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Hathaway et al.

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(54) **ADVANCED WARNING AND RISK EVASION SYSTEM AND METHOD**

(71) Applicant: **Oldcastle Materials, Inc.**, Atlanta, GA (US)

(72) Inventors: **Edwin Hathaway**, Santa Monica, CA (US); **Mark Green**, New York, NY (US); **Kent Baumann**, Rockwall, TX (US); **Chad Green**, Ashburn, VA (US); **Lee Cole**, Brandon, MS (US); **Chris Schwedtmann**, Columbia, MO (US); **Nathan Creech**, Austin, TX (US)

(73) Assignee: **CRH Americas Materials, Inc.**, Atlanta, GA (US)

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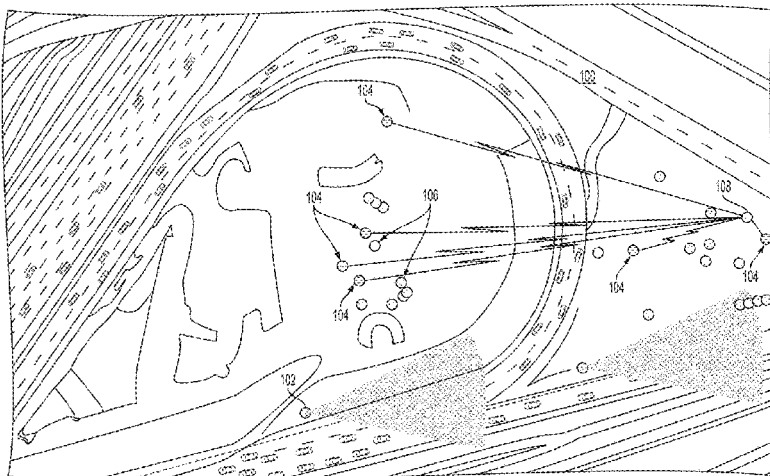
Primary Examiner — Daryl Pope

(74) *Attorney, Agent, or Firm* — Bell Nunnally & Martin LLP; Jeffrey A. Tinker

(57) **ABSTRACT**

This invention relates in general to the field of safety devices, and more particularly, but not by way of limitation, to systems and methods for providing advanced warning and risk evasion when hazardous conditions exist. In one embodiment, a vicinity monitoring unit is provided for monitoring, for example, oncoming traffic near a construction zone. In some embodiments, the vicinity monitoring unit may be mounted onto a construction vehicle to monitor nearby traffic and send a warning signal if hazardous conditions exist. In some embodiments, personnel tracking units may be worn by construction workers and the personnel tracking units may be in communication with the vicinity monitoring unit. In some embodiments, a base station is provided for monitoring activities taking place in or near a construction site including monitoring the locations of various personnel and vehicles within the construction site.

17 Claims, 15 Drawing Sheets



Related U.S. Application Data

- continuation-in-part of application No. 14/500,778, filed on Sep. 29, 2014, now Pat. No. 9,365,155.
- (60) Provisional application No. 61/884,030, filed on Sep. 28, 2013.
- (51) **Int. Cl.**
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| G01S 7/00 | (2006.01) |
| G01S 7/10 | (2006.01) |
| G01S 7/22 | (2006.01) |
| G01S 13/86 | (2006.01) |
| G01S 13/93 | (2006.01) |
| G01S 19/03 | (2010.01) |
| G08B 21/02 | (2006.01) |
| G08G 1/04 | (2006.01) |
| G08G 1/052 | (2006.01) |
| G08G 1/0955 | (2006.01) |
| G08G 1/16 | (2006.01) |
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| G01S 13/91 | (2006.01) |
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See application file for complete search history.

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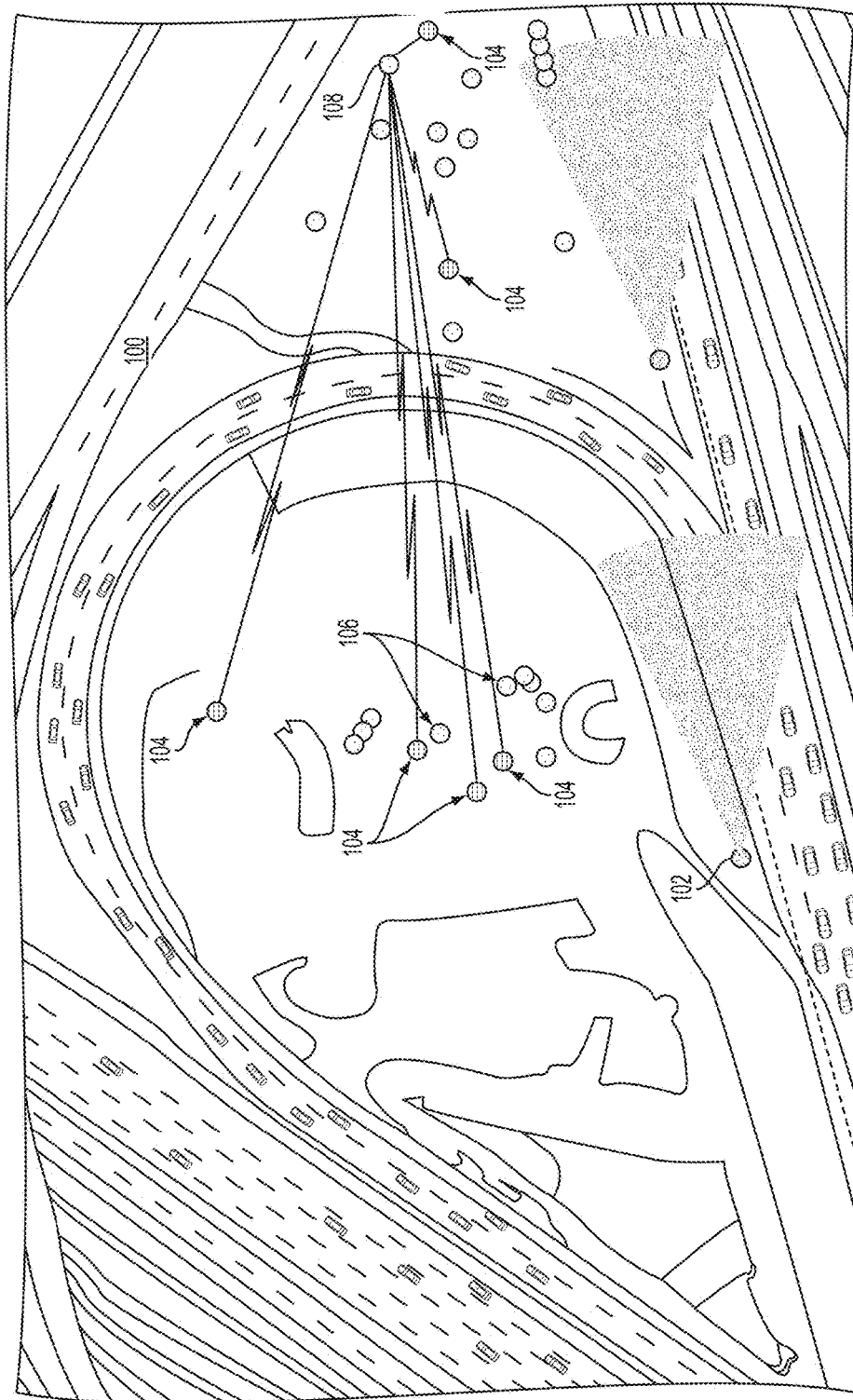


FIG. 1

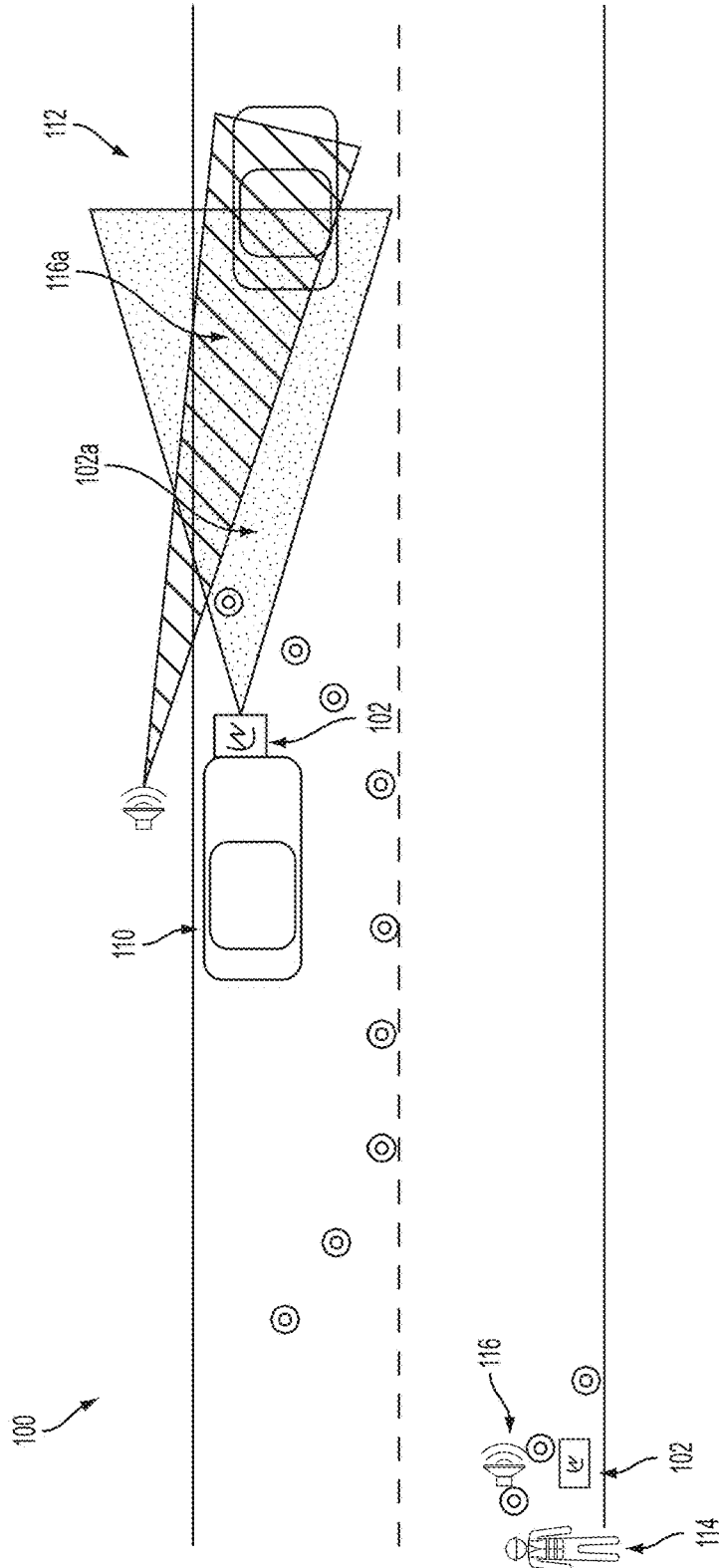


FIG. 2

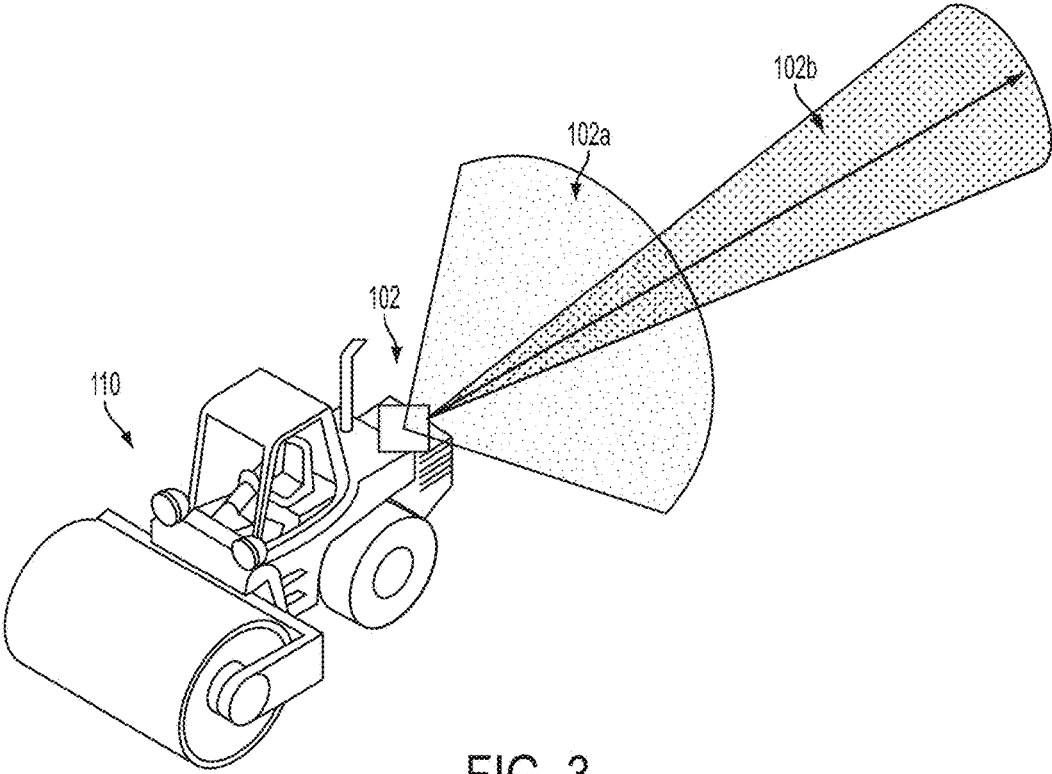


FIG. 3

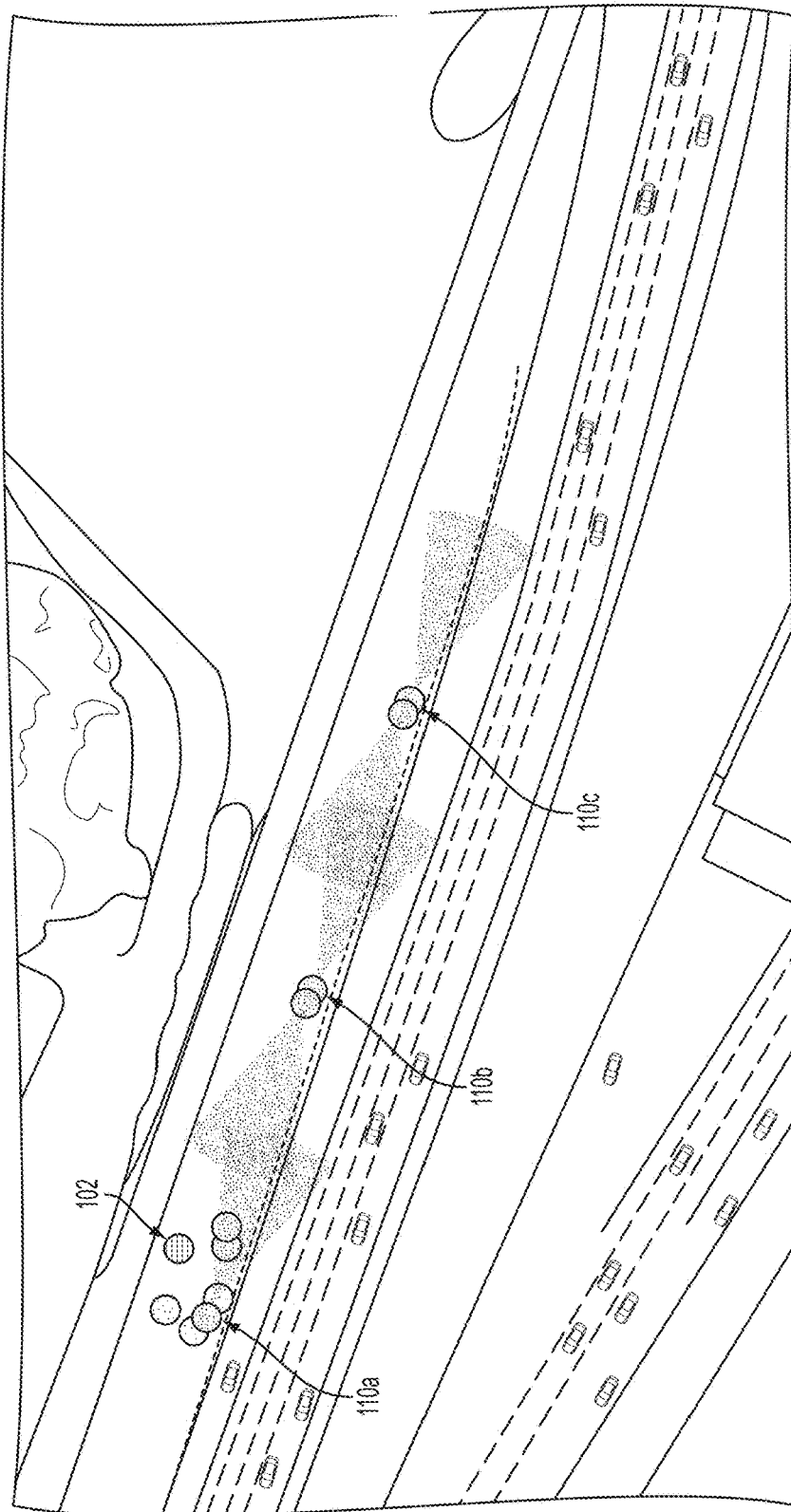


FIG. 4

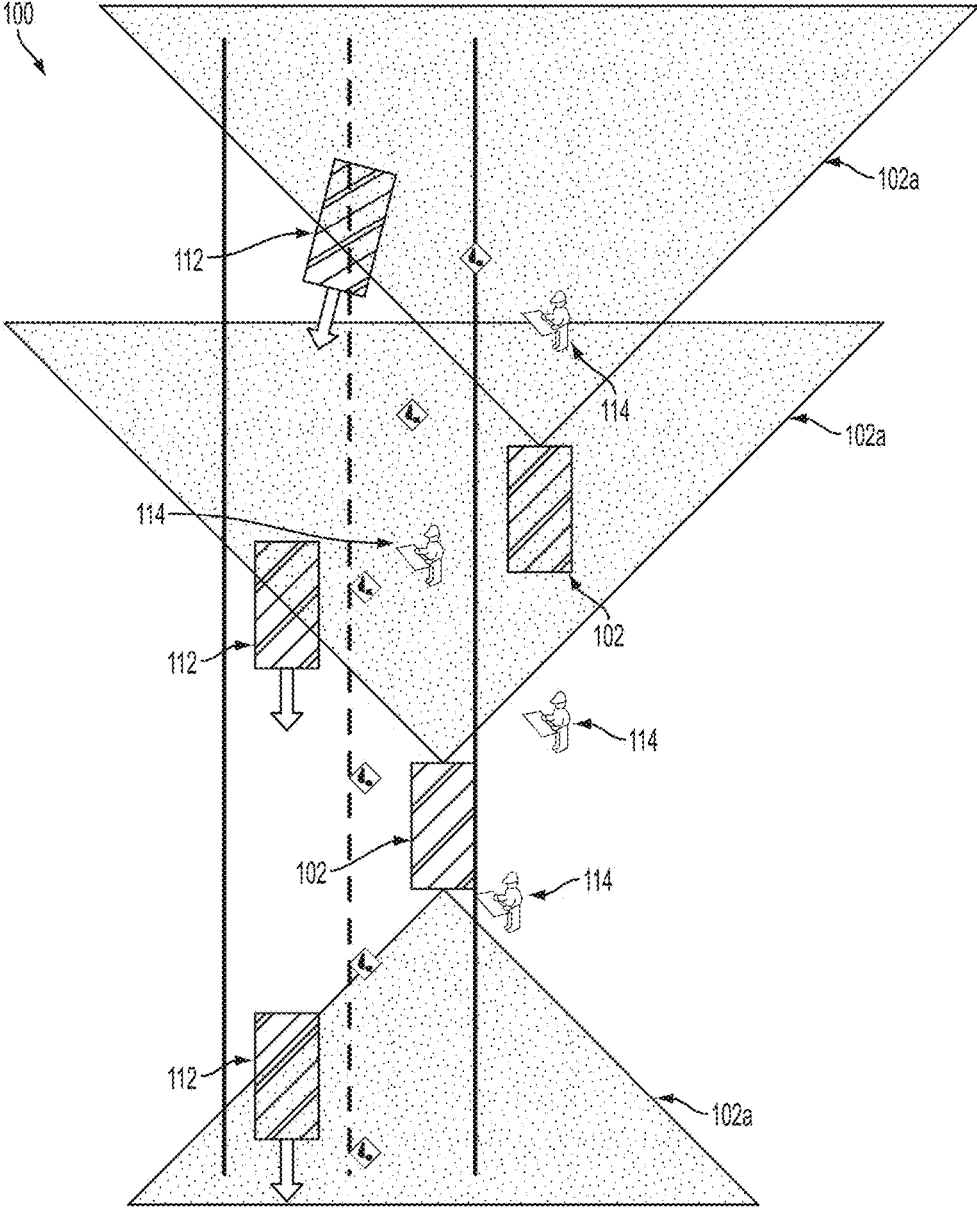


FIG. 5A

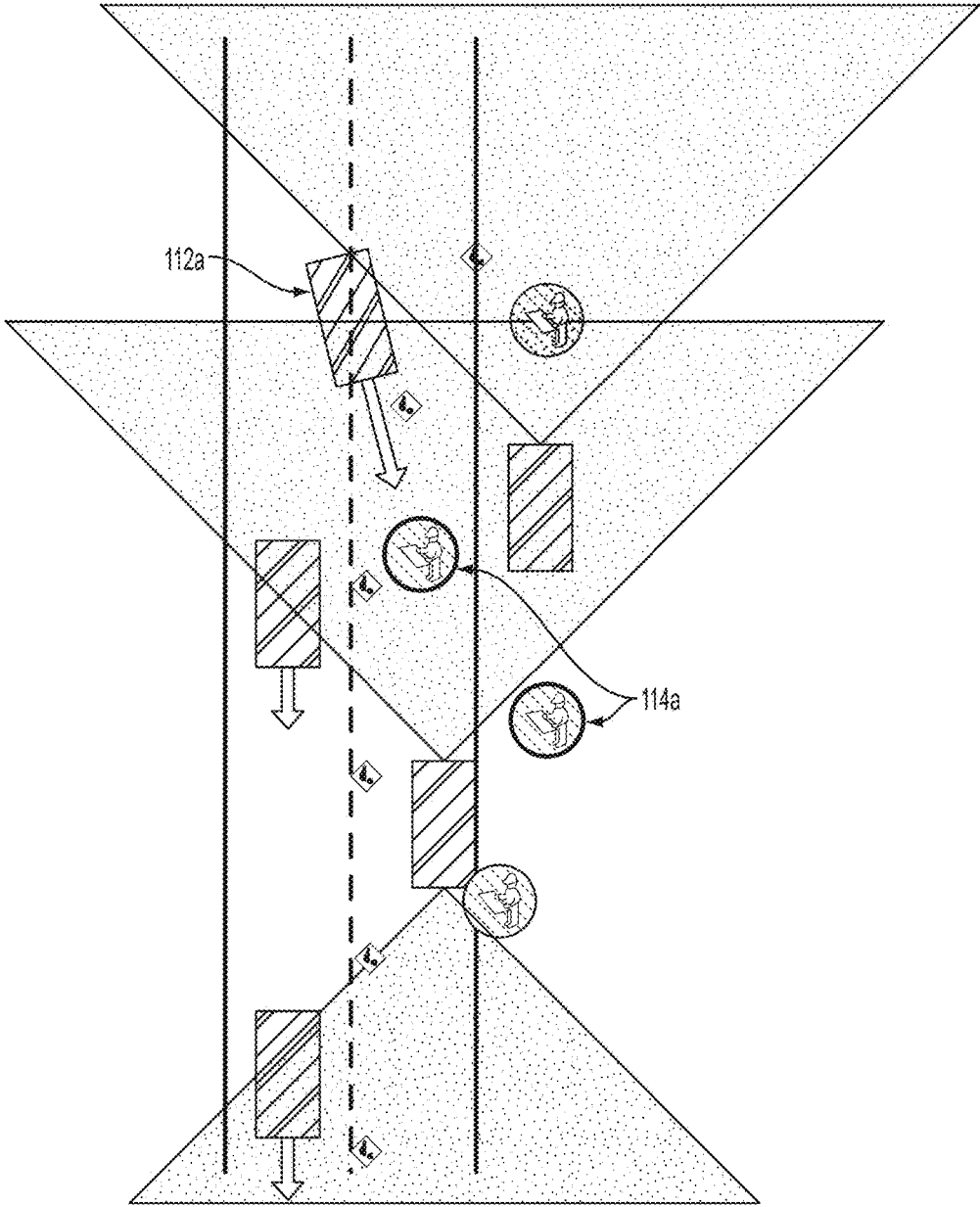


FIG. 5B

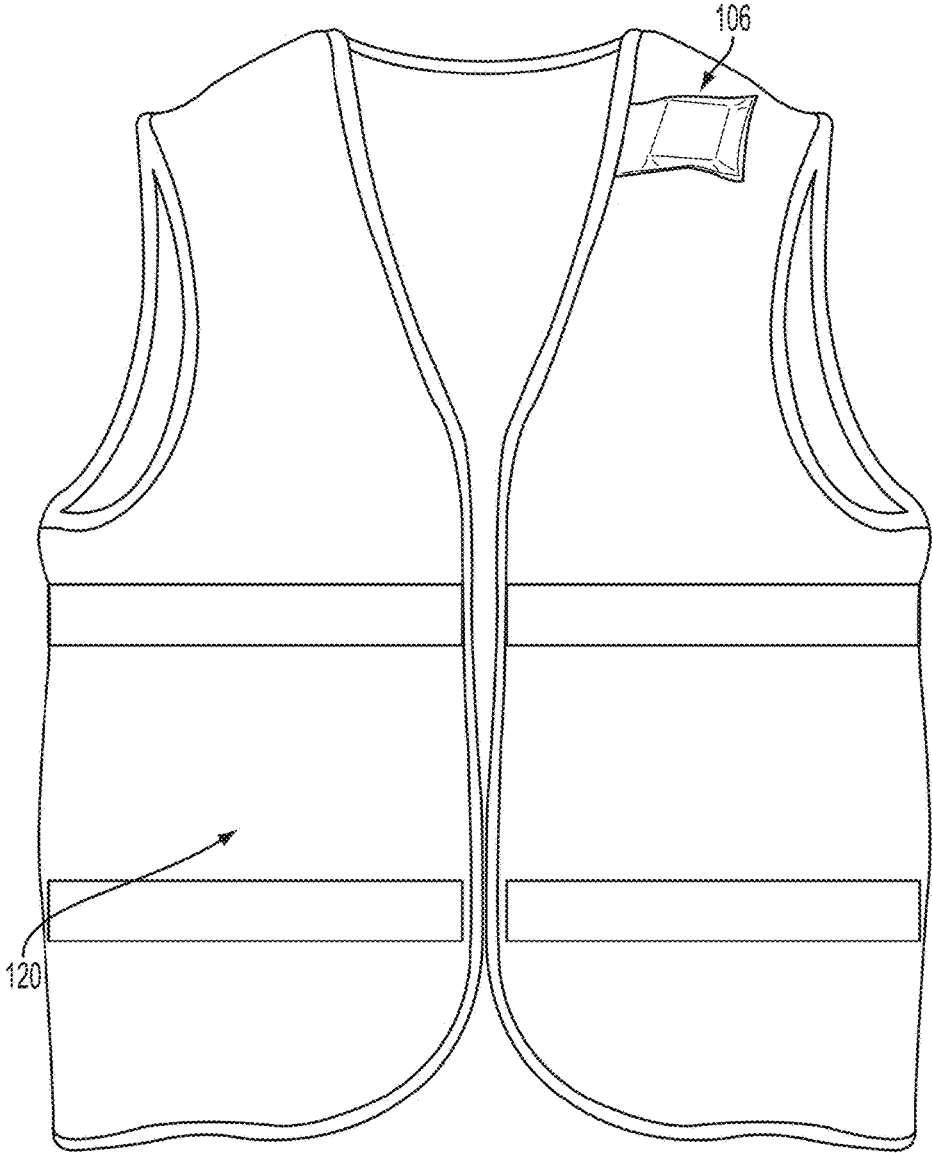


FIG. 6A

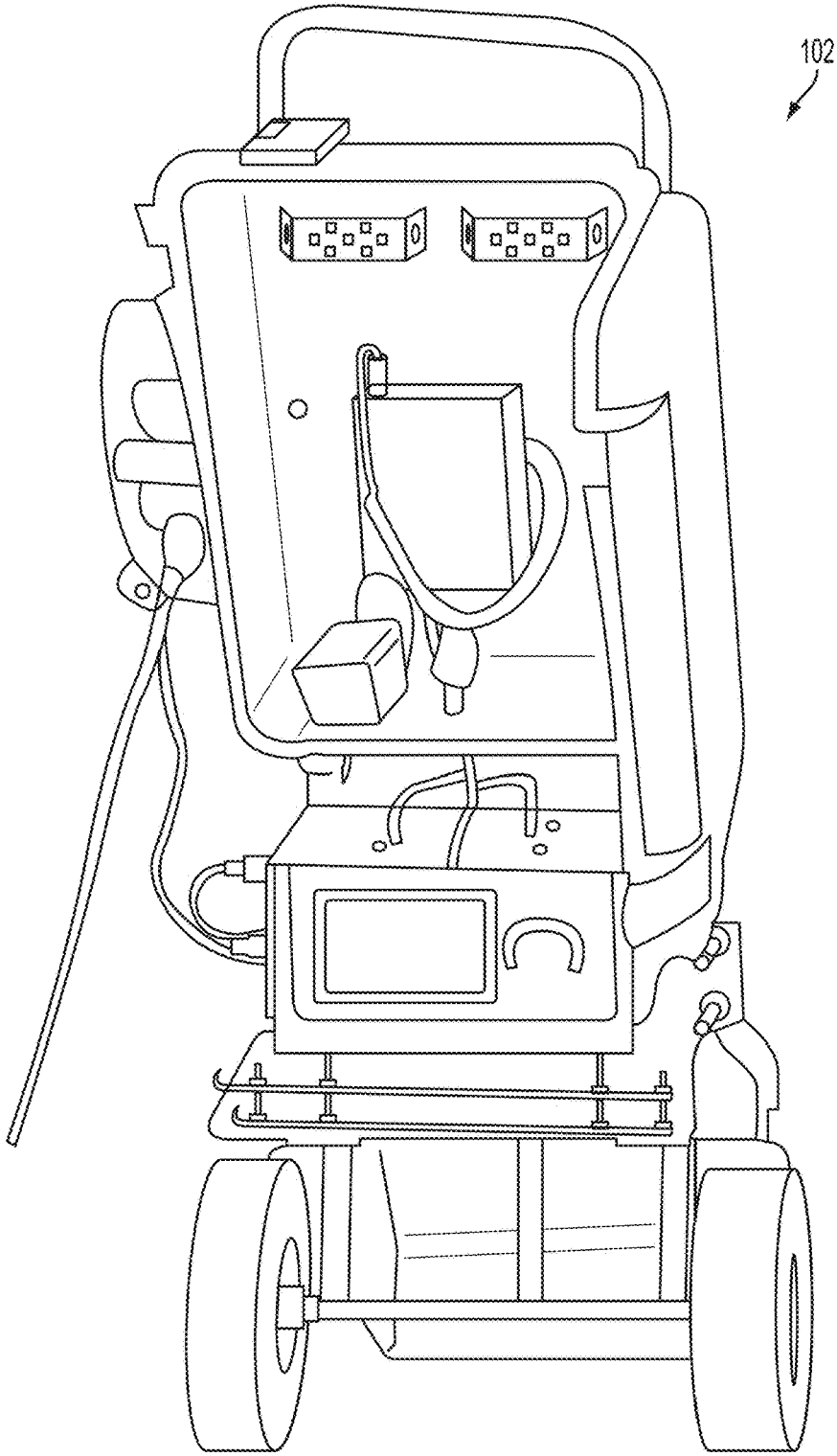


FIG. 6B

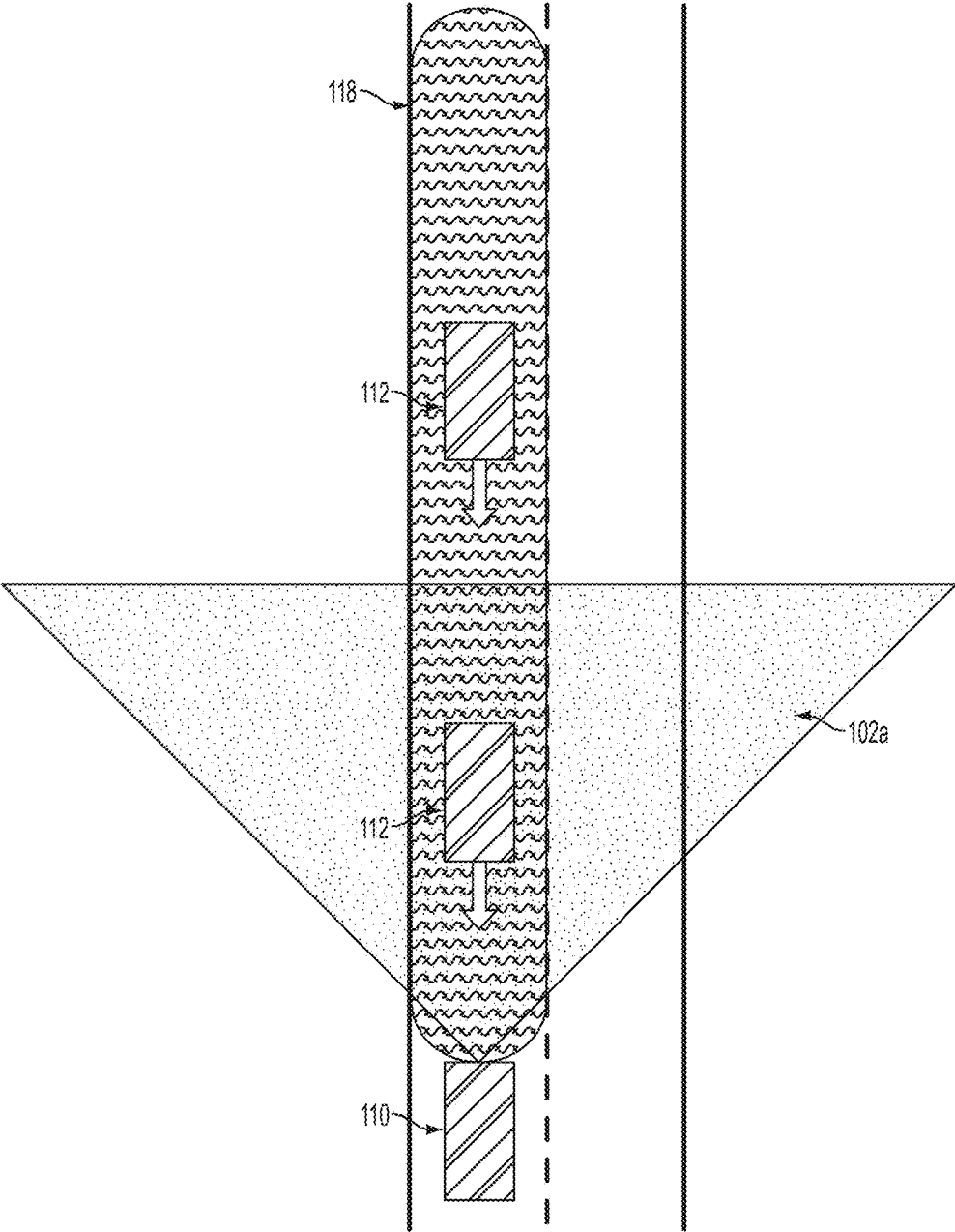


FIG. 7

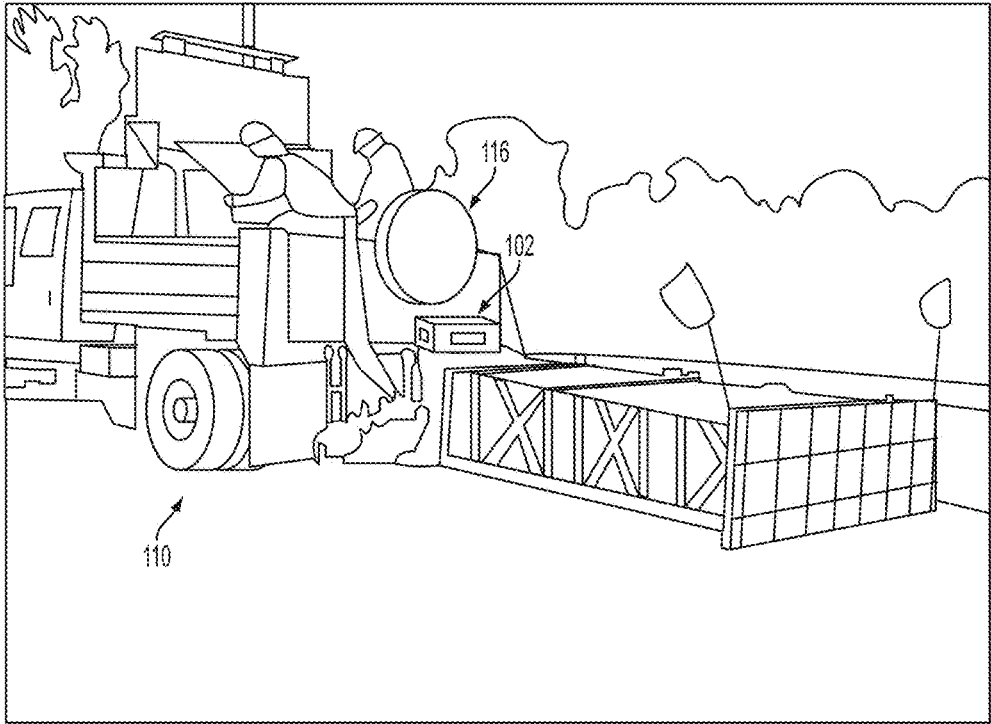


FIG. 8

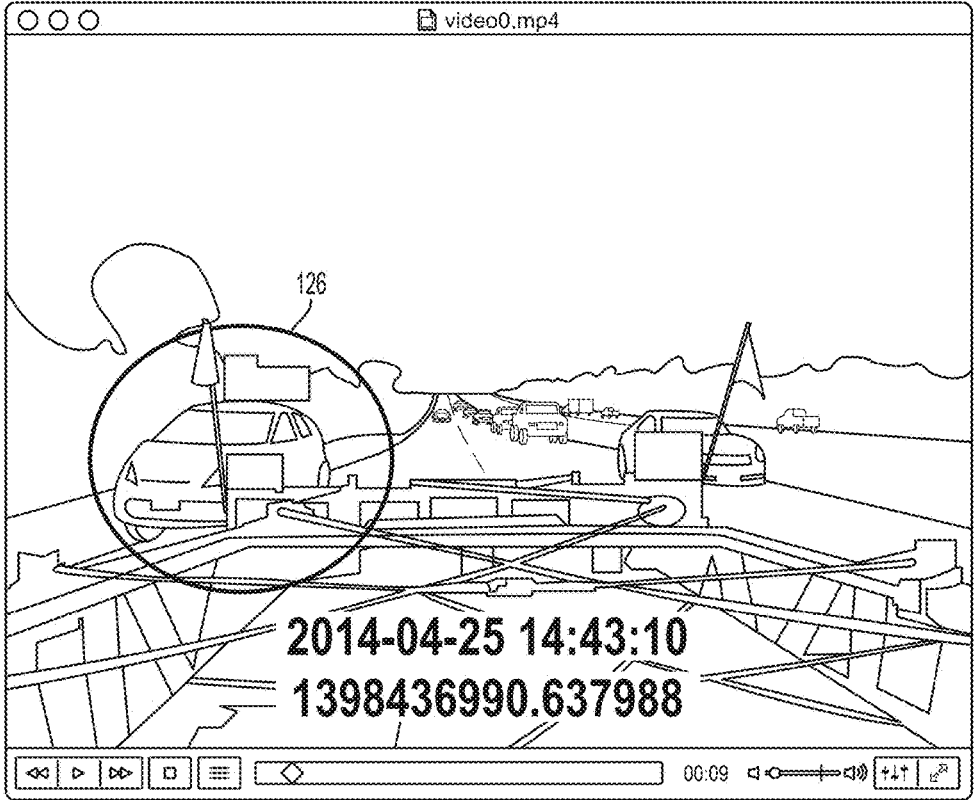


FIG. 9A

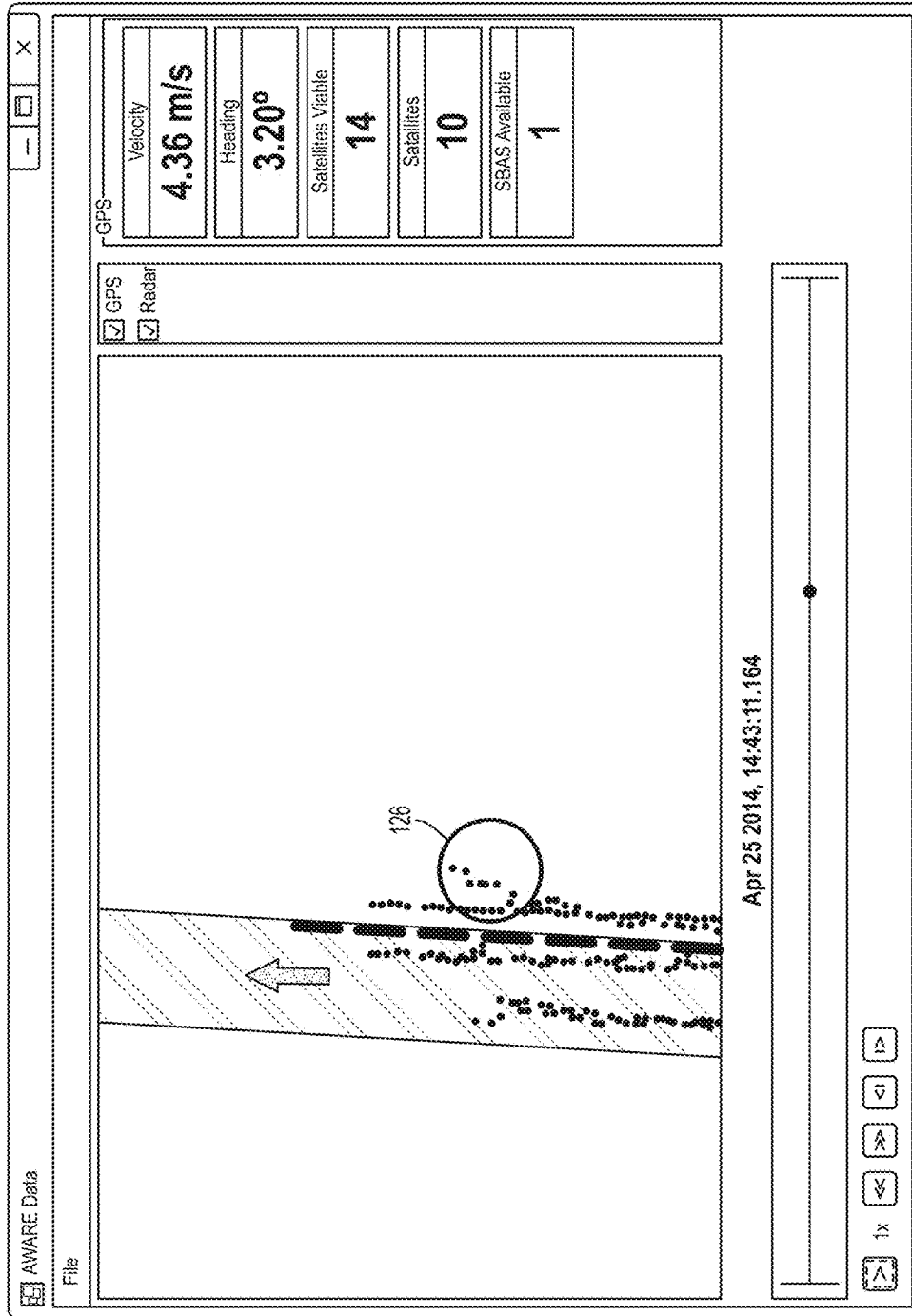


FIG. 9B

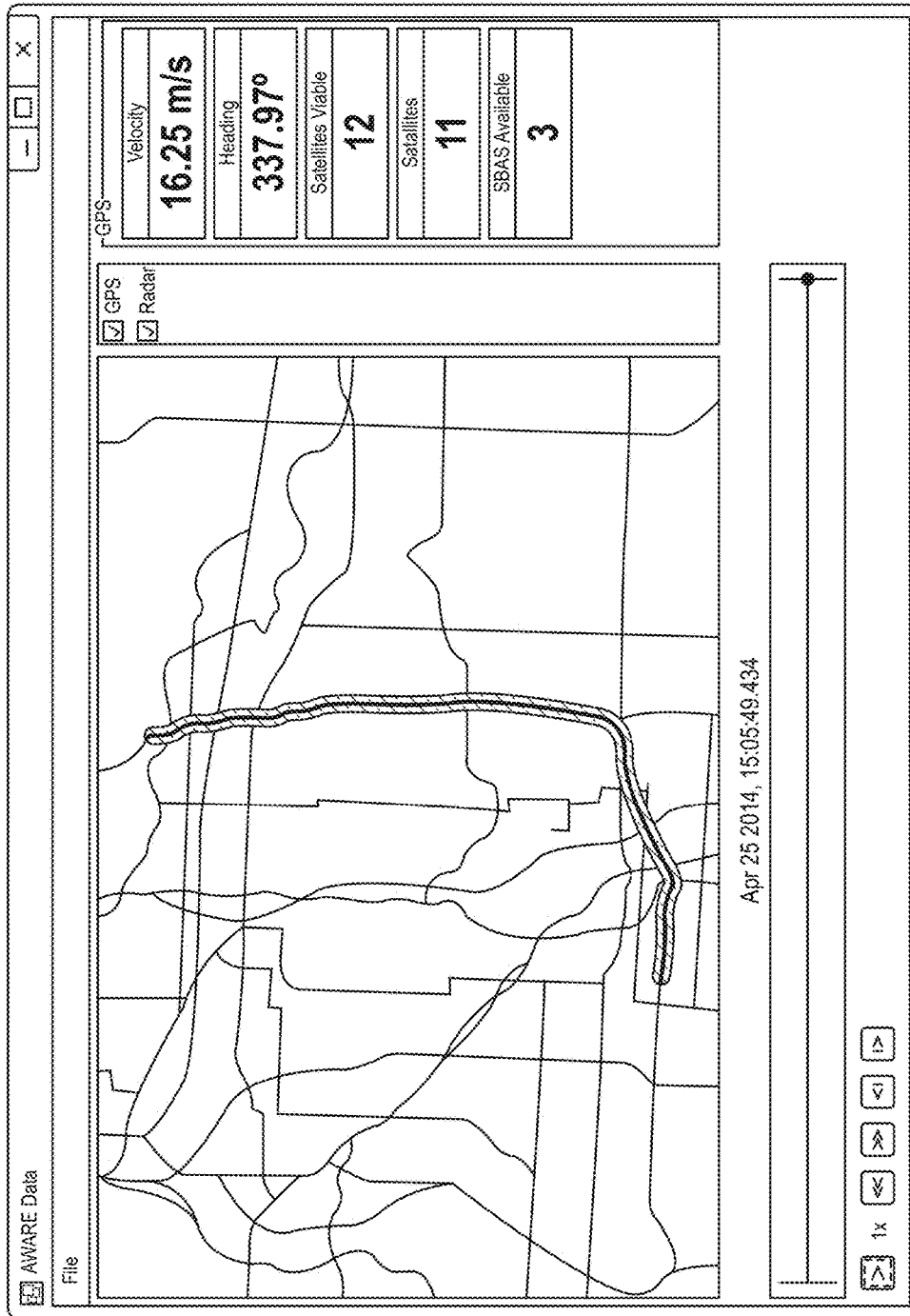


FIG. 10

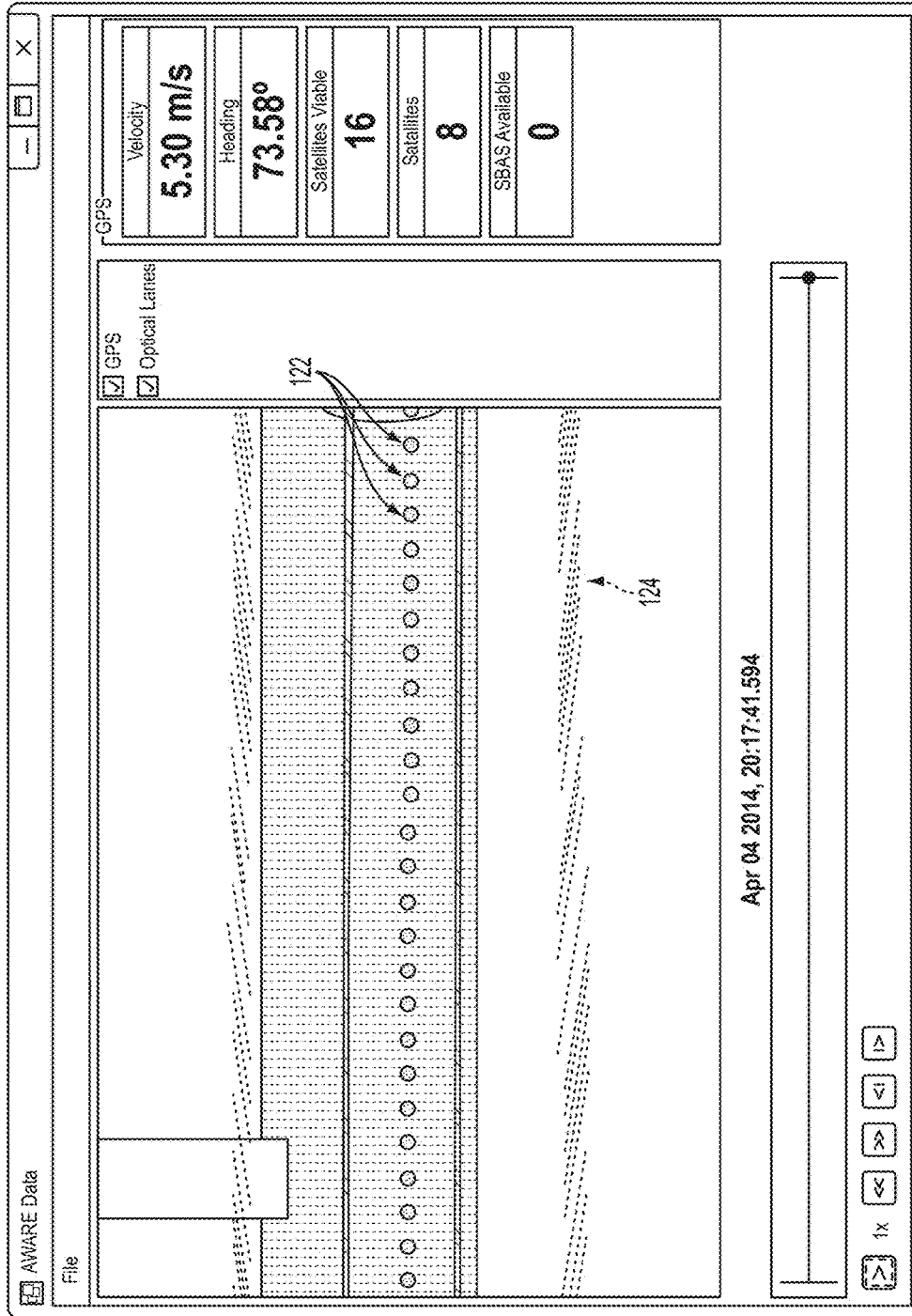


FIG. 11

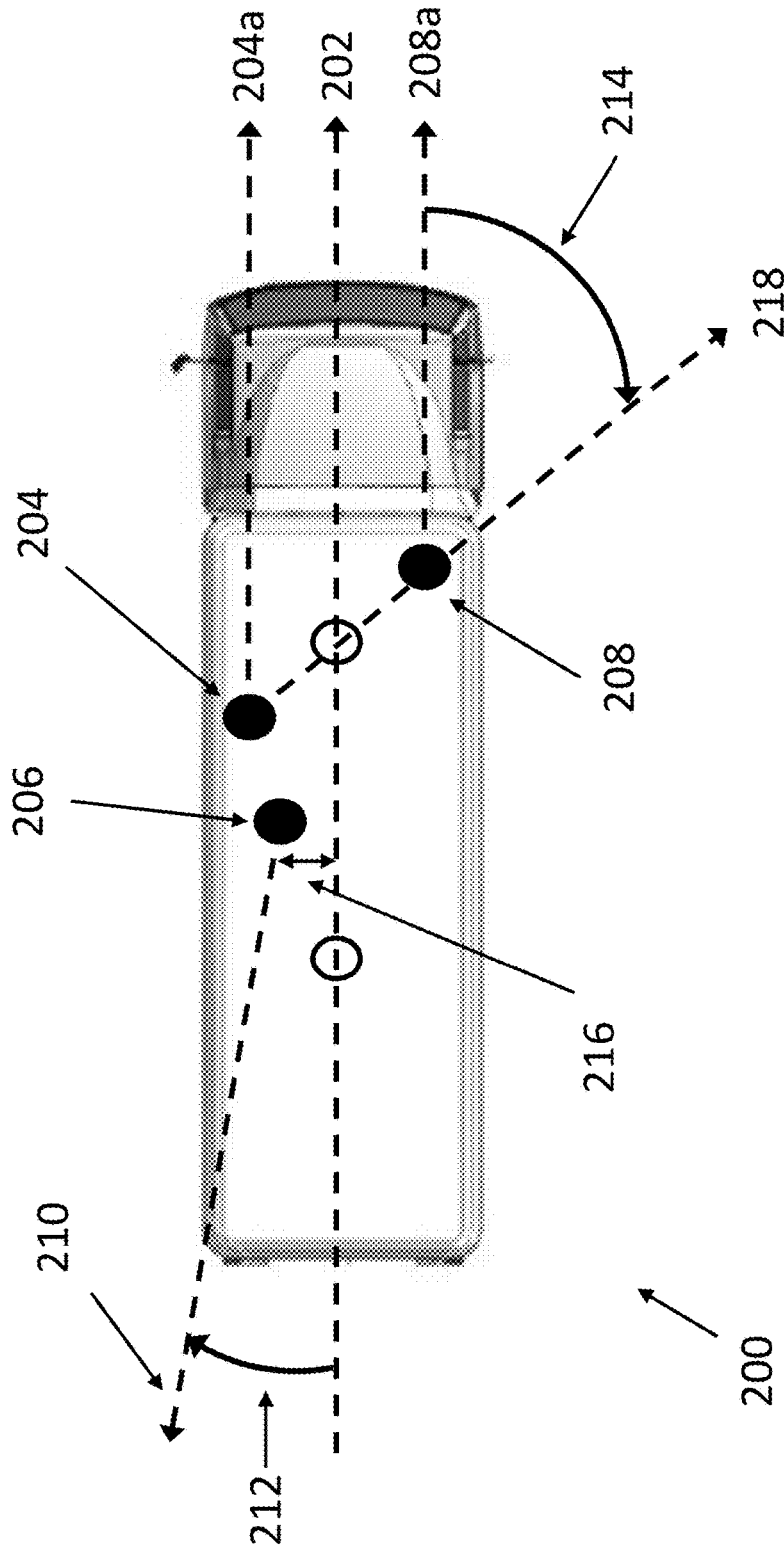


FIG. 12

ADVANCED WARNING AND RISK EVASION SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation of U.S. patent application Ser. No. 15/180,924, filed Jun. 13, 2016 entitled, "Advanced Warning And Risk Evasion System And Method," which claims priority to U.S. patent application Ser. No. 14/500,778, filed Sep. 29, 2014 entitled, "Advanced Warning And Risk Evasion System And Method," which claims priority to U.S. Provisional Patent Application Ser. No. 61/884,030, filed Sep. 28, 2013 entitled, "Advanced Warning And Risk Evasion System And Method," all of which are hereby incorporated by reference for all purposes.

BACKGROUND

Technical Field

This invention relates in general to the field of safety devices, and more particularly, but not by way of limitation, to systems and methods for providing advanced warning and risk evasion when hazardous conditions exist.

Background

Devices for increasing the safety of drivers are well known and widely available. For example, signs physically placed by highway road crews to warn of an upcoming hazard or construction site have been used to alert drivers to adjust their speed to the posted limit to accommodate the upcoming road hazard or construction. One drawback of such signs is that if not properly placed or lighted, such signs may be missed by drivers. Another drawback to such signs is that since signs must be physically placed into position by appropriate personnel they often cannot be used to warn drivers of transient conditions, such as a street sweeper or paint striper truck moving slowly down a roadway. Radars transmitting in the X, K, or Ka bands have been used by law enforcement agencies to enforce speed limits for some time. Many drivers employ radar detectors which alert the driver when the vehicle is being radiated by such police radar. In response to the alert, the driver can verify his compliance with the speed limit or adjust vehicle speed to be within the posted limit.

Some highways employ radio broadcasts to alert drivers to upcoming hazards. However, radio broadcast warning systems are of limited value because these systems require the driver to tune the radio receiver to a designated AM or FM band frequency, not already assigned to another broadcaster.

Warning systems to prevent collisions between vehicles or pedestrians and trains have been used for decades. They are found in many forms. The most commonly known is a crossing gate with audible and visible warning signals. Separate from the railroad intersection warning systems is a sound blast emanating from the train itself. The sound generated by the train blast warning, can be heard, often very loudly, outside of the danger zone. These horn blasts, however, cause undue noise pollution, disturbing those living within audible range of the intersection. While attempts have been made to address the noise pollution issue, these devices continue to disrupt an unnecessarily large area surrounding an intersection. One such solution attempts to calculate the speed of an oncoming hazard in

order to better time the warning signal. One prior art solution employed a triggering mechanism, speed/distance calculating and sound emission software, and an acoustic beam emitter. Such solution calculated the speed of an oncoming train in relation to a particular railway crossing. Based upon the speed of the train, the software will calculate the timing and, if needed, the type of warning blast to be emitted from the acoustic beam emitter. The acoustic beam emitter then generates a focused beam of sound in the direction of the warning zone. Due to the unique characteristics of the acoustic beam emitter, only those within the warning zone will hear the warning blast.

In the conventional systems described above, it is not practical to use signs or radio broadcast messages to alert drivers of an approaching emergency vehicle. Thus, a more reliable system to alert drivers of such hazards and conditions without distracting the driver is desirable to improve safety. No system presently exists that can predict an accident before it happens and coupled to a countermeasure to an imminent threat to provide sufficient warning in a high percentage of accident scenarios.

SUMMARY OF THE INVENTION

In accordance with the present invention, an advanced warning and risk evasion system and method is provided. In accordance with one aspect of the present invention, a complete advanced warning system is provided which includes sensors coupled to warning devices and in communication with real-time information processing to warn appropriate personnel of an impending danger. In some embodiments, the system may utilize one or more sensors and one or more sensor types, including radar-based sensors, GPS devices, and/or differential GPS tracking devices. In some embodiments, the sensors may be coupled to visual, acoustic, and/or other projection modality warning devices, such as a Long-Range Acoustic Device (LRAD) for providing a focused, acoustic warning to a small area, such as the driver of an offending vehicle. In various embodiments, the advanced warning system may provide an increased probability of hazard detection with a reduced rate of false alarms. In various embodiments, the advanced warning system may include a radar vicinity monitoring unit; a vehicle tracking unit; a personnel tracking unit; and a site monitoring unit.

In some embodiments, the advanced warning system may provide comprehensive situation awareness of on-site and near-site traffic and personnel to management via a base station. In various embodiments, the advanced warning system may contribute to site safety through sensing the location of all on-site personnel and mobile equipment, traffic in the local vicinity, and rapidly assessing potentially dangerous situations. Using that information, management may be able to monitor all movements on-site, across access points, and/or in the near vicinity in real-time. Such enhanced situation awareness may enable managers to assess broad safety and efficiency related situations and take corrective actions prior to dangerous or inefficient actions occurring. In some embodiments, the system may include an ability to simulate a potentially hazardous scenario to facilitate selection and location of sensors and warning devices and the creation of thresholds for warning activation.

The above summary of the invention is not intended to represent each embodiment or every aspect of the present

invention. Particular embodiments may include one, some, or none of the listed advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the method and apparatus of the present invention may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

FIG. 1 illustrates an overview of an advanced warning and risk evasion system according to an embodiment of the present invention;

FIG. 2 illustrates an overview of one aspect of the advanced warning and risk evasion system of FIG. 1;

FIG. 3 illustrates a perspective view of a construction vehicle having short-range and long-range radar fields in a rearward direction;

FIG. 4 illustrates an overview of an alternative embodiment of the advanced warning and risk evasion system of FIG. 1;

FIG. 5A illustrates an overhead view of another embodiment of an advanced warning and risk evasion system at a first point in time;

FIG. 5B illustrates the embodiment of an advanced warning and risk evasion system of FIG. 5A at a second point in time;

FIG. 6A illustrates a safety vest having a personnel monitoring device incorporated therein;

FIG. 6B illustrates an embodiment of a mobile monitoring station;

FIG. 7 illustrates an overhead view of another aspect of an embodiment of an advanced warning and risk evasion system;

FIG. 8 is a perspective view of a construction vehicle having a radar and warning device mounted thereon;

FIG. 9A is a screen shot of a video recorded from a rear facing camera mounted to the construction vehicle of FIG. 8;

FIG. 9B is a screen shot of data corresponding to the video of FIG. 9B;

FIG. 10 is a screen shot of data recorded by an embodiment of an advanced warning and risk evasion system;

FIG. 11 is a screen shot of data recorded by an embodiment of an advanced warning and risk evasion system; and

FIG. 12 is a top view of a construction vehicle having a radar and warning device mounted thereon.

DETAILED DESCRIPTION

In accordance with various embodiments of the present invention, an advance warning and risk evasion system and method is provided. The advanced warning system may incorporate the tracking of on-site vehicles and workers along with off-site traffic leading to predictions of accidents and appropriate warnings. One aspect of the advanced warning system provides one or more sensors adapted to detect and provide an early warning of an imminent hazard to personnel on a construction site. Hazards may include moving vehicles near a defined safe zone, such as, for example, during highway maintenance or on construction sites.

Referring now to FIG. 1, an embodiment of an advance warning system 100 is shown incorporating vicinity monitoring units 102; vehicle tracking units 104; personnel tracking units 106; and a site monitoring unit or base station 108. In some embodiments, the vicinity monitoring units 102 may be a radar unit that monitors traffic on the boundary

of a worksite looking for aberrant driver behavior that may result in an accident. In the embodiment shown, a vicinity monitoring unit 102 has been positioned at an entrance to a construction site with a radar detection zone directed towards oncoming traffic to monitor for vehicles veering into a predetermined safety zone (shown as a dashed line). Once a dangerous situation is assessed, warnings may be transmitted to nearby personnel, an alert message may be sent to the hazardous traffic element, and/or on-site management personnel may be alerted. In various embodiments, the vicinity monitoring unit 102 may be configurable to any work site scenario. In various embodiments, the vicinity monitoring unit 102 may be a stationary unit, may be transportable, or may be mounted to a vehicle, such as, for example, via a standard trailer hitch receiver.

Still referring to FIG. 1, in some embodiments of the system 100, the vehicle tracking unit 104 may include a GPS unit or a differential GPS system that may be mounted on vehicles dedicated towards working in the construction zone. In some embodiments, the personnel tracking unit 106 may be a battery powered device that may be simpler and/or smaller than the vehicle tracking unit 104 that is designed to track the position of personnel or temporary vehicles on the construction site and transmit the positions to various other devices. In various embodiments, the base station 108 of the system 100 may be located at an onsite headquarters and may give construction site management a map display of all personnel (via the personnel tracking units 106), vehicles (via the vehicle tracking units 104), and local traffic (via the vicinity monitoring unit 102). The system 100 may include personnel tracking unit 106 and/or vehicle tracking unit 104 optimized for low-power and maintain a charge using a photocell that may be magnetically attached to assets (such as, personnel, construction vehicles, crane booms, forklift forks, etc.) to actively monitor their position, such as, for example, via GPS and report in real-time via an integrated long-range RF transceiver. In operation, the personnel tracking unit 106 may transmit data directly to the base station 108 and/or may transmit data to the vehicle tracking unit 104. In various embodiments, personnel tracking unit 106 may be worn by each worker as well as placed on every piece of moveable machinery and all vehicles entering a worksite. The vehicle tracking unit 104 may be used to collect data from any personnel tracking unit 106 that may be nearby and process this data in real time via a threat estimation engine. The vehicle tracking unit 104 may be utilized to provide a data link between the personnel tracking unit 106 to the base station 108 or other base station. In some embodiments, accidents, warnings, or near misses may be sent to the base station 108 along with video, GPS tracking information, radar tracking information, and other data for storage and off-line analyses.

Still referring to FIG. 1, in various embodiments of the system 100, the vehicle tracking unit 104 may be utilized to lower the risk of any accident at the worksite itself. The vehicle tracking unit 104 may be mounted on the most dangerous systems at the worksite, such as large construction vehicles. It is often necessary to know the precise locations of these vehicles as well as their shape and orientation relative to the worksite. In addition, the vehicle tracking units 104 may serve as a communications node for the personnel tracking units 106. The locations of construction workers having personnel tracking units 106 may be automatically transmitted to the vehicle tracking units 104 when in reasonably close proximity. The vehicle tracking unit 104 will then do the threat estimation and communicate an alert if needed. In this way, power hungry communica-

tions and processing can be avoided for those systems relying on battery operation, such as the personnel tracking unit **106**. In various embodiments, the vehicle tracking unit **104** may include one or more of the following software modules: a threat estimation engine to examine nearby personnel tracking units **106** to estimate a threat probability based on proximity, path, and speeds, and may include identification of individuals who are required to work in close proximity to specific vehicles; an event management engine to record path and video data for set periods of time and/or record data permanently after an accident or close call event, and send warnings to base station **108**, appropriate personnel, and other units; a configuration manager to define vehicle geometry and control parameters such as camera FOV, WiFi connections, cellular connections, etc. and establish allowable personnel for close proximity operations; a BITS and maintenance manager; and/or a playback system. In various embodiments, the vehicle tracking unit **104** may include many of the same components as the vicinity monitoring unit **102** and may also include one or more of the following: INS; LCD monitor showing position and near-vicinity units; power and power management; and/or warning mechanisms (horn, voice, lights).

Referring now to FIG. 2, an embodiment of a vicinity monitoring unit **102** of the advance warning system **100** is shown in an exemplary operational scenario. In the embodiment shown, the vicinity monitoring unit **102** includes a radar sensor such as, for example, an electronically scanning radar coupled to a warning device **116** such as, for example, a long-range acoustic device (LRAD). In the embodiment of FIG. 2, two vicinity monitoring units **102** are shown, one mounted to the back of a construction vehicle **110**, such as a paint striping vehicle, and one placed near a construction worker **114**. The warning devices **116** may be configured to send an alert, such as an audible or visible message to an oncoming vehicle **112** to warn the approaching vehicle of the slow moving construction vehicle **110** and/or the presence of construction worker **114**. In some embodiments, a single message may be sent to all oncoming drivers, regardless of driver behavior. In other embodiments, a warning message could be sent only to certain drivers exhibiting hazardous behavior, such as excessive speed. In some embodiments, the system **100** may trigger an audible warning from the warning device **116** when the oncoming vehicle **112** crosses a specified velocity or distance threshold. In some embodiments, the vicinity monitoring unit **102** may include a control device for interfacing with the radar and controlling the warning device **116**. In such embodiments, the risk evasion system **100** may be utilized to warn only those drivers exhibiting dangerous behaviors and tailoring the warning to those behaviors, resulting in a more effective warning that is less intrusive to the general public. In various embodiments, the vicinity monitoring unit **102** may be operated as a stand-alone warning system, for example, a single vicinity monitoring unit **102** mounted to a moving vehicle, or may be operated as part of larger system where one or more vicinity monitoring units **102** may be disposed at various locations and in communication with each other and/or with other sub-components of the advance warning system **100**. In various embodiments, the vicinity monitoring unit **102** may be capable of providing one or more of the following functionality: collision warning, pre-crash sensing, auto-brake support (triggering external devices), and radar/camera sensor fusion; and multiple target discrimination in range, range rate, and angle for best performance in dense multi-object scenarios.

Major subcomponents of the vicinity monitoring unit **102** include the radar and the warning device **116**, such as, for example, an LRAD acoustic warning system. In various embodiments, the warning device **116** would only be triggered when a collision is imminent. The radar of the vicinity monitoring unit **102** has a field of view **102a** that may be configurable to monitor a user-selected area, such as the space adjacent to or directly behind construction vehicle **110**. In various embodiments, the warning device **116** may be configured to send directional warnings **116a** to vehicles **112** approaching a protected area. In various embodiments, the warning device **116** may be an LRAD capable of providing an audible directional warning **116a** to oncoming hazards over 3000 meters away, given line of site. In operation, the LRAD focuses acoustic energy into a very tight beam and specialized drivers allow for high acoustic energy without distortion. In various embodiments, the LRAD (such as for example, the LRAD 1000x) focused on an oncoming vehicle **112** 85 meters away may be able to deliver an audible siren with the windows up, stereo on, air-conditioner running, and other the background noise present. In a preferred embodiment, the sound would be alerting, but not startling or intolerable, and, thereafter, a verbal command would issue that would be clearly decipherable over the din. Such an audible warning may provide an effective countermeasure, enabling prevention of accidents before they even happen. In a preferred embodiment, the warning would be loud enough to be heard and not ignored, without disrupting work within the worksite or too far beyond the offending vehicle.

In various embodiments, the vicinity monitoring unit **102** may include one or more of the following: a radar, such as a Delphi ESR radar; a warning device **116**, such as an LRAD system; a video camera; local communication systems, such as WiFi, Bluetooth, and/or Zigbee, to provide communications to other components of the system **100** in the near vicinity; long-haul communication systems, such as cellular, radio, or other; a GPS or differential GPS system for proper integration with setup planning tools and base station **108**; accelerometers; tamper monitoring devices; and/or batteries or other power supplies and power management systems. In some embodiments, the vicinity monitoring unit **102** may be in communication with a smaller warning device, such as a handheld LRAD device that could be carried and/or placed in front of a work station, such as the flagger in a work zone. The vicinity monitoring unit **102** may include several sensor inputs to monitor a work zone, including, for example, radar, one or more independent GPS sensors, one or more independent inertial measurement units, and a magnetometer. In various embodiments, the vicinity monitoring unit **102** may be configured to utilize one or more of these sensors to allow the use of lower cost sensors while still achieving performance goals. In various embodiments, an algorithm may be employed to combine the results of each sensor to provide more accurate information.

In various embodiments, the radar used in the vicinity monitoring unit **102** may be an electronically scanned radar capable of measuring both speed as well as range of up to sixty-four approaching targets. In various embodiments, an algorithm may be employed to accommodate for the placement of the radar relative to the ground. For example, in embodiments where the radar is mounted four to eight feet off the ground, the radar may lose track of oncoming targets in close proximity to the radar. In such embodiments, algorithms may be employed to predict the forward trajectory of oncoming objects based on the last known trajectory of those objects. In some embodiments, the algorithm may

also compensate for situations where the vicinity monitoring unit **102** is set at a yaw angle, skewed from the path of flowing traffic.

Although GPS is a common sensing modality in navigation applications, the vicinity monitoring unit **102** of the present application may require higher precision in heading accuracy in order to measure where the radar is pointed at all times. In various embodiments, a single GPS sensor may provide acceptable heading accuracy above, for example, fifteen miles per hour. However, oftentimes construction equipment, for example in paving operations, may move much slower and frequently stop or reverse direction. To improve the accuracy of the heading measurement, the vicinity monitoring unit **102** may use two independent GPS sensors, spaced apart, for example at a distance greater than five feet, to measure the differential position of each GPS using an algorithm, such as, for example, a processing technique called real time kinematic (RTK) satellite navigation. In various embodiments, the vicinity monitoring unit **102** may use a unique approach to RTK processing by managing five independent RTK instantiations running concurrently on a processor of the vicinity monitoring unit **102**. The settings for each instantiation are shown below:

- RTK[0] Continuous Mode, Always Running, Ambiguity Ratio threshold 3.0
- RTK[1] Fix-and-hold mode, re-started after incorrect fix, Ambiguity Ratio threshold 3.0
- RTK[2] Fix-and-hold mode, re-started after incorrect fix, Ambiguity Ratio threshold 5.0
- RTK[3] Fix-and-hold mode, re-started after incorrect fix, Ambiguity Ratio threshold 4.0
- RTK[4] Continuous Mode, always running, AR threshold 2.7

Each instance uses identical GPS inputs, but each plays a unique roll in helping to determine the most reliable RTK solution.

As an initial step, the algorithm uses RTK[0] to estimate the physical Baseline Distance (BL) and Baseline Height (BL_H) between the two GPS sensors by taking sufficient measurements over time to establish statistical confidence and eliminate uncertainty do to typical GPS drift. Once the measurements are made, they are saved to non-volatile memory where they can be recalled for future use in RTK algorithms.

Using the stored BL and BL_H, each RTK instantiation is evaluated for reliability based on the following criteria:

- 1) Is the current BL measurement within +/-1.5 cm of the stored BL measurement?
- 2) Is the current BL_H measurement within +/-10 cm of the stored BL_H measurement?
- 3) Is the Ambiguity Ratio greater than required for that instantiation?

Next, the algorithm may combine RTK instantiations into a single best estimate by finding the best estimate of BL and BL_H by finding the minimum deviation from the stored values using a weighted linear combination of the squares of the deviations. Then, if all RTK instantiations are invalid (i.e., RTK [0 through n]), the combined best instance is also invalid. The final step in the GPS processing algorithm includes obtaining GPS correction codes from open sources on the internet. GPS correction codes improves the absolute position measurement of each of the single GPS sensor by compensating for aberrations caused by the Earth's atmosphere. When the vicinity monitoring unit **102** has a connection to the internet through its Wifi or 2G cellular modem or other connection, the codes are downloaded and processed.

In various embodiments, the vicinity monitoring unit **102** may include an inertial measurement unit (IMU) that may consist of both a 3-axis gyroscope as well as a 3-axis accelerometer. All IMU devices have a non-zero amount of drift, meaning that even when they are held still, the IMU measures a small amount of motion. The drift usually scales with cost—as drift performance goes down, cost goes up. In various embodiments, the vicinity monitoring unit **102** may utilize a plurality of low-cost IMU sensors mounted 180 degrees from each other. In this configuration, a differential measurement may be made where only common-mode signal swing is regarded. Differential signals are almost always caused by drift in the individual IMU devices, so averaging the two signals provides a good estimate. In various embodiments, the vicinity monitoring unit **102** may utilize a magnetometer to detect when the host vehicle reverses direction. Since the magnetometer may be mounted to heavy ferrous equipment, like a roller or paver, the magnetic measurement is usually offset from the Earth's magnetic field, but it can help to provide an estimate in the relative shift of the heading.

Referring now to FIG. 12, a typical vehicle or piece of equipment **200** is shown wherein the vicinity monitoring unit **102** mounted thereon (not shown) determines the radar heading based on one or more of the following: RTK GPS heading; single GPS heading; radar offset distance; radar offset angle; and vehicle heading. The Radar Offset Distance **216** may be measured during the installation process, and the mounting bracket for the vicinity monitoring unit **102** may be adjusted to set the Radar Offset Angle **212** to zero degrees, but the other measurements may be taken by the vicinity monitoring unit **102** in close to realtime. The Radar Heading **210** is then given by the Vehicle Heading **202** minus 180 Degrees when moving forward, and it is equal to the Vehicle Heading **202** when moving backward. Additionally, since the GPS may move from time to time, the RTK GPS heading **218** may not be consistently pointed in the same direction relative to the Single GPS heading **204a** and **208a** measurements. The RTK heading **218** is generally the most accurate heading measurement, providing down to 0.1 degree resolution even when the system is static, but the RTK heading measurement **218** is usually offset from the Vehicle Heading **202**, shown in FIG. 12 as **214**. An RTK GPS measurement **218** becomes available when the system has a clear view of the sky and has had time to monitor all the satellites in the constellation and combine their inputs. This process can take several minutes from power-up. The Single GPS heading **204a** and **208a** measurements are available when a clear view of the sky is available and the host vehicle **200** moves at a speed greater than **15** mph. When both of these measurements are available the difference between the Single GPS Heading **204a** and **208a** measurements and the RTK GPS heading **218** can be measured and stored for future use. This measurement does not need to be repeated unless a significant change in Baseline Distance or Baseline Height is detected by the RTK algorithms, indicating the GPS sensors **204** or **208** have been moved. The gyroscope measurement may assist in determining the heading of the host vehicle/equipment **200**, but it provides a relative measurement of the change in heading, not an absolute heading measurement. For example, the gyroscope can tell when and by how much the host vehicle **200** begins to turn, but it cannot tell whether it was heading North, South, East, or West to begin with. In order to reference the gyroscope heading to an absolute heading, the RTK GPS **218** or Single GPS heading **204a** or **208a** measurement must be obtained. Once one of those two condi-

tions is met, the gyroscope can be calibrated and future drop-outs of GPS coverage become less impactful to the Sensor Fusion solution. Gyroscope calibration may be repeated periodically to reduce the drift.

The ability to track all vehicles in and around the work zone is enhanced by the Sensor Fusion Algorithm. The processing and filtering of each of the sensor modalities has been discussed, but the final step includes a novel use of each of the sensors to achieve a fusion which accurately describes the motion of the host vehicle **200** as well as the surrounding traffic. The GPS, IMU and Magnetometer sensors may be combined using a weighting algorithm, such as a weighted Kalman filter. This process may be implemented when the vehicle **200** begins to move. If it is static, the system relies on the radar heat map (discussed below) to determine the Traffic Area. The Kalman process runs with the following priority given to each sensor: RTK heading; single GPS heading; drift-compensated gyro heading; and compensated magnetometer heading. Each sensor provides a confidence estimate to the fusion algorithm based on its availability and quality of measurement. The algorithm then combines the measurements appropriately, giving the most weight to the most reliable input, and applies a non-holonomic filter which removes motion that would be impossible for the given vehicle. For example, equipment may be restricted to forward or backward motion. Since it is unlikely a piece of equipment will move side to side without pulling forward or backward, side to side motion may be filtered out.

In various embodiments, the vicinity monitoring unit **102** may be configurable to perform many functions. For example, the vicinity monitoring unit **102** may detect and track vehicles, such as vehicle **112**, approaching a worksite, record relevant data and communicate the data back to the base station **108**, monitor the internal health of the unit **102**, and/or communicate with other vicinity monitoring units to assist in proper setup. In some embodiments, the software modules performing one or more of these tasks may include: a threat estimation engine to examine tracks developed by radar and estimate threat probability based on actual versus ideal path locations and speeds; an event management engine to record all radar and video data for a set period of time and record all data permanently; give accident or close call event and send warnings to a management unit, appropriate personnel, and other units; a configuration manager to control parameters (if any) such as radar/camera FOV, WiFi connections, cellular plan, etc.; a BITS and maintenance manager; a setup planning and assistance tool to display a map of a site, assist in simulation of threat parameters to be adjusted (max speed, level of path deviation for threat, etc.), and analysis of data collected and any real-world tests run, such as driving a "test car" with GPS through a work zone on a predetermined path at predetermined speeds.

Referring now to FIG. 3, a construction vehicle **110** is shown having a vicinity monitoring unit **102** mounted thereon. In various embodiments, the radar utilized in the vicinity monitoring unit **102** to monitor traffic flow may be the Delphi ESR RADAR, as it is currently being used by several automotive manufacturers in applications such as adaptive cruise control and parking assist. In the embodiment shown, the radar sensor of the vicinity monitoring unit **102** may be configured to provide dual detection zones, a close range FOV **102a** and a far range FOV **102b**. In some embodiments, the close range FOV **102a** may include a field of view of approximately plus or minus 45 degrees up to a distance of approximately 60 meters and the far range FOV may include a field of view of approximately plus or minus 10 degrees up to a distance of approximately 174 meters.

In various embodiments, the vicinity monitoring unit **102** may need to be calibrated after being mounted to construction vehicle **110**. In some embodiments, the vicinity monitoring unit **102** may be configured to allow a one-step calibration process. In such embodiments, after being mounted to the construction vehicle **110**, a calibration unit (not shown) may be placed in the field of view **102a** of the vicinity monitoring unit **102**. In some embodiments, the calibration unit may be a personnel monitoring unit having a radar reflected coupled therewith. After being mounted, the position of the GPS antennae of the vicinity monitoring unit **102** may be measured. After the antennae have been measured, an installation technician may place the calibration unit in the field of view **102a**, such as, for example, by mounting the calibration unit onto a tripod and placing it anywhere in the field of view **102a**. The calibration must take place outdoors so that the GPS antennae have a clear view of the sky. The calibration unit transmits its GPS position, for example, via radio, to the vicinity monitoring unit **102** being calibrated. The vicinity monitoring unit **102** then compares the measurements from its own DGPS set to the calibration unit's GPS position and calibrates that to the measurements being received by the sensor from the reflector. Using these data points the system can determine the exact orientation of the field of view **102a** of the sensor relative to the DGPS system. In various embodiments, the technician may perform this procedure at several points within the sensor's field of view **102a** to improve accuracy and the vicinity monitoring unit **102** may store these measurements as calibration constants.

Referring now to FIG. 4, an overview of a construction site adjacent to a roadway is shown. In the embodiment shown, the construction site includes a first construction vehicle **110a**, such as a paver, followed by a second construction vehicle **110b**, such as a roller, followed by a third construction vehicle **110c**, such as a sweeper. In various embodiments, the first construction vehicle **110a** may have a vicinity monitoring unit mounted thereon with a rearward facing field of view. The second construction vehicle **110b** may have two vicinity monitoring units mounted thereon, a first forward facing unit and a second rearward facing unit. The third construction vehicle **110c** may have two vicinity monitoring units mounted thereon, first forward facing unit and a second rearward facing unit. In such an embodiment, each of the vicinity monitoring units could be configured to monitor oncoming traffic and construction vehicles in close proximity thereto. In the embodiment shown, each construction vehicle **110a-c** may include a vicinity monitoring unit and/or may include a vehicle monitoring unit. In some embodiments, construction workers may be wearing personnel monitoring units in communication with one or more of the vicinity monitoring units, the vehicle monitoring units, and/or a base station **108**. In operation, the vicinity monitoring units may be configured to transmit a warning message if a hazardous condition arises, such as, for example, a vehicle in oncoming traffic crosses into a safe zone (shown as a dashed line); a vehicle in oncoming traffic is approaching at an unsafe speed or direction, a nearby construction vehicle is getting too close; and/or personnel are at an unsafe location. In some embodiments, the warning message may include audible and/or visual signals being sent to the oncoming traffic, a warning being sent to the operator of the construction vehicle, a warning being sent to the base station **108** and/or construction workers wearing personnel monitoring units.

Referring now to FIGS. 5A and 5B, an overview of an embodiment of the risk evasion system **100** is shown. In the

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embodiment shown, construction workers **114** are working in a construction zone adjacent to a roadway having vehicles **112** travelling thereon. In various embodiments, the system may incorporate traffic control devices, such as mobile safety barriers or other physical blockades (shown in FIGS. **5A** and **5B** as a plurality of square flags between the construction zone and the roadway) to further improve safety. In the embodiment shown, vicinity monitoring units **102** have been disposed in the construction zone, where the units **102** have fields of view **102a** configured to monitor oncoming traffic and the locations of the construction workers **114**. In some embodiments, the locations of the construction workers **114** may be monitored either by radar, video, motion, pressure, magnetic sensors, personnel tracking units (if being worn), or some combination thereof. Referring now specifically to FIG. **5B**, the vicinity monitoring units **102** are monitoring the path of oncoming vehicle **112a** and have detected that the oncoming vehicle **112a** is travelling on a path towards the construction zone. In various embodiments, upon detecting a potentially hazardous situation, the vicinity monitoring units **102** may send a warning signal to the oncoming vehicle **112a** to alert the driver to change course and/or may send a signal to the construction workers **114a** located in the path of the oncoming vehicle **112a** either by sending an audible and/or visual warning signal to the construction workers **114a** and/or transmitting a signal to their personnel tracking units. As explained in more detail below, in some embodiments, the personnel tracking units worn by the construction workers may include warning devices such that, when a hazard is detected from within the site or otherwise, the individual at risk may receive a customized warning such as "STOP," or "TAKE COVER." The warning may be clear, timely, and with very low false alarms to ensure the worker reacts in time to find safety.

Referring now to FIG. **6A**, a personnel tracking unit **106** is shown integrated into a safety vest **120** that may be worn by a construction worker. In various embodiments, the personnel tracking unit **106** may be integrated into other devices, such as a hardhat, a handheld device, a clip-on device, a protective enclosure, and/or other enclosures. The personnel tracking unit **106** may be a simpler, lower power and lower cost device than, for example, the vehicle tracking unit. The personnel tracking unit **106** may track the position of the construction worker and then transmit this information to nearby vehicle tracking units, vicinity monitoring units, and/or a base station. The personnel tracking unit **106** may include local communication functionality to provide communications onsite to other units/personnel in the near vicinity; may include a tracking system for visiting personnel and/or vehicles; may include BITS and maintenance manager; power management that may record time since a last battery charge; configuration tools; and/or a site exit warning to prevent theft or accidental site removal. In various embodiments, the personnel tracking unit **106** may include, for example, vibration capabilities, audible indicators, and/or visual indicators that may be configurable to warn the construction worker of a hazardous situation. Referring now to FIG. **6B**, an embodiment of a transportable vicinity monitoring unit **102** is shown that may be utilized in conjunction with a plurality of personnel tracking units **106**. In operation, the transportable vicinity monitoring unit **102** may be disposed in proximity to one or more construction workers wearing personnel tracking units **106** at a construction site, such as, for example, a flagger station adjacent a roadway. In various embodiments, a plurality of personnel tracking units **106** may communicate directly with the

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transportable vicinity monitoring unit **102** which may be configured to communicate with, for example, a base station, other vicinity monitoring units, and/or vehicle tracking units.

Referring now to FIG. **7**, a construction vehicle **110**, such as, a paint striping vehicle, is shown travelling along a roadway with oncoming traffic **112** travelling behind the construction vehicle **110**. The construction vehicle has a vicinity monitoring unit disposed thereon with a rearward facing field of view **102a**. In some embodiments, the vicinity monitoring unit may be configured to create a protected area **118** by combining data from one or more sources including GPS, radar, and optical sensors to build a probability map of where the protected area **118** should be located. If a vehicle **112** enters the protected area **118**, the vicinity monitoring unit applies a stopping distance equation and triggers a warning signal if the oncoming vehicle **112** approaches the construction vehicle **110** too fast or too close.

Since the radar is capable of measuring both speed and position of oncoming motorists, the position of each radar measurement may be stored. When several motorists are detected in the same position, or lane of traffic, the probability of detecting another motorist in the same position is increased. This probability can be plotted on a map as shown in FIG. **7**. The image in the center of FIG. **7** **118** shows the many radar returns captured after a time period, for example, five minutes, of collecting data while the host vehicle **110** was parked on the shoulder of a highway. The host vehicle's GPS track may be plotted and the Radar's orientation is depicted by the triangle overlay. Based on these measurements, a probability map or heat map may be constructed where "hotter" colors depict a higher probability of finding another motorist in that position. The heat map may be utilized to predict where the traffic area is, or in other words, the area where public motorists may be allowed to pass. The heat map may also depict where active work is occurring and public traffic is not allowed (for example, as shown in FIGS. **5A** and **5B**). Any deviation of public motorists from the traffic area to the protected area is considered an intrusion and various rulesets are then evaluated to determine when to send a warning to the workers via a personnel tracking unit **106**, and when to send a warning to the motorist via the visual and acoustic alerts **116**.

Referring now to FIG. **8**, a construction vehicle **110**, such as a paint striping vehicle, is shown having a vicinity monitoring unit **102** and a warning device **116** mounted thereon in a rearward facing direction. In various embodiments, the vicinity monitoring unit **102** may be configured to send an audible or visual warning signal to the vehicle if a vehicle enters a protected area (such as **118** in FIG. **7**). In some embodiments, the vicinity monitoring unit **102** may be configured to transmit data to a base station to allow construction site managers to monitor information in real-time or at a later time. The base station may include a map display of all personnel, vehicles, and local traffic. In various embodiments, aspects and functionality of various devices described herein may be included in one or more other devices, such as, for example, a base station may be incorporated into a vicinity monitoring unit or vice versa. Any warnings or near misses may be sent to the base station along with video, GPS tracks, radar tracks, and other data for real-time viewing and/or storage and later analyses. In addition, the base station may be equipped with software tools for analyzing safety situations and sensor placement to determine if the site is set up correctly; all vehicles are communicating their positions; any personnel in inherently dangerous locations, etc.

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Referring now to FIG. 9A, a screenshot captured from a camera disposed within the vicinity monitoring unit 102 of FIG. 8 is shown. In some embodiments, the video may be viewable on a monitor disposed inside the construction vehicle 110, may be saved by the vicinity monitoring unit 102 for later viewing, or may be relayed to a base station for monitoring either in real-time or at a later time. In the embodiment shown in FIG. 9A, a hazardous situation (identified by circle 126) has been detected by a vehicle entering a protected area. The hazardous situation 126 may be caused by the vehicle being too close to the construction vehicle, approaching the construction vehicle at too high of a velocity, or exhibiting erratic behavior such as driving on the shoulder of the roadway.

Referring now to FIG. 9B, a screenshot of data being displayed at, for example, a base station is shown. The base station provides a map display enabling site management to monitor all movement and view any hazardous situations detected along with backup data permitting post analysis. In the embodiment shown, data collected by the vicinity monitoring unit 102 of FIG. 8 is being played back, which may be correlated to the captured video, such as, for example, shown in FIG. 9A. The dashes shown in the figure may be GPS position measurements made by the vicinity monitoring unit 102. The dots shown in the figure may be radar returns from vehicles as they pass the vicinity monitoring unit 102. In particular, the dots located within the hazardous situation (identified by circle 126) correspond to the vehicle swerving to the right of the construction vehicle, for example, as shown in FIG. 9A.

Referring now to FIG. 10, a screenshot of a zoomed out view of the data collected from the vicinity monitoring unit 102 of FIG. 8 is shown. The data has been overlaid on a map for reference purposes. Referring now to FIG. 11, a screenshot of a zoomed in view of route data is shown. In the screenshot, GPS measurements 122 are shown as dots and optical measurements of an estimated lane position 124 are shown as hash marks. In addition to the functions mentioned above, including real time monitoring of a construction site and playback of past data for review and analysis, in various embodiments, the base station may perform higher level tasks such as examining site operations for systemic situations known to result in higher accident rates. Software modules may include one or more of the following: site map display; warning alert locator; and conditional event monitor (e.g. establish "pre-warning" conditions warranting increased monitoring).

Another aspect of the present invention involves methods for determining the selection and placement of radar sensors around a potentially hazardous location and the triggering criteria for when warnings should be activated. Using accident data, a computer simulation may be made of actual scenarios as well as other possible scenarios derived from the data to allow scenarios to be recreated and "played through" to find points at which a countermeasure could be applied in order to prevent an accident. An event simulator based on past events may be employed to accurately describe each event scenario and allow the scenario to be repeated in the computer. Additionally, it may also be possible to add other stimuli to the simulation to quantify their effect on the situation. Performance characteristics of the one or more sensors may be added to the simulation as well as proposed countermeasures so that effectiveness in a variety of scenarios may be measured. The output of the simulations may include a statistical estimate of the strengths and weaknesses of each approach.

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Simulations may be run in many different scenarios to allow for good statistical confidence of detecting imminent danger. Many different roadway factors may be measured such as, for example, velocity changes and rate; lane wandering; following distances; velocity vector; horn honking; tire squealing; sun angle, fog, smoke, wind, dust, rain, snow, and ice. A variety of sensors and computer algorithms may be utilized to detect events such as, for example, human foot traffic; 6-axis acceleration; geo-location using GPS satellites; threat detection using radar and optical sensors; pyrotechnic shock; heat, humidity, and pressure; as well as many variants of these in numerous applications. Sensor installation as well as ease of use may also be evaluated based on performance criteria, including: time to setup and install; required calibration; false alarm rate; maintenance and need for local monitoring; and required end-user training. The simulation may also evaluate how quickly the warning can be processed and transmitted to those in danger. Human reaction time and distance required to escape may be used to influence the results of each simulation. In some embodiments, the advance warning and risk evasion system may include software integrated with the system that automatically surveys a site and optimizes the placement of sensors, warning devices, and barriers based on traffic patterns.

With the problem defined and causal factors better understood, a sensor or suite of sensors may be selected to detect the potential hazards and audible and visual warning devices may be selected to provide alerts of a potential hazard. In various embodiments, performance characteristics of various potential technology and arrangements may be entered into the simulation model. The model may be varied as necessary to allow each mitigating technology to appropriately modify the outcome based on its performance data. For example, the manufacturer specifications for a certain optical sensor, such as, for example, its field of view, sensing distance, and/or image resolution, may be utilized when establishing an initial location within a scenario, whether a test scenario or real-life scenario. Thereafter, the specifications may be varied and the location further optimized as measurements of its actual performance are taken. If the required detection cannot be achieved, or the sensor is affected too heavily by environmental factors, a different device may be required. Any number of sensing devices and orientations may be tested in this virtual environment without having to acquire the device and physically evaluate it in the field. Additionally, data from actual usage can provide feedback to continually refine the system. The modified event simulator with proposed sensor performance data will enable an analysis of system performance.

In one embodiment, data from the radar is captured as a vehicle approaches and is saved into memory for later processing, as well as used to monitor the speed and range of each approaching vehicle. Saved data can be used to make the system more effective and/or for accident reconstruction in the event an accident occurs at the construction site. The saved data can be analyzed to establish and/or modify a threshold for velocity and range at which the risk evasion system may trigger the warning device, such as an LRAD unit, and send an appropriate message to the driver. In some embodiments, the radar may communicate via CAN Bus, which is a standard communication protocol commonly found in automotive applications. A control device, such as a Diligent board with a CAN Bus module, can be used to communicate with the radar as well as make the decision for when to trigger the warning device, such as an LRAD.

The advanced warning system 100 described herein inherently measures many points of interest to third parties or

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applications, which may not be of direct interest to advanced warning system **100** performance. Some examples might include: monitoring traffic volumes, patterns, and speeds near mobile work zones; monitoring the number of workers, visitors, and pieces of equipment on site in real-time; monitoring the performance of the work zone, such as start time, paving rates, down-time, and completion time; asset tracking; protecting other vulnerable operations, such as maintenance crews, first responders, or even school buses; and/or communicating work zone boundaries to approaching “connected vehicles” to help driverless vehicles navigate through work zones.

Although various embodiments of the method and apparatus of the present invention have been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it will be understood that the invention is not limited to the embodiments disclosed, but is capable of numerous rearrangements, modifications, and substitutions without departing from the spirit and scope of the invention.

What is claimed is:

1. An advanced warning and risk evasion system comprising:

a vicinity monitoring unit having a radar, the radar comprising a transmitter and a receiver configured to detect vehicles travelling through the radar’s field of view; a processor communicatively connected to the radar and configured to utilize information received from the radar to calculate a velocity of each of the detected vehicles and plot each of the detected vehicles’ position on a map;

the processor configured to identify traffic patterns on the map based at least in part on a frequency and direction of travel of the detected vehicles over time, the traffic patterns including at least one traffic area corresponding to a portion of the map where a higher number of detected vehicles pass through over time relative to other portions of the map;

the processor further configured to identify protected areas on the map corresponding to regions of the map where vehicles are not allowed to enter and to detect a hazardous situation when a target vehicle has deviated from the traffic patterns and entrance into one of the protected areas is imminent;

a warning device coupled to the vicinity monitoring unit and configured to transmit a warning signal to the target vehicle upon receiving an indication from the processor that the hazardous situation has been detected.

2. The advanced warning and risk evasion system of claim **1**, wherein at least one of the protected areas on the map moves with respect to the traffic patterns when the vicinity monitoring unit moves.

3. The advanced warning and risk evasion system of claim **1** and further comprising:

a personnel tracking unit in communication with the vicinity monitoring unit; and wherein one of the protected areas corresponds to a region of the map in close proximity to the personnel tracking unit.

4. The advanced warning and risk evasion system of claim **3**, wherein a second warning signal is sent to the personnel tracking unit when the hazardous situation has been detected.

5. The advanced warning and risk evasion system of claim **1**, wherein the warning device is a long range acoustical device capable of sending a directional acoustic beam at the target vehicle.

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6. An advanced warning and risk evasion system comprising:

a sensor comprising a transmitter and a receiver for detecting objects in the sensor’s field of view and determining a speed and position of each of the detected objects;

a processor communicatively connected to the sensor, the processor being configured to:

record the speed and the position of the detected objects over time and plot the recorded data on a map;

estimate traffic patterns, including boundaries of a traffic area on the map, based at least in part on the recorded data;

identify a protected area on the map proximate to the sensor, the protected area corresponding to a subset of a region of the map between the sensor and the traffic area;

determine a current position of a target object relative to the protected area;

compute a trajectory of the target object relative to the protected area; and

determine that a hazardous situation exists when the trajectory of the target object indicates that the target object has deviated from the traffic patterns and entrance into the protected area is imminent; and

a warning device coupled to the processor and configured to transmit a warning signal to the target object upon the determination that the hazardous situation exists.

7. The advanced warning and risk evasion system of claim **6**, wherein the protected area changes relative to the traffic area when the sensor moves.

8. The advanced warning and risk evasion system of claim **6** and further comprising:

a personnel tracking unit in communication with the processor; and

wherein the processor is configured to transmit a second warning signal to the personnel tracking unit upon the determination that the hazardous situation exists.

9. The advanced warning and risk evasion system of claim **8**, wherein the personnel tracking unit is configured to alert a user of the personnel tracking unit of the hazardous situation upon receipt of the second warning signal.

10. The advanced warning and risk evasion system of claim **6**, wherein the warning device is a long range acoustical device capable of sending a directional acoustic beam at the target vehicle.

11. An advanced warning and risk evasion system comprising:

a vicinity monitoring unit comprising:

a data storage device having program instructions and a heat map stored therein;

a sensor having a transmitter and a receiver for detecting objects in the sensor’s field of view; and a processor operatively coupled to the data storage device and the sensor;

a personnel tracking unit communicatively coupled to the vicinity monitoring unit;

wherein the processor is configured to receive information from the sensor and execute the program instructions to:

calculate velocities and positions for each of the objects detected by the sensor;

plot the positions of each of the detected objects relative to the sensor to corresponding locations on the heat map;

estimate where a lane of traffic is located on the heat map based at least in part on the plotted positions;

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analyze the calculated velocities and positions of the detected objects to estimate a trajectory of each of the detected objects; and identifying that a hazardous situation exists when the estimated trajectory of one of the detected objects indicates collision with the vicinity monitoring unit is imminent; and a warning device coupled to the vicinity monitoring unit and configured to transmit a warning signal to the one of the detected objects upon the hazardous situation existing.

12. The advanced warning and risk evasion system of claim 11, wherein the hazardous situation exists when the estimated trajectory of one of the detected objects indicates the detected object is heading towards the vicinity monitoring unit and is not following the lane of traffic.

13. The advanced warning and risk evasion system of claim 11, wherein the hazardous situation exists when the estimated trajectory of one of the detected objects indicates the detected object is heading towards the vicinity monitoring unit and a distance of the detected object from the vicinity monitoring unit is below a predetermined threshold.

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14. The advanced warning and risk evasion system of claim 11, wherein the estimated lane of traffic on the heat map changes relative to the vicinity monitoring unit when the vicinity monitoring unit moves.

15. The advanced warning and risk evasion system of claim 11 and further comprising:

a personnel tracking unit in communication with the processor; and

wherein the processor is configured to cause a second warning signal to be transmitted to the personnel tracking unit upon the identification that the hazardous situation exists.

16. The advanced warning and risk evasion system of claim 15, wherein the personnel tracking unit is configured to alert a user of the personnel tracking unit of the hazardous situation upon receipt of the second warning signal.

17. The advanced warning and risk evasion system of claim 11, wherein the warning device is a long range acoustical device capable of sending a directional acoustic beam at the one of the detected objects.

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