embodiment, the extrapolated target vehicle location of the selected target vehicle and the extrapolated target vehicle velocity of the selected target vehicle determined at block **306** are saved in the host vehicle media **60** and/or the server database **32**. As discussed above, the extrapolated target vehicle location of the selected target vehicle and the extrapolated target vehicle velocity of the selected target vehicle may include a confidence value which decays as time since the last ground-truth measurement of the selected target vehicle elapses. In another exemplary embodiment, the target vehicle location of the selected target vehicle and the target vehicle velocity of the selected target vehicle measured at block **308** are saved in the host vehicle media **60** and/or the server database **32**. As discussed above, the target vehicle location of the selected target vehicle and the target vehicle velocity of the selected target vehicle measured at block **308** may be later retrieved from the host vehicle media **60** and/or the server database **32** for use to perform extrapolation at block **306**. After block **310**, the exemplary embodiment **104a** proceeds to block **312**.

[0107] At block **312**, if all of the target vehicles **20** have not yet been selected in the exemplary embodiment **104a**, the exemplary embodiment **104a** returns to block **302** to select a next selected target vehicle. If all of the target vehicles **20** have been selected in the exemplary embodiment **104a**, the exemplary embodiment **104a** is concluded, and the method **100** proceeds as discussed above.

[0108] The system **10** and method **100** of the present disclosure offer several advantages. By utilizing the host vehicle system **14** of the host vehicle **16** equipped with the host vehicle sensor **54** to gather data about target vehicles **20**, data about safety events related to the target vehicles **20** may be acquired, even if the target vehicles **20** do not have measurement and/or wireless communication capabilities. According to the present disclosure, the system **10** and method **100** may be applied using a plurality of host vehicles, allowing for large amounts of measurement data about unconnected target vehicles to be aggregated by the remote server system **12**. Therefore, the remote server system **12** may fuse data from multiple host vehicles to provide a high degree of measurement coverage of the roadway **18**. The fused data may be used with advanced driver assistance systems (ADAS) to provide occupants with critical information about safety events on the roadway **18**. The fused data may be used with global navigation satellite systems (GNSS) to adjust navigation routing based on safety events on the roadway **18**. The fused data may further be used to improve road infrastructure and/or road safety, create regional road risk assessments, and/or the like.

[0109] The description of the present disclosure is merely exemplary in nature and variations that do not depart from the gist of the present disclosure are intended to be within the scope of the present disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the present disclosure.

## Claims

- 1.** A method for identifying roadway safety events, the method comprising: performing a measurement of one or more target vehicles using a sensor; identifying a safety event based at least in part on the measurement of the one or more target vehicles; and performing an action based at least in part on the safety event.
- 2.** The method of claim 1, wherein performing the measurement further comprises: performing the measurement of the one or more target vehicles, wherein the sensor includes at least one of: a host vehicle sensor of a host vehicle, a mobile device, and a roadside unit (RSU), wherein the measurement of the one or more target vehicles includes at least a target vehicle location of each of the one or more target vehicles and a target vehicle velocity of each of the one or more target vehicles.
- 3.** The method of claim 2, wherein performing the measurement further comprises: performing the measurement of the one or more target vehicles, wherein the sensor is the host vehicle sensor of the host vehicle.
- 4.** The method of claim 2, wherein performing the measurement further comprises: extrapolating at least one of: the target vehicle location and the target vehicle velocity of a first target vehicle of the one or more target vehicles in response to determining that the first target vehicle is outside of a field of view of the sensor, wherein the at least one of: the target vehicle location and the target vehicle velocity of the first target vehicle is extrapolated based at least in part on one or more past measurements of the first target vehicle.
- 5.** The method of claim 1, wherein identifying the safety event further comprises: evaluating the measurement of the one or more target vehicles to identify a target-to-infrastructure safety event; evaluating the measurement of the one or more target vehicles to identify a target-to-target safety event; evaluating the measurement of the one or more target vehicles to identify an erratic driving safety event; and evaluating the measurement of the one or more target vehicles to identify an unobserved safety event.
- 6.** The method of claim 5, wherein evaluating the measurement of the one or more target vehicles to identify the target-to-infrastructure safety event further comprises: evaluating the measurement of the one or more target vehicles based at least in part on one or more traffic regulations; and identifying the target-to-infrastructure safety event in response to determining that at least one of the one or more target vehicles is in violation of the one or more traffic regulations.
- 7.** The method of claim 5, wherein evaluating the measurement of the one or more target vehicles to identify the target-to-infrastructure safety event further comprises: calculating a time-to-collision between a first target vehicle and a second target vehicle of the one or more target vehicles based at least in part on the measurement of the one or more target vehicles; and identifying the target-to-target safety event in response to determining that the time-to-collision is less than or equal to a predetermined time-to-collision threshold.
- 8.** The method of claim 5, wherein evaluating the measurement of the one or more target vehicles to identify the erratic driving safety event further comprises: executing an erratic driving identification machine learning model, wherein the erratic driving identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the erratic driving safety event based at least in part on the measurement of the one or more target vehicles.
- 9.** The method of claim 5, wherein evaluating the measurement of the one or more target vehicles to identify the unobserved safety event further comprises: executing an unobserved safety event identification machine learning model, wherein the unobserved safety event identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the unobserved safety event based at least in part on the measurement of the one or more target vehicles, and wherein the unobserved safety event occurs outside of a field of view of the sensor.

- 10.** The method of claim 1, wherein performing the action based at least in part on the safety event further comprises: providing an in-vehicle warning to an occupant; and providing a navigation suggestion based at least in part on a quantity of safety events within a particular geographical area.
- 11.** A system for identifying roadway safety events for a host vehicle, the system comprising: a remote server system including: a server communication system; and a server controller in electrical communication with the server communication system, wherein the server controller is programmed to: receive a measurement of one or more target vehicles using the server communication system; identify a safety event based at least in part on the measurement of the one or more target vehicles; and perform an action based at least in part on the safety event.
- 12.** The system of claim 11, wherein to identify the safety event, the server controller is further programmed to: evaluate the measurement of the one or more target vehicles to identify a target-to-infrastructure safety event; evaluate the measurement of the one or more target vehicles to identify a target-to-target safety event; evaluate the measurement of the one or more target vehicles to identify an erratic driving safety event; and evaluate the measurement of the one or more target vehicles to identify an unobserved safety event.
- 13.** The system of claim 12, wherein to identify the safety event, the server controller is further programmed to: evaluate the measurement of the one or more target vehicles based at least in part on one or more traffic regulations; calculate a time-to-collision between a first target vehicle and a second target vehicle of the one or more target vehicles based at least in part on the measurement of the one or more target vehicles; identify the target-to-infrastructure safety event in response to determining that at least one of the one or more target vehicles is in violation of the one or more traffic regulations; and identify the target-to-target safety event in response to determining that the time-to-collision is less than or equal to a predetermined time-to-collision threshold.
- 14.** The system of claim 12, wherein to evaluate the measurement of the one or more target vehicles to identify the erratic driving safety event, the server controller is further programmed to: execute an erratic driving identification machine learning model, wherein the erratic driving identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the erratic driving safety event based at least in part on the measurement of the one or more target vehicles.
- 15.** The system of claim 12, wherein to evaluate the measurement of the one or more target vehicles to identify the unobserved safety event, the server controller is further programmed to: execute an unobserved safety event identification machine learning model, wherein the unobserved safety event identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the unobserved safety event based at least in part on the measurement of the one or more target vehicles.
- 16.** The system of claim 11, further comprising: a host vehicle system including: a host vehicle communication system; a host vehicle sensor; and a host vehicle controller in electrical communication with the host vehicle communication system and the host vehicle sensor, wherein the host vehicle controller is programmed to: perform a measurement of one or more target vehicles using the host vehicle sensor, wherein the one or more target vehicles are remote from the host vehicle; and transmit the measurement of the one or more target vehicles to the remote server system using the host vehicle communication system.
- 17.** The system of claim 16: wherein to perform the action based at least in part on the safety event, the server controller is further programmed to: transmit a safety event message to the host vehicle using the server communication system, wherein the safety event message includes information regarding the safety event; and wherein the host vehicle system further comprises a host vehicle display in electrical communication with the host vehicle controller, and wherein to perform the action based at least in part on the safety event, the host vehicle controller is further programmed to: receive the safety event message from the remote server system using the host vehicle communication system; and provide an in-vehicle warning to an occupant of the host vehicle using

the host vehicle display based at least in part on the safety event message.

**18.** A method for identifying roadway safety events, the method comprising: performing a measurement of one or more target vehicles using a sensor, wherein the sensor is remote from the one or more target vehicles, and wherein the sensor includes at least one of: a host vehicle sensor of a host vehicle, a mobile device, and a roadside unit (RSU), wherein the measurement of the one or more target vehicles includes at least a target vehicle location of each of the one or more target vehicles and a target vehicle velocity of each of the one or more target vehicles; identifying a safety event based at least in part on the measurement of the of one or more target vehicles, wherein the safety event includes at least one of: a target-to-infrastructure safety event, a target-to-target safety event, an erratic driving safety event, and an unobserved safety event; and performing an action based at least in part on the safety event.

**19.** The method of claim 18, wherein performing the measurement further comprises: extrapolating at least one of: the target vehicle location and the target vehicle velocity of a first target vehicle of the one or more target vehicles in response to determining that the first target vehicle is outside of a field of view of the sensor, wherein the at least one of: the target vehicle location and the target vehicle velocity of the first target vehicle is extrapolated based at least in part on one or more past measurements of the first target vehicle.

**20.** The method of claim 19, wherein identifying the safety event further comprises: evaluating the measurement of the one or more target vehicles based at least in part on one or more traffic regulations; identifying the target-to-infrastructure safety event in response to determining that the first target vehicle is in violation of the one or more traffic regulations; calculating a time-to-collision between the first target vehicle and a second target vehicle based at least in part on the measurement of the one or more target vehicles; identifying the target-to-target safety event in response to determining that the time-to-collision is less than or equal to a predetermined time-to-collision threshold; executing an erratic driving identification machine learning model, wherein the erratic driving identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the erratic driving safety event based at least in part on the measurement of the one or more target vehicles; and executing an unobserved safety event identification machine learning model, wherein the unobserved safety event identification machine learning model is configured to receive the measurement of the one or more target vehicles as an input and identify the unobserved safety event based at least in part on the measurement of the one or more target vehicles, and wherein the unobserved safety event occurs outside of the field of view of the sensor.

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