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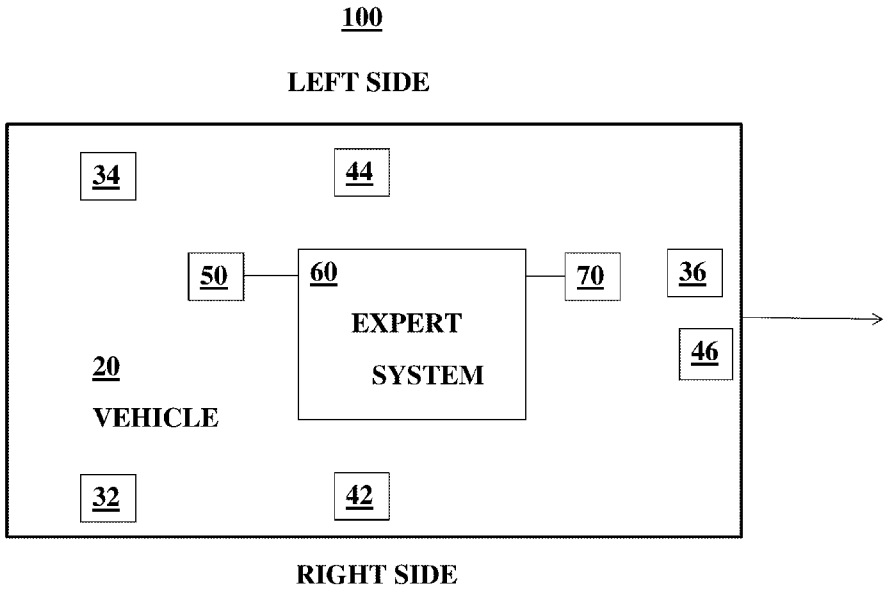
(54) Title: PEDESTRIAN COLLISION WARNING SYSTEM FOR VEHICLES

FIG. 1



(57) Abstract: A collision warning system for vehicles includes: a detection, tracking, and localization (DTL) laser module receiving laser data from a first laser range scanner, and generating laser data output, wherein the first laser range scanner covers a first laser area; a detection, tracking, and localization (DTL) thermal module receiving thermal data from a first thermal video sensor, and generating thermal data output, wherein the first thermal video sensor covers a first thermal area; a fusion module receiving the laser data output and the thermal data output, fusing the laser data output and the thermal data output, and generating a situational awareness map; and a collision prediction module receiving the situational awareness map, predicting a collision between a detected object and a vehicle, and warning an operator regarding the predicted collision.

[Continued on next page]

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PEDESTRIAN COLLISION WARNING SYSTEM FOR VEHICLES

Field of the Disclosure

[01] The present disclosure relates to a pedestrian collision warning system for vehicles. In one embodiment, a transit bus detects pedestrians or cyclists and warns a bus operator to avoid collisions.

Background of the Disclosure

[02] The background of the disclosure section is merely to present the context of the disclosure and the known problems and difficulties of the prior art. However, the statements herein are not admitted as prior art against the present disclosure.

[03] Pedestrians represent a considerable portion of traffic-related (cars, trucks and transit) injuries and deaths on our nation's highways. In 2008, 4,378 pedestrians were killed and 69,000 were injured in traffic crashes in the United States. This represents 12% and 3%, respectively, of all the traffic fatalities and injuries. The majority of these fatalities occurred in urban areas (72%) where pedestrians, cyclists, and vehicular traffic, including transit buses, tend to co-mingle. Although the pedestrian injuries and fatalities are few in number relative to other collision types, bus collisions involving pedestrians and cyclists usually carry high cost (injury claims), attract negative media attention, and have the potential to create a negative public perception of transit safety. These reasons along with increasing pedestrian traffic in urban areas and the rise of "distracted walking" of pedestrians using electronic devices, and recent efforts to promote public transit as a more sustainable and environmental friendly transportation alternative, has led transit agencies to pay substantial attention on pedestrian safety.

[04] It has been determined by many studies that a large percentage of pedestrian accidents involving transit buses are avoidable if the threat is detected early and the driver and/or pedestrians are alerted accordingly. Therefore, there is an increased demand of economically viable, accurate, and durable sensor technologies that can detect pedestrians and cyclists, estimate threat of collision, and present this information to the drivers (and optionally to pedestrians and cyclists) in a timely fashion. Effective collision warning

systems (CWS) for transit buses can address many of the incidences related to pedestrians and have the potential to save both the lives and costs.

[05] There are some sensor systems and collision warning technologies currently available, however, there are significant concerns about the reliability and questions about their performance in challenging scenarios that are typical in transit bus operations in urban environment. Accident data has shown that most of the transit bus accidents involving pedestrians occur either near the bus stops as the bus is approaching or leaving the bus stop, or as the bus is making a turn. However existing collision warning technologies are more catered towards detecting frontal collisions that are typical in highway settings. Moreover, many of the existing pedestrian detection technologies heavily rely on the use of visual sensors that have limited operating conditions in terms of lighting and weather conditions.

[06] The two primary limitations of the current pedestrian detection technologies for transit buses are: i) the inability of the sensors and detection system to perform in different environmental conditions, and ii) the inability of the detection and the threat warning generation system to operate with high-enough accuracy so that the false alarms do not become a nuisance factor for the driver/operator that they start to ignore the alerts.

[07] The existing technologies use a variety of sensors for pedestrian detection and collision avoidance, each with its own benefits, limitations, and performance tradeoffs. Almost all of the commercially available technologies for pedestrian and cyclist detection exploit image features obtained from electro-optical sensors (especially from color or monochrome video sensors). For example, MobilEye® and SafetyShield Systems Ltd, both of which employ monocular cameras to detect pedestrians around the vehicle. The performance of these systems suffer significantly with environmental and lighting conditions. In addition to challenges with different environmental conditions, the monocular camera-based systems are unable to measure the distance/relative position of the pedestrians with respect to the bus and therefore cannot make accurate collision threat assessments. Fusion Processing's CycleEye® system combines radar sensors with the visual sensor, however, due to known limitations of radar sensors for pedestrian detection, their system is only used for detection of moving cyclists around the bus. [MD+05] uses

LIDAR sensors for collision warning, however, the system is unable to distinguish between pedestrians and other objects like trees, poles, water splashes etc.

[08] [MD+05] is described by C. Mertz, D. Duggins, J. Gowdy, J. Kozar, R. MacLachlan, A. Steinfeld, A. Suppe, C. Thorpe, and C. Wang, "Collision Warning and Sensor Data Processing in Urban Areas," Intl. Conf. on ITS telecommunications, 2005.

[09] Although transit buses are used as a specific example, the ideas disclosed in this application are broadly applicable to other situations such as: any vehicle turning at an intersection or changing lanes (including airplanes turning at runways), and any vehicle entering or exiting a congested area (such as a commercial transport truck entering a loading area).

Summary of the Disclosure

[10] In one embodiment, a collision warning system for vehicles includes four major modules: a detection, tracking, and localization (DTL) laser module, a detection, tracking, and localization (DTL) thermal module, a fusion module, and a collision prediction module. The detection, tracking, and localization (DTL) laser module receives laser data from a first laser range scanner, and generates laser data output, wherein the first laser range scanner covers a first laser area. The detection, tracking, and localization (DTL) thermal module receives thermal data from a first thermal video sensor, and generates thermal data output, wherein the first thermal video sensor covers a first thermal area, and wherein the first thermal area overlaps with at least a portion of the first laser area to create a first overlap area. The fusion module receives the laser data output and the thermal data output, fuses the laser data output and the thermal data output, and generates a situational awareness map. The collision prediction module receives the situational awareness map, predicts a collision between a detected object and a vehicle, and warns an operator regarding the predicted collision.

Brief Description of the Drawings

[11] Figure 1 is a schematic block diagram of a vehicle including sensors and an expert system of one embodiment of the present disclosure.

[12] Figure 2 is a schematic block diagram of the vehicle illustrating coverage of various sensors of one embodiment of the present disclosure.

[13] Figure 3 is a schematic block diagram of components of the collision avoidance system of one embodiment of the present disclosure.

[14] Figure 4 is a schematic block diagram of an exemplary and non-limiting list of sensors.

[15] Figure 5 is a schematic block diagram illustrating some exemplary modules of an expert system of one embodiment of the present disclosure.

[16] Figure 6 illustrates a flowchart of one embodiment of an expert system.

[17] Figure 7 illustrates accidents that may occur as a transit bus pulls (a) into a bus stop or (b) out of a bus stop.

[18] Figure 8 illustrates accidents that may occur at an intersection while a bus is turning (a) to the right, or (b) to the left.

[19] Figure 9 illustrates a perspective view of a sensor configuration described in Figures 1 and 2.

[20] Figure 10 illustrates one embodiment of the collision warning system described in Figures 3-6.

Detailed Description of the Preferred Embodiments

[21] Reference will now be made in detail to embodiments of the present disclosure, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout the several views. In this regard, the present embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Accordingly, the embodiments are merely described below, by referring to the figures, to explain aspects of the present description. Terms used herein are for descriptive purposes only and are not intended to limit the scope of the disclosure. The terms “comprises” and/or “comprising” are used to specify the presence of stated elements, steps, operations, and/or components, but do not preclude the presence or addition of one or more other elements, steps, operations, and/or components. The terms “first,” “second,” and the like may be used to describe various elements, but do not limit the elements. Such terms are only used to distinguish one element from another. These and/or other aspects become apparent and are more readily appreciated by those of

ordinary skill in the art from the following description of embodiments of the present disclosure, taken in conjunction with the accompanying drawings.

[22] The words and phrases used herein should be understood and interpreted to have a meaning consistent with the understanding of those words and phrases by those skilled in the relevant art. No special definition of a term or phrase, i.e., a definition that is different from the ordinary and customary meaning as understood by those skilled in the art, is intended to be implied by consistent usage of the term or phrase herein. To the extent that a term or phrase is intended to have a special meaning, i.e., a meaning other than the broadest meaning understood by skilled artisans, such a special or clarifying definition will be expressly set forth in the specification in a definitional manner that provides the special or clarifying definition for the term or phrase.

[23] For example, the following discussion contains a non-exhaustive list of definitions of several specific terms used in this disclosure (other terms may be defined or clarified in a definitional manner elsewhere herein). These definitions are intended to clarify the meanings of the terms used herein. It is believed that the terms are used in a manner consistent with their ordinary meaning, but the definitions are nonetheless specified here for clarity.

[24] A/an: The indefinite articles "a" and "an" as used herein mean one or more when applied to any feature in embodiments and implementations of the present disclosure described in the specification and claims. The use of "a" and "an" does not limit the meaning to a single feature unless such a limit is specifically stated. The term "a" or "an" entity refers to one or more of that entity. As such, the terms "a" (or "an"), "one or more" and "at least one" can be used interchangeably herein.

[25] At least: As used herein in the specification and in the claims, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified. Thus,

as a non-limiting example, "at least one of A and B" (or, equivalently, "at least one of A or B," or, equivalently "at least one of A and/or B") can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements). The phrases "at least one", "one or more", and "and/or" are open-ended expressions that are both conjunctive and disjunctive in operation. For example, each of the expressions "at least one of A, B and C", "at least one of A, B, or C", "one or more of A, B, and C", "one or more of A, B, or C" and "A, B, and/or C" means A alone, B alone, C alone, A and B together, A and C together, B and C together, or A, B and C together.

[26] Comprising: In the claims, as well as in the specification, all transitional phrases such as "comprising," "including," "carrying," "having," "containing," "involving," "holding," "composed of," and the like are to be understood to be open-ended, i.e., to mean including but not limited to.

[27] Embodiments: Reference throughout the specification to "one embodiment," "an embodiment," "some embodiments," "one aspect," "an aspect," "some aspects," "some implementations," "one implementation," "an implementation," or similar construction means that a particular component, feature, structure, method, or characteristic described in connection with the embodiment, aspect, or implementation is included in at least one embodiment and/or implementation of the claimed subject matter. Thus, the appearance of the phrases "in one embodiment" or "in an embodiment" or "in some embodiments" (or "aspects" or "implementations") in various places throughout the specification are not necessarily all referring to the same embodiment and/or implementation. Furthermore, the particular features, structures, methods, or characteristics may be combined in any suitable manner in one or more embodiments or implementations.

[28] Exemplary: "Exemplary" is used exclusively herein to mean "serving as an example, instance, or illustration." Any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

[29] Figure 1 is a schematic block diagram of a collision warning system 100 of a vehicle 20. The collision warning system 100 includes a hardware Application Program Interface (API) 50, an expert system 60, sensors 80, and an Operator Alert Interface (OAI) (not shown in Figure 1) of one embodiment of the present disclosure.

[30] Vehicle 20 can be comprised of any kind of vehicles including a car, a bus, a truck, a motorcycle, etc. For the exemplary purpose only, a transit bus will be interchangeably used with vehicle 20 hereinafter along with a reference number 20. Transit bus 20 may travel in a forward direction as indicated by the arrow of Figure 1. The sensors 80 may include thermal video sensors 32, 34, and 36 and laser range scanners 42, 44, and 46. Specifically the thermal video sensors 32, 34, and 36 may include a right-side thermal video sensor 32, a left-side thermal video sensor 34, and a front thermal video sensor 36. Additional thermal video sensors (not shown) may be provided at the rear, or near a passenger door, or at other useful locations (such as the front right corner or the front left corner). The thermal video sensors 32, 34, and 36 may be mounted high on the transit bus 20 and be pointed partially downward.

[31] The laser range scanners 42, 44, and 46 may include a right-side laser range scanner 42, a left side laser range scanner 44, and a front laser range scanner 46. The laser range scanners may also detect velocity of objects (relative to the vehicle) and additional laser range scanners may be present.

[32] Figure 2 is a schematic block diagram 200 of the vehicle 20 illustrating coverage of various sensors 32, 34, 36, 42, 44, and 46 of one embodiment of the present disclosure. Specifically the right-side thermal video sensor 32 covers an right-side thermal area 33, the front thermal video sensor 36 covers a front thermal area 33, the right-side laser range scanner 42 covers a right-side laser area 43, and the front laser range scanner 46 covers a front laser area 46.

[33] As illustrated in Figure 2, the areas covered by the sensors may overlap. For example, front thermal area 37 substantially overlaps with front laser area 47 to create a front overlap area. Right-side thermal area 33 substantially overlaps with right-side laser area 43 to create a side overlap area. In some configurations, more than two sensed areas may overlap. For example, areas 37, 47, 33, and 43 may all overlap in a “four-fold overlap” area 49 that is in front of the vehicle 20 and to the right of the vehicle 20. This four-fold

overlap is particularly useful for transit buses in the United States (and in other countries with vehicles that drive on the right hand side of the road) as they pull into or pull out of bus stops, and as they make right hand turns at intersections. Although only one (1) four-fold overlap area 49 is described in Figure 2, every four (4) corner may have the four-fold overlap area by the coverage of various sensors 32, 34, 36, 42, 44, and 46 or any additional sensors (not shown).

[34] In one embodiment, the right-side laser range scanner 42 is mounted a few feet above the ground, near the center of the right side of the vehicle 20. The left side laser range scanner 44 is mounted a few feet above the ground, near the center of the left side of the vehicle 20. The front laser range scanner 46 is mounted a few feet above the ground, near the center of the front of the vehicle 20. Additionally, right-side thermal video sensor 32 is mounted near the roof (or on the roof), near the rear, and at the right side of the vehicle 20 (and pointed substantially forward and partially downward). The left side thermal video sensor 44 is mounted near the roof (or on the roof), near the rear, and at the left side of the vehicle 20 (and pointed substantially forward and partially downward). The front laser range scanner 46 is mounted near the roof (or on the roof), near the middle, and at the front of the vehicle 20.

[35] Figure 3 is a schematic block diagram of components 50, 60, 70, 75, and 80 of the pedestrian collision warning system 300 of one embodiment of the present disclosure.

[36] The pedestrian collision warning system may comprise a number of hardware sensors and software (instructions stored in non-transitory computer readable media) components interconnected in a modular architecture for real-time execution. The overall data acquisition and processing framework is shown in the figures. The architecture enables a unified solution for both frontal and side collision predictions and warnings. All of the system components (instructions stored in non-transitory computer readable media and/or hardware) may communicate over wired and/or wireless Internet protocol (IP), thus simplifying interconnectivity and installation during development and final deployment.

[37] Situational awareness may be developed and analyzed by capturing and processing data from the surroundings as well as from the vehicle using the sensors listed below.

[38] Specifically, sensors 80 may include the thermal video sensors 32, 34, and 36 and the laser range scanners 42, 44, and 46 previously discussed, as well as additional sensors

(discussed below regarding Figure 4). Hardware application program interface (API) 50 may connect sensors 80 to expert system 60. Operator Alert Interface (OAI) 70 transmits information from the expert system 60 to a vehicle operator. Public Alert Interface (PAI) 75 transmits information from the expert system 60 to members of the public that may be approaching the vehicle. The Public Alert Interface (PAI) 75 may be located on the vehicle, or may be located external to the vehicle, such as at a bus stop.

[39] Expert system 60 may include modules (discussed below regarding Figure 5) that process data from sensors, create a situational awareness map, predict collisions, and generate warnings. The situational awareness map and the warnings may be transmitted to the operator alert interface (OAI) 70 and/or to the public alert interface (PAI) 75.

[40] The operator alert interface (OAI) 70 may include: a display screen (not shown) illustrating a map of the area around the vehicle with various icons representing the vehicle and representing nearby pedestrians; a speaker for broadcasting alarms (such as "brake now" or "pedestrian crossing from the right"); a haptic interface for vibrating the steering wheel (and/or the brake pedal, and/or the accelerator pedal) as a warning; and a horn of the vehicle.

[41] The public alert interface (PAI) 75 may include: an external loudspeaker (not shown) for broadcasting audio alarms (such as "danger, stand back"); a visual alarm such as flashing red light; or a nozzle for spraying water to alert pedestrians.

[42] Figure 4 is a schematic block diagram of an exemplary and non-limiting list of sensors 80. The sensors 80 may include: thermal video sensors 81 as described above (32, 34, and 36), laser range scanners 82 as described above (42, 44, and 46) and optionally detecting velocity relative to the vehicle), a global positioning system (GPS) sensor 83, an inertial measuring unit (IMU) 84, a steering wheel sensor 85, a blinker/black-up signals sensor 86, a vehicle speed sensor 87 (directly measured by the vehicle), optical sensors 88 (such as a monocular or stereo black and white camera system, or color camera system), signal intelligence sensors 89, and auxiliary measurements sensor (not shown). The signal intelligence sensors 89 may detect electromagnetic signals from external sources such as: cell phones, radios, MP3 players, electrical wheelchairs, and other electronic devices. The sensors 80 may be comprised of any subset of the above listed sensors, and may include sensors not listed above. In particular, the sensors 80 may be constituted without

any one or more of a global positioning system (GPS) sensor 83, an inertial measuring unit (IMU) 84, and the auxiliary measurements sensor (not shown).

[43] Thermal video sensors 81 may be used in conjunction with laser range scanners 82 to improve detection and localization of objects in the scene. Thermal cameras (such as FLIR TCX ™ Thermal Bullet, not shown) are preferred over standard color cameras due to their ability to function in degraded environments and at night. Moreover, thermal cameras provide a better signature for detecting humans (which are often very challenging to detect) in comparison to using color cameras that frequently generate false alarms for poles and trees.

[44] The thermal video sensors 81 may be installed and positioned (e.g., on a transit bus) in a way to maximize fields-of-view overlap with laser range scanners 82 in order to facilitate information fusion for improved pedestrian detection and localization. For example, see Figure 2 discussed above.

[45] A GPS sensor 83 provides a vehicle geo-location. This vehicle geo-location may determine the vehicle's location on a map, which is useful for the system to identify its environment (near an intersection, or near a bus stop).

[46] An IMU 84 may be affixed to the vehicle's bed, may establish the vehicle orientation with respect to the road network, and may determine the anticipated motion trajectory of the vehicle 20. The IMU 84 with 9-degrees of freedom usually incorporates three integrated sensors including a MEMS (Micro-ElectroMechanical System) based triple-axis gyro, a triple-axis accelerometer, and a triple-axis magnetometer which collectively provide sufficient information to model the orientation and movement of the vehicle with respect to the environment

[47] Vehicle sensors (such as steering wheel sensor 85, blinker/backup signals sensor 86, and/or vehicle speed sensor 87) provide optional auxiliary (or additional) measurements from different components of the vehicle 20. These measurements may be obtained directly from a vehicle electronic interface. The auxiliary measurements (such as steering wheel, turn-light status, etc.), when available, can be used to predict the driver's intentions and the expected motions trajectory of the bus. For example, a driver initiated right turn blinker indicates that the driver intends to turn right, or to shift to a lane on the right, or to enter a bus stop region on the right.

[48] System components may be linked via wired (LAN) or wireless (WiFi) connectivity using off-the-shelf networking equipment. Data acquisition and processing may be performed by commercial off-the-shelf processing boards. All of the equipment may be powered from the vehicle's electrical system via an uninterrupted power supply pass through to prevent any hardware failure including rebooting and/or resets during engine shutdown/startup.

[49] Regarding signal intelligence sensors 89, many pedestrians carry electrical equipment (such as cell phones) that generates electromagnetic signals. These electromagnetic signals may be received and triangulated using antennas on the vehicle. Further, many cell phones constantly update and transmit their locations, such that a telecommunications carrier (e.g., Verizon) may know the physical location of many of its cell phones (especially if a GPS application of the cell phone is currently operating). This cell phone generated GPS information may be transmitted to the signal intelligence sensors on the vehicle indirectly via the telecommunications carrier, or directly from the cell phone to the vehicle. In one embodiment, the vehicle "pings" for GPS information from nearby cell phones. For example, the vehicle may be linked to Verizon or Google Maps, then Verizon or Google Maps may identify any cell phones near the vehicle (or identify other vehicles that are nearby), and then Verizon or Google Maps may send location information of those cell phones to the vehicle. In another embodiment, the vehicle may communicate directly with nearby cell phones (or nearby vehicles). In yet another embodiment, the location information may also include physical handicap information such as blindness or deafness of the cell phone user so that the vehicle may customize warnings (blasting a horn will not alert a deaf person, and the vehicle may utilize this information). Also, if a cell phone is being used to play a game (or talk on the phone, or cruise the Internet), then the vehicle may be notified that the user of the cell phone may be distracted and may require extra caution.

[50] Further, sensors may be permanently located at danger areas such as bus stops and intersections, and these sensors may communicate with the vehicle as the vehicle approaches the bus stop or intersection.

[51] Figure 5 is a schematic block diagram illustrating some modules of the expert system 60. Modules are hereby defined in the specification and claims as hardware, or circuit, or

instructions stored on a non-transitory computer readable medium, or a combination of hardware and of instructions stored on a non-transitory computer readable medium.

[52] There may be 4 modules: a detection, tracking, and localization (DTL) laser module 62, a detection, tracking, and localization (DTL) thermal module 64, a fusion module 66, and a collision prediction module 68.

[53] In Figure 5, the detection, tracking, and localization (DTL) laser module 62 receives an input sensor stream (laser data) from the laser range scanners 82, and detects, tracks, and localizes objects of interest using this laser data. The output of this DTL laser module 62 may include groups of laser returns in a given frame, wherein each group ideally corresponds to an object in the world. For each group, the DTL laser module 62 may output a first unique identifier that remains the same for at least a duration during which the object is detected. Additionally, the DTL laser module 62 may output a position and a velocity of each object using a vehicle coordinate system (relative to the vehicle) and/or using a geo coordinate system.

[54] Similarly, a detection, tracking, and localization (DTL) thermal module 64 receives an input sensor stream (thermal data) from the thermal video sensors 81, and detects tracks, and localizes objects of interest using this thermal data. The output of this DTL thermal module 64 may include groups of thermal returns in a given frame, wherein each group ideally corresponds to an object in the world. For each group, the DTL thermal module 64 may output a second unique identifier that remains the same for at least the duration during which the object is detected. Further, the DTL thermal module may output a bounding box in an image-space (such as a rectangle in a 2-dimensional space, or a cube in a 3-dimensional space) around each detected object and may output the second unique identifier of the detected object. Additionally, the DTL thermal module may output a position and velocity of each object in a bus coordinate system (relative to the bus) or in a geo coordinate system.

[55] The fusion module 66 may receive and then fuse (or integrate) information from the DTL laser module 62 and the DTL thermal module 64 to generate a situational awareness map 67 providing the position and velocity of each detected object (probable pedestrian or cyclist) in the bus coordinate system (or in a geo coordinate system) and in an image

space. This situational awareness map 67, along with other data 69 (such as GPS, IMU, and other measurements) may be input to the collision prediction module 68.

[56] The other data 69 may also include physical data such as a detailed physical map identifying permanent objects (such as telephone poles, curbs, and benches at a bus stop). The other data 69 may also include historical accident data from previous accidents that occurred at the same location, or at similar locations.

[57] For example, if a pedestrian stumbled over a certain curb at 11:30 PM on a Friday night at a certain location and collided with a bus last year, then the collision predictor module 68 may consider this historical accident data as part of its collision prediction process. For example, the collision prediction module 68 may attach greater importance to potential pedestrian detections late on Friday nights, and/or near the actual location where the previous accident occurred, and/or near curbs that are similar to where the previous accident occurred. The historical accident data may be regularly updated. The fusion module 66 may also use this historical accident data in a similar fashion (e.g., accepting a higher risk of false positive detections of pedestrians under certain conditions).

[58] Additionally, the fusion module 66 may consider the detailed physical map to help generate the situational awareness map. For example, known telephone poles may be compared with potential detected pedestrians (at or near the location of the known telephone pole), and some of the potential detected pedestrians may be identified/excluded as known telephone poles (instead of as pedestrians).

[59] As described above, the collision prediction module 68 may use the situational awareness map 67 and other data 69 to predict collisions. Information about predicted collisions (including warnings) may be output to an operator alert interface (OAI) 70, to a public alert interface (PAI) 75, and/or to vehicle controls 78 (such as vehicle brakes).

[60] For example, the operator alert interface (OAI) 70 may provide audio instructions (such as "be careful, pedestrian approaching from the right"), or audio alarms (such as a beeping that increases in frequency and in loudness as the risk of collision increases), or haptic alarms (such as vibrating the steering wheel).

[61] The audio instructions may increase in volume, or in tone, or in specific wording as the probability of collision increases. For example, a first audio instruction may be a gentle "be careful," then a second audio instruction may be a firm "please brake now," and

finally a third audio instruction may be a loud and repetitive "Brake hard! Brake hard! Brake hard!" Any one of these audio instruction may be broadcast by the operator alert interface (OAI) 70 as a single instruction, or may be broadcast as a series of instruction if the first instruction does not mitigate or resolve the danger of collision.

[62] Further, the operator alert interface (OAI) 70 may include a visual display (not shown) of at least a portion of the situational awareness map. This visual display may display detected pedestrians (and/or cyclists) as various icons, and may indicate pedestrians with a high probability of collision as large icons, and/or as red icons, and/or as flashing icons, and/or as boxed icons. Inversely, a pedestrian with a low probability of collision may be displayed as a small icon, and/or as a green icon, or might not be displayed at all (to reduce visual clutter). This visual display may be a "heads up" display that is displayed upon the vehicle windshield (or on a driver's glasses), and may display an icon on the windshield at a windshield location where the driver should look to see the pedestrian that is at risk.

[63] The public alert interface (PAI) 75 may include a directional loudspeaker, a vehicle horn, flashing lights, and may include a nozzle that sprays water towards a detected pedestrian or towards a danger zone. Sprayed water may alert blind pedestrians (that would not see flashing lights) and may alert deaf pedestrians (that would not hear a vehicle horn). Alternately, a combination of flashing lights and a vehicle horn may alert both blind pedestrians and deaf pedestrians. A pedestrian wearing ear plugs and watching a video on his smart phone is extremely distracted, but may be alerted by sprayed water. The nozzle may be permanently directed to a danger zone relative to the vehicle, or may be specifically directed towards a specific pedestrian.

[64] The public alert interface (PAI) 75 may operate simultaneously with the operator alert interface (OAI) 70 in order to warn the public (especially the pedestrian that is at risk) and the vehicle operator simultaneously.

[65] The vehicle controls 78 (such as the vehicle brakes) may be activated by the collision prediction module upon predicting a high probability of a forward collision. In a vehicle 20 with advanced vehicle controls (such as a self-driving vehicle), the vehicle controls may be ordered to turn left by the collision prediction module upon predicting a high

probability of collision with the front right corner of the vehicle. The vehicle controls 78 may include a vehicle horn and/or vehicle hazard lights.

[66] Figure 6 illustrates a flowchart 600 of one embodiment of the expert system 60.

[67] Step 610 receives laser data from laser range scanners 82, and then performs detection, tracking, and localization upon the laser data to generate laser data output.

[68] Step 612 receives thermal data from thermal video sensors 81 and then performs detection, tracking, and localization upon the thermal data to generate thermal data output.

[69] Optional step 614 receives other data (such as vehicle status data). These receiving steps may occur in any order.

[70] Step 616 fuses the generated laser data output and generated thermal data output. For example, thermal data output can be used to exclude (or to confirm) some potential pedestrians that are indicated by the laser data output.

[71] Step 618 generates a situational awareness map. The situational awareness map may include the vehicle 20 as a frame of reference, and may map nearby identified pedestrians (or cyclists) relative to the vehicle. The situational awareness map may include vector information (such as speed and direction) for the vehicle and for each identified pedestrian.

[72] Step 620 predicts collisions (probability of collision and/or severity of collision) for each pedestrian, based upon the situational awareness map and/or other data such as historical data.

[73] Step 622 alerts the operator (via the operator alert interface 70) when the probability of a collision with a pedestrian (or a cyclist) exceeds a predetermined level. Step 622 may also alert the public via the public alert interface 75. Step 622 may also control the vehicle through the vehicle controls 78 (especially the vehicle brakes) to avoid a collision.

[74] Figure 7 illustrates accidents that may occur as a transit bus pulls (a) into a bus stop and (b) out of a bus stop. The sensor placement described above in Figure 2 provides full coverage of pedestrian and cyclist presence around a transit bus and is able to detect a wide variety of collision scenarios involving pedestrians/cyclists and transit buses. Two of the primary scenarios that encompass a majority of accidents between transit buses and pedestrians involve bus stops and turns at intersections.

[75] In Figure 7, the system needs to observe and monitor pedestrians (depicted by small ovals) or cyclists who may in the direct trajectory of motion of the bus. In these scenarios, a pedestrian may be detected by both the front thermal video sensor 36 (also known as an IR sensor) and by front laser range scanner 46. The front thermal video sensor is particularly useful for classifying (and/or for confirming) a detected object as a pedestrian, and the front laser range scanner is particularly useful for estimating the distance and relative position of the pedestrian (relative to the vehicle) for assessing a risk of collision. Note, Figure 7 (and all of the other drawings) are not necessarily to scale.

[76] Figure 8 illustrates accidents that may occur at an intersection while a bus is turning (a) to the right, or (b) to the left. This pictures illustrate intersections at countries such as the United States where vehicles travel on the right side of the road.

[77] The bottom portion of Figure 8 illustrates a right hand turn at an intersection. In this example, a pedestrian (the oval object) at a crosswalk may be located in an area monitored by multiple sensors, as discussed above regarding Figure 2. For example, front thermal area 37 substantially overlaps with front laser area 47 to create a front overlap area. Right-side thermal area 33 substantially overlaps with right-side laser area 43 to create a side overlap area. Additionally, areas 37, 47, 33, and 43 may all overlap in a "four-fold overlap" area 49 that is in front of the vehicle and to the right of the vehicle. This four-fold overlap is particularly useful for transit buses in the United States (and in other countries that drive on the right hand side of the road) as they pull into or pull out of bus stops, and as they make right hand turns at intersections. The pedestrian in the bottom portion of Figure 8 is located in this four-fold overlap area, and is easily detected with a low probability of a false positive detection (a low probability of a false alarm).

[78] The top portion of Figure 8 illustrates a bus making a left hand turn with a pedestrian (indicated by an oval object in the figure) located on a crosswalk. Referring to Figure 2, left side thermal video sensor 34 and left side laser range scanner 44 may simultaneously detect the pedestrian during a left hand turn at an intersection. This pedestrian may or may not be in a four-fold overlap area. However, this pedestrian is at least in an overlap area covered by both the left-side thermal video sensor 34 and the left-side laser range scanner 44, facilitating the accurate detection of this pedestrian.

[79] Figure 9 illustrates a perspective view of the sensor configuration described above in Figures 1 and 2.

[80] Figure 10 illustrates one embodiment of the collision warning system described in Figures 3-6.

[81] It is to be understood that the exemplary embodiments described herein are that for presently preferred embodiments and thus should be considered in a descriptive sense only and not for purposes of limitation. Descriptions of features or aspects within each embodiment should typically be considered as available for other similar features or aspects in other embodiments.

What is claimed:

1. A collision warning system comprising:

a detection, tracking, and localization (DTL) laser module receiving laser data from a first laser range scanner, and generating laser data output, wherein the first laser range scanner covers a first laser area;

a detection, tracking, and localization (DTL) thermal module receiving thermal data from a first thermal video sensor, and generating thermal data output, wherein the first thermal video sensor covers a first thermal area, and wherein the first thermal area overlaps with at least a portion of the first laser area to create a first overlap area;

a fusion module receiving the laser data output and the thermal data output, fusing the laser data output and the thermal data output, and generating a situational awareness map; and

a collision prediction module receiving the situational awareness map, predicting a collision between a detected object and a vehicle, and warning an operator regarding the predicted collision.

2. The collision warning system of claim 1, wherein the fusion module receives additional data from an additional sensor, wherein the additional data includes a speed of the vehicle, and wherein the fusion module fuses the additional data with the laser data output and the thermal data output and generates the situational awareness map.

3. The collision warning system of claim 1, wherein the first laser range scanner is located on a front of the vehicle, and wherein the first thermal video sensor is located on the front of the vehicle and substantially above the first laser range scanner.

4. The collision warning system of claim 1, wherein the laser data output from the DTL laser module includes groups of laser returns in a given frame, wherein each group corresponds to a detected object, and wherein the laser data output further includes a unique identifier for each detected object.

5. The collision warning system of claim 1, wherein the thermal data output from the DTL thermal module includes

a unique identifier for each detected pedestrian, and includes either a bounding box around each detected pedestrian or a point location for each detected pedestrian.

6. The collision warning system of claim 1, wherein:

the DTL laser module additionally receives laser data from a second laser range scanner covering a second laser area,

the DTL thermal module additionally receives thermal data from a second thermal video sensor covering a second thermal area,

the second thermal area overlaps with at least a portion of the second laser area to create a second overlap area, and

the first overlap area overlaps at least a portion of the second overlap area, creating a four-fold overlap area.

7. The collision warning system of claim 1, wherein the collision prediction module transmits a collision warning to an operator alert interface.

8. The collision warning system of claim 1, wherein the collision warning system further comprises:

the first laser range scanner located in an inclusive range of 1 to 10 feet above a ground, in close proximity to a center of a front of the vehicle;

the first thermal video sensor located in close proximity to a roof of the vehicle, and in close proximity to the center of the front of the vehicle;

a second laser range scanner located in an inclusive range of 1 to 10 feet above the ground, and in close proximity to a center of a right side of the vehicle; and

a second thermal video sensor located in close proximity to the roof of the vehicle, and in close proximity to the back of the right side of the vehicle.

9. The collision warning system of claim 1, wherein the fusion module receives additional data from an additional sensor, wherein the additional data includes data from a global positioning system (GPS) and/or data from an inertial measurement unit (IMU),and wherein the

fusion module fuses the additional data with the laser data output and the thermal data output and generates the situational awareness map.

10. A method for predicting collisions, the method comprising:

receiving, by a detection, tracking, and localization (DTL) laser module, laser data from a first laser range scanner;

generating, by the DTL laser module, laser data output, wherein the first laser range scanner covers a first laser area;

receiving, by a detection, tracking, and localization (DTL) thermal module, thermal data from a first thermal video sensor;

generating, by the DTL thermal module, thermal data output, wherein the first thermal video sensor covers a first thermal area, and wherein the first thermal area overlaps with at least a portion of the first laser area to create a first overlap area;

receiving, by a fusion module, the laser data output and the thermal data output;

fusing, by the fusion module, the laser data output and the thermal data output;

generating, by the fusion module, a situational awareness map; and

receiving, by a collision prediction module, the situational awareness map;

predicting, by the collision prediction module, a collision between a detected object and a vehicle; and

warning, by the collision prediction module, an operator regarding the predicted collision.

11. The collision prediction method of claim 10, further comprising:

receiving, by the fusion module, additional data from an additional sensor, wherein the additional data includes speed of the vehicle, and

fusing, by the fusion module, the additional data with the laser data output and the thermal data output.

12. The collision prediction method of claim 10, wherein the first laser range scanner is located on a front of the vehicle, and wherein the first thermal video sensor is located on the front of the vehicle and substantially above the first laser range scanner.

13. The collision prediction method of claim 10, wherein the laser data output from the DTL laser module includes groups of laser returns in a given frame, wherein each group corresponds to a detected object, and wherein the laser data output further includes a unique identifier for each detected object.

14. The collision prediction method of claim 10, wherein the thermal data output from the DTL thermal module includes a unique identifier for each detected pedestrian, and includes either a bounding box around each detected pedestrian or a point location for each detected pedestrian.

15. The collision prediction method of claim 10, wherein:

the DTL laser module additionally receives laser data from a second laser range scanner covering a second laser area,

the DTL thermal module additionally receives thermal data from a second thermal video sensor covering a second thermal area,

the second thermal area overlaps with at least a portion of the second laser area to create a second overlap area, and

the first overlap area overlaps at least a portion of the second overlap area, creating a four-fold overlap area.

16. The collision prediction method of claim 10, further comprising:

transmitting, by the collision prediction module, a collision warning to an operator alert interface.

17. The collision prediction method of claim 10, wherein:

the first laser range scanner is located in an inclusive range of 1 to 10 feet above a ground, in close proximity to a center of a front of the vehicle;

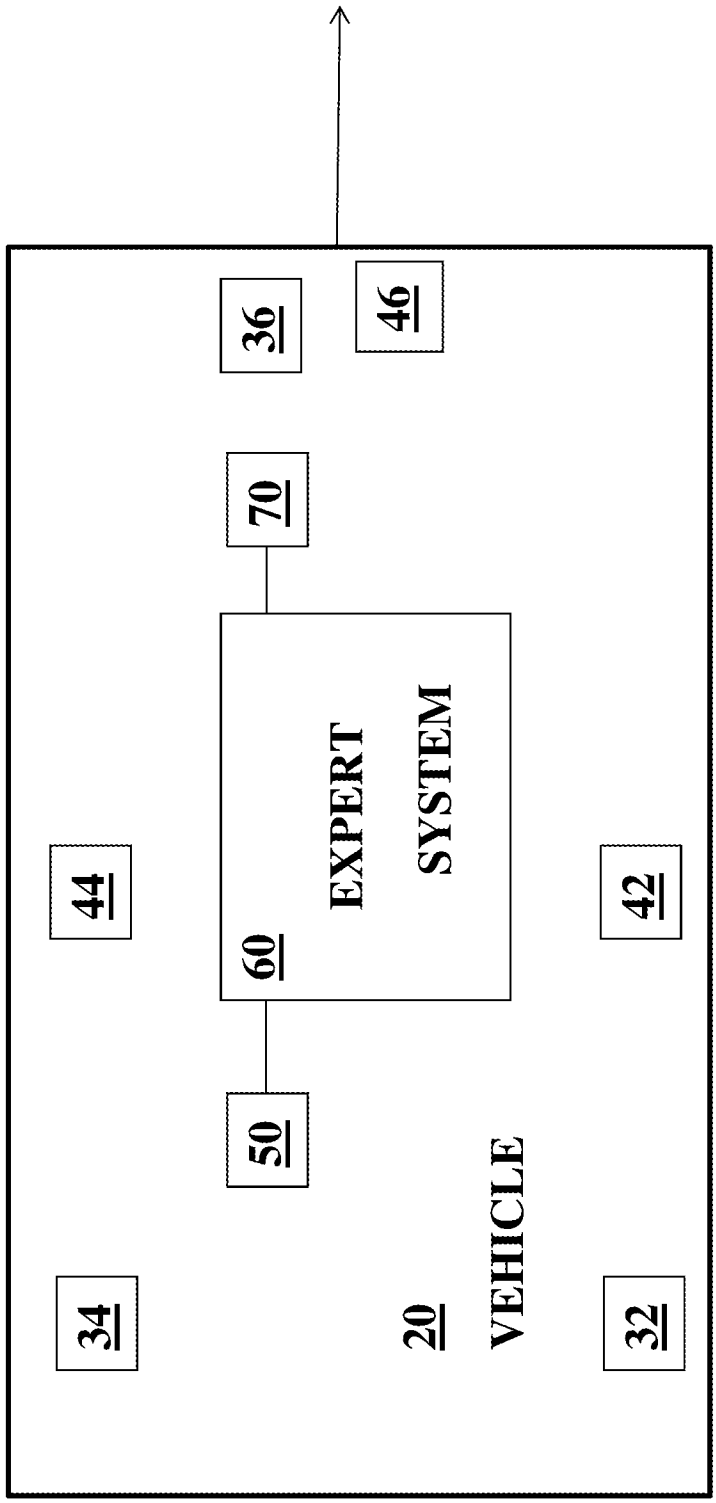
the first thermal video sensor is located in close proximity to a roof of the vehicle, and in close proximity to the center of the front of the vehicle;

a second laser range scanner is located in an inclusive range of 1 to 10 feet above the ground, in close proximity to a center of a right side or a center of a left side of the vehicle; and

a second thermal video sensor is located in close proximity to the roof of the vehicle, and in close proximity to the back of the right side of the vehicle.

18. The collision prediction method of claim 10, wherein the fusion module receives additional data from an additional sensor, wherein the additional data includes data from a global positioning system (GPS) and/or data from an inertial measurement unit (IMU), and wherein the fusion module fuses the additional data with the laser data output and with the thermal data output, and generates the situational awareness map.

FIG. 1


100
LEFT SIDE
RIGHT SIDE
36
46
70
EXPERT
SYSTEM
60
44
42
50
34
20
VEHICLE
32

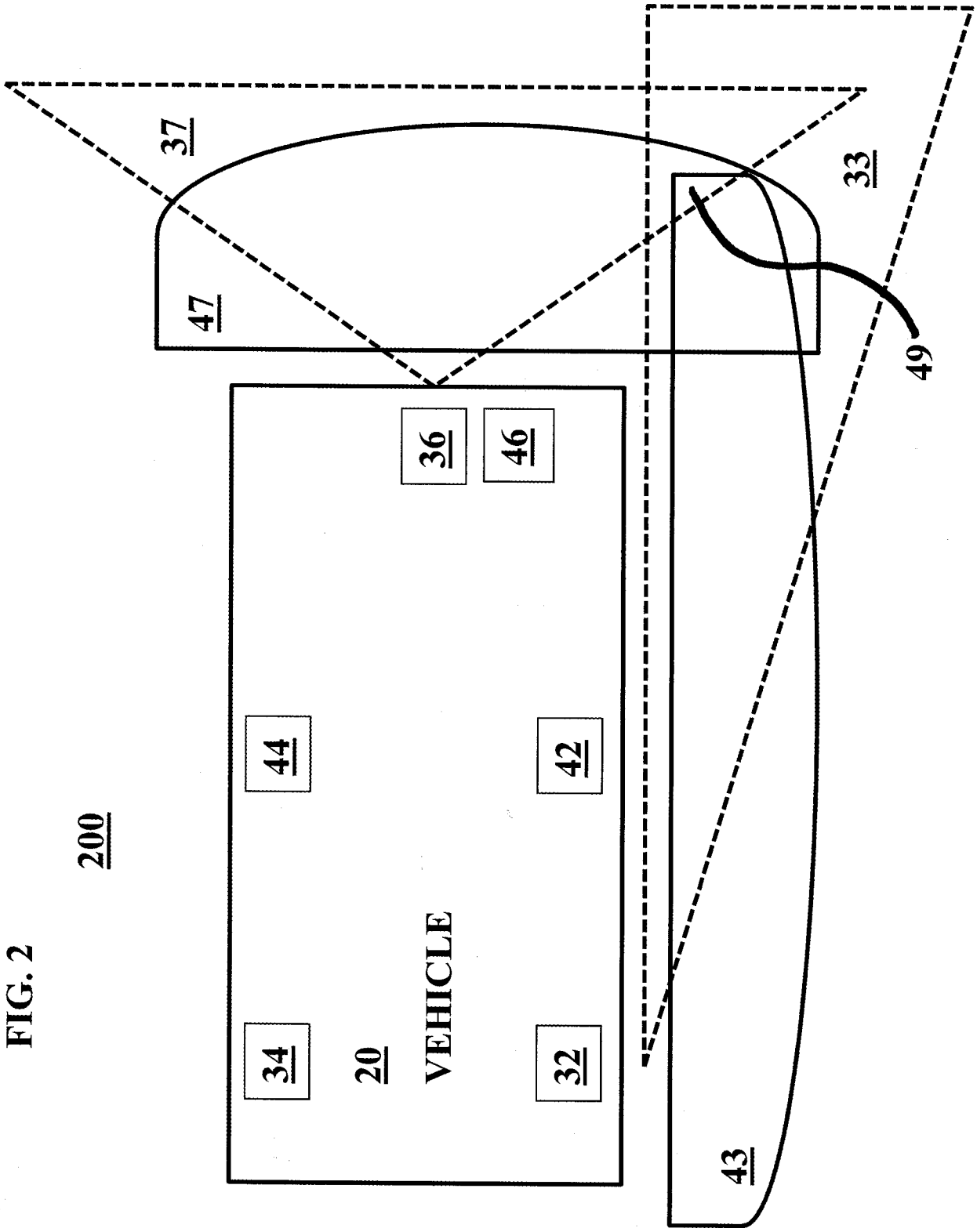


FIG. 2

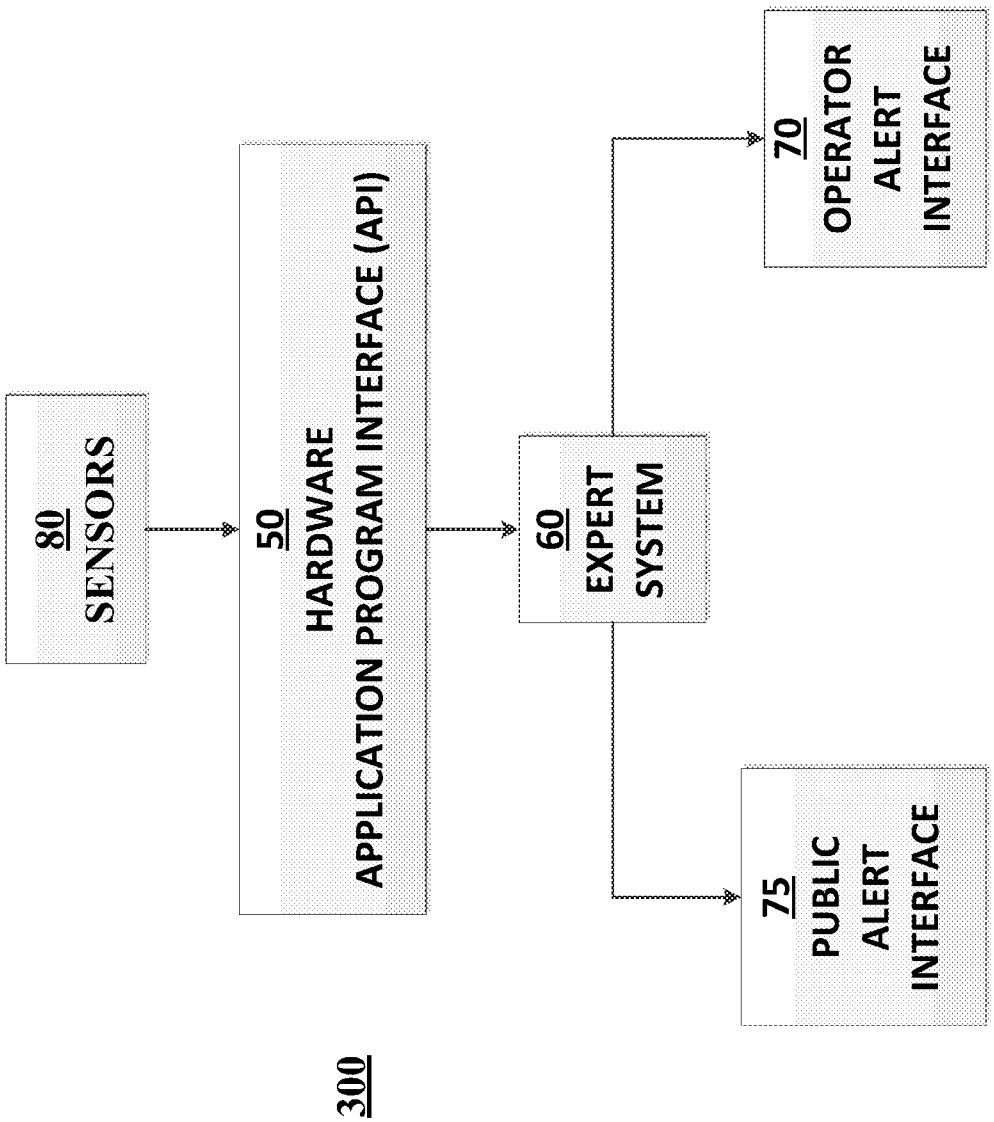

80
SENSORS
50
HARDWARE
APPLICATION PROGRAM INTERFACE (API)
60
EXPERT
SYSTEM
70
OPERATOR
ALERT
INTERFACE
75
PUBLIC
ALERT
INTERFACE
300

FIG. 3

FIG. 4

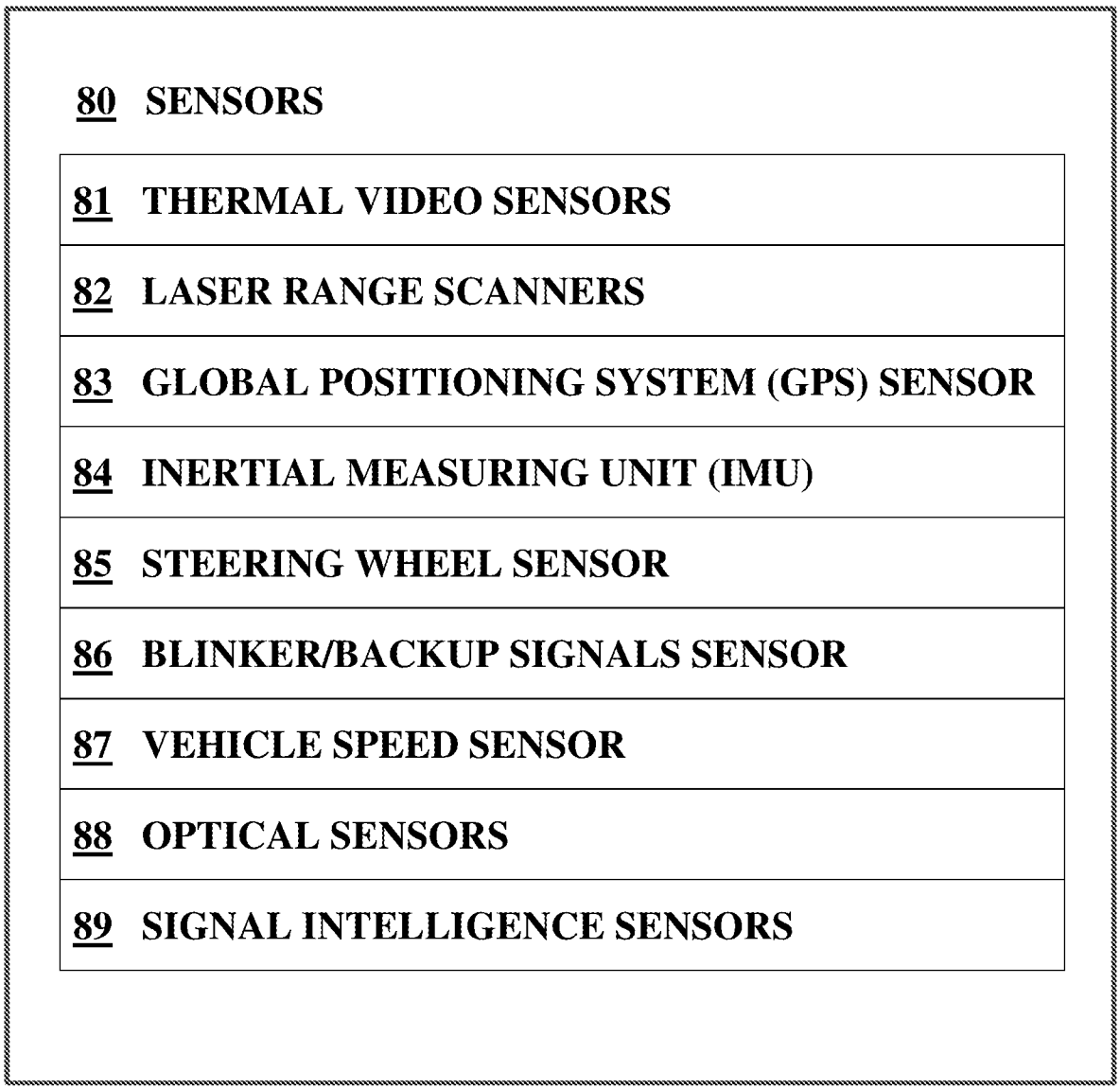

80 SENSORS
81 THERMAL VIDEO SENSORS
82 LASER RANGE SCANNERS
83 GLOBAL POSITIONING SYSTEM (GPS) SENSOR
84 INERTIAL MEASURING UNIT (IMU)
85 STEERING WHEEL SENSOR
86 BLINKER/BACKUP SIGNALS SENSOR
87 VEHICLE SPEED SENSOR
88 OPTICAL SENSORS
89 SIGNAL INTELLIGENCE SENSORS

FIG. 5

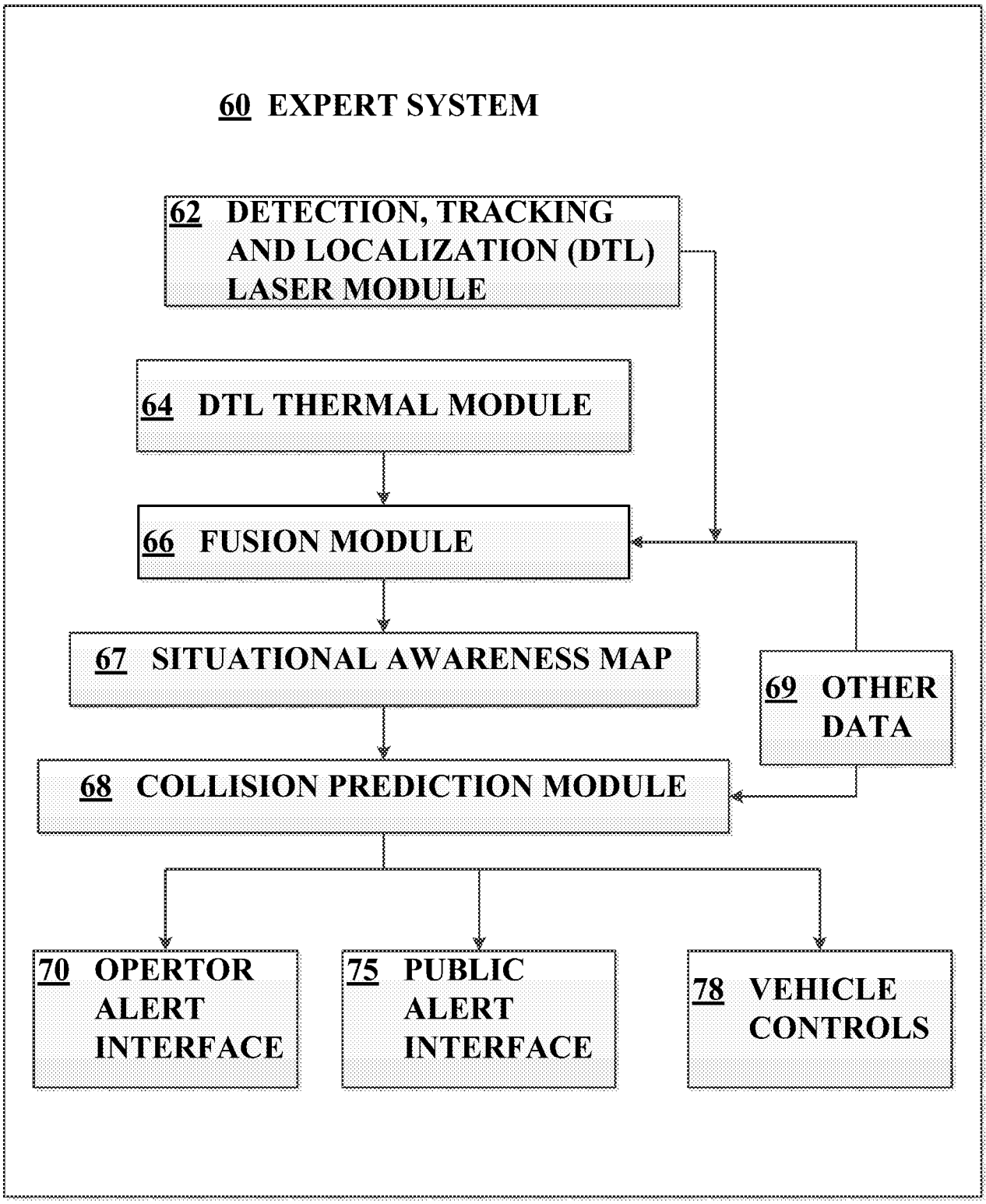
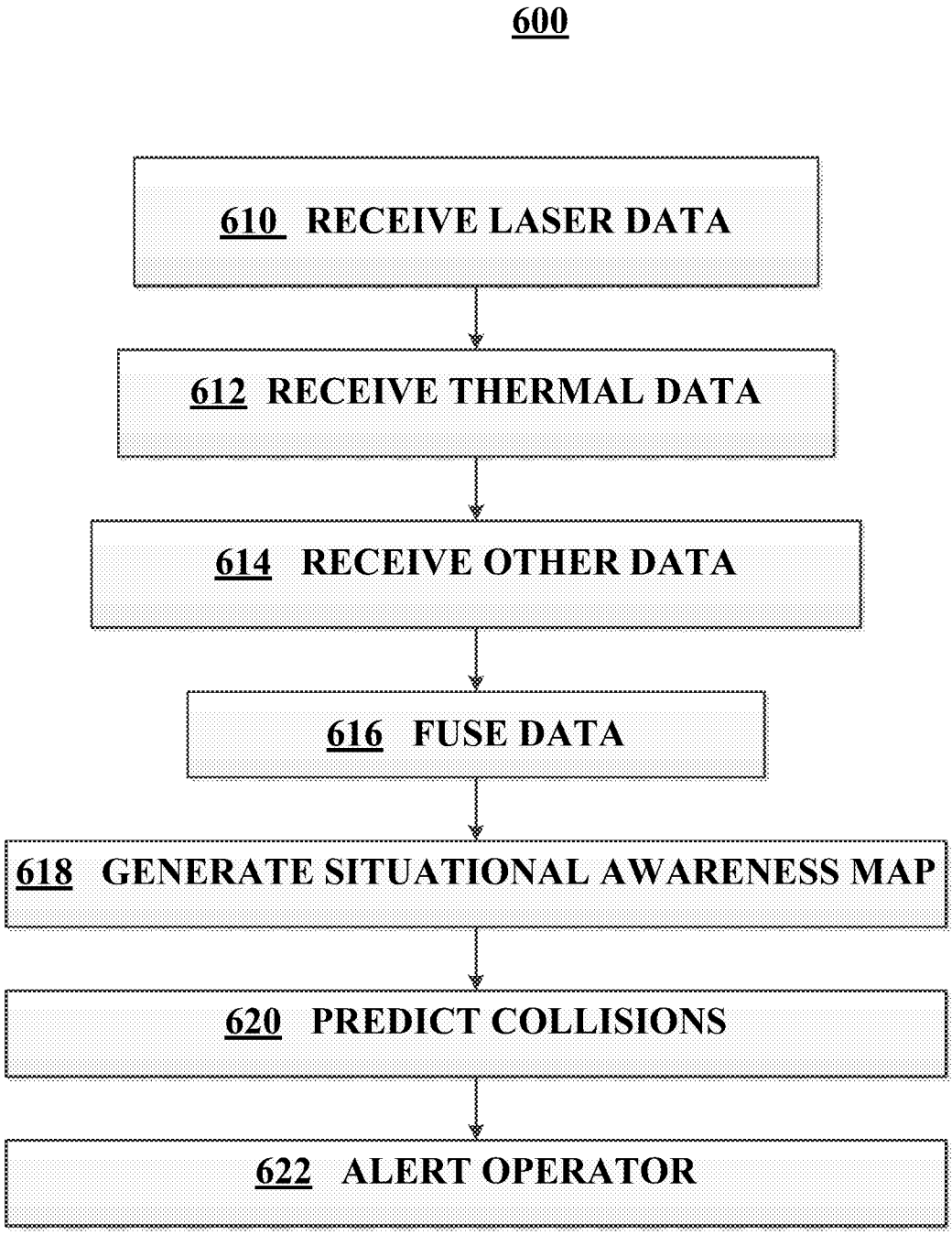
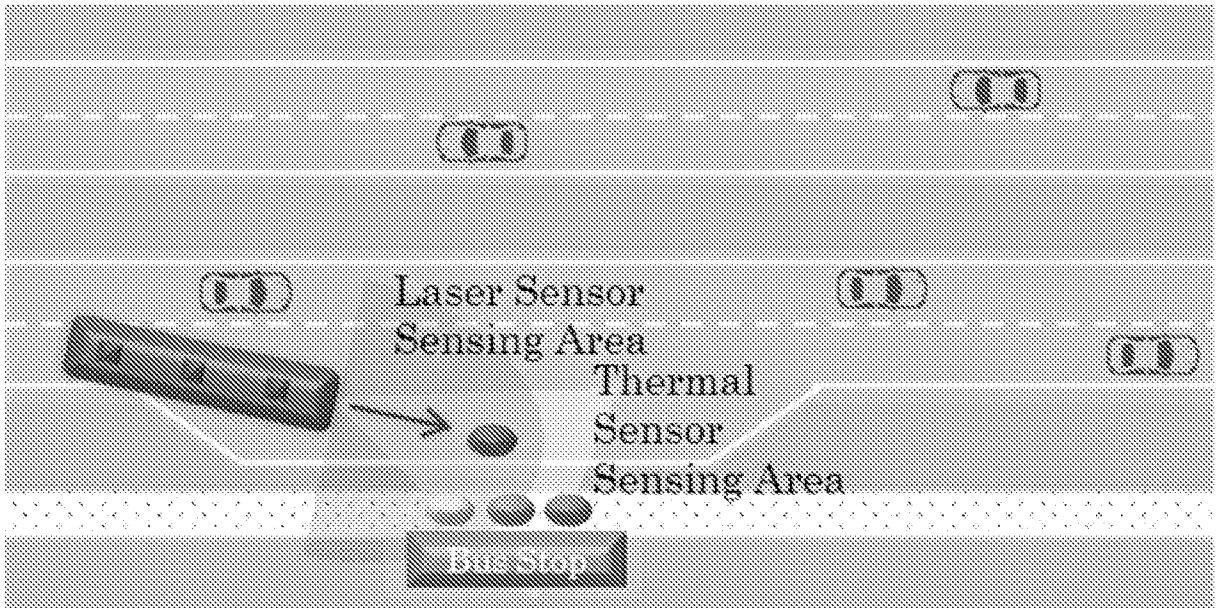

60 EXPERT SYSTEM
62 DETECTION, TRACKING AND LOCALIZATION (DTL) LASER MODULE
64 DTL THERMAL MODULE
66 FUSION MODULE
67 SITUATIONAL AWARENESS MAP
69 OTHER DATA
68 COLLISION PREDICTION MODULE
70 OPERTOR ALERT INTERFACE
75 PUBLIC ALERT INTERFACE
78 VEHICLE CONTROLS

FIG. 6

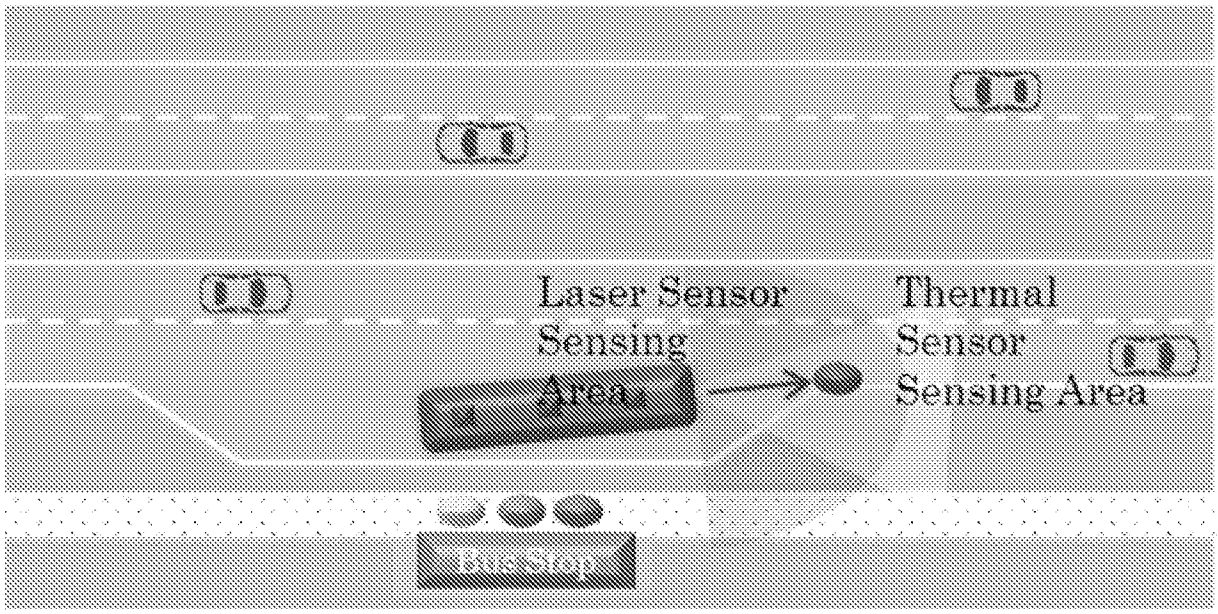


SUBSTITUTE SHEET (RULE 26)

FIGURE 7


Laser Sensor
Sensing Area
Thermal
Sensor
Sensing Area
Bus Stop

(a)


Laser Sensor
Sensing
Area
Thermal
Sensor
Sensing Area
Bus Stop

(b)

FIGURE 8

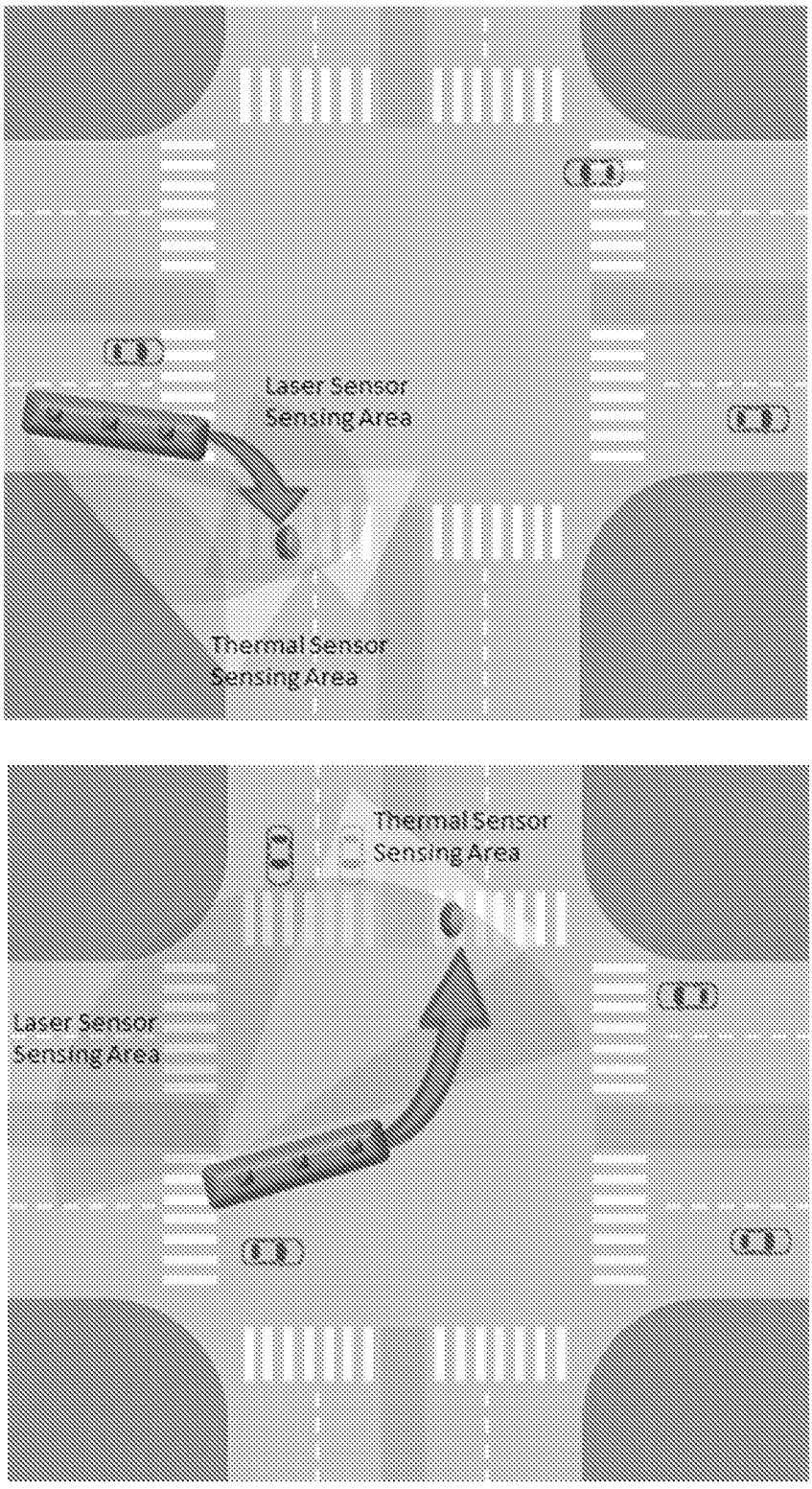

Laser Sensor
Sensing Area
Thermal Sensor
Sensing Area
Thermal Sensor
Sensing Area
Laser Sensor
Sensing Area

FIGURE 9

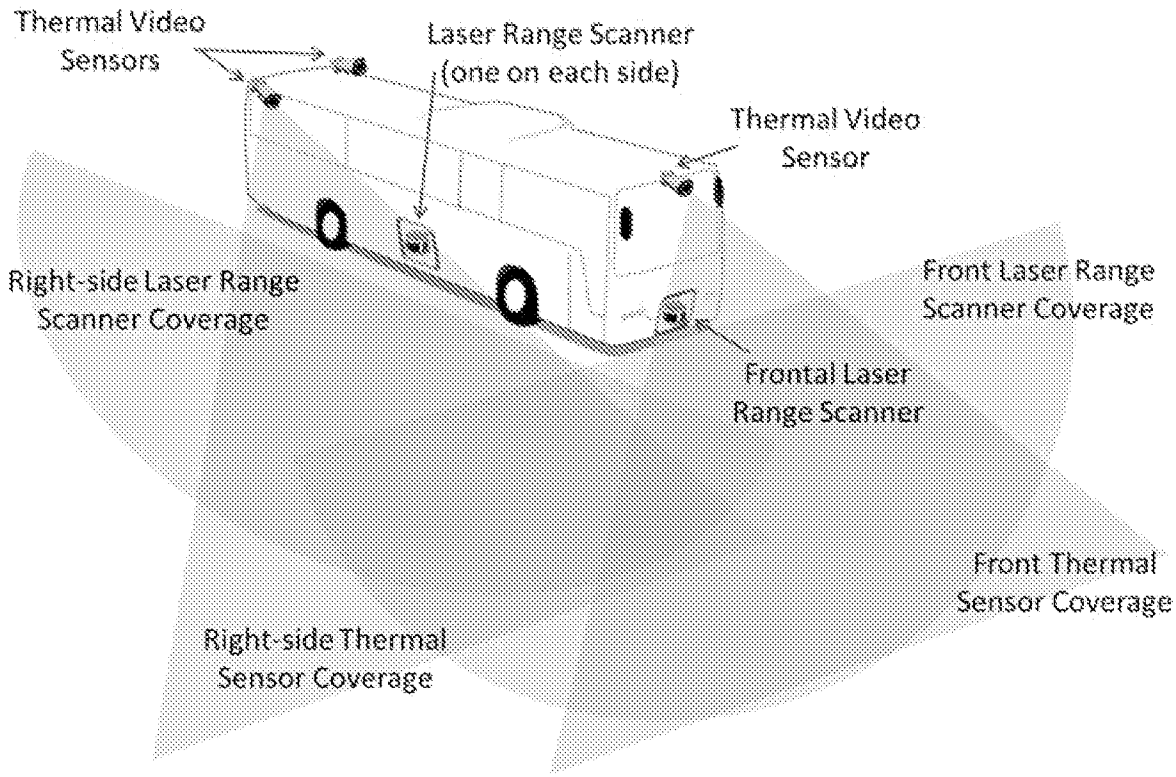
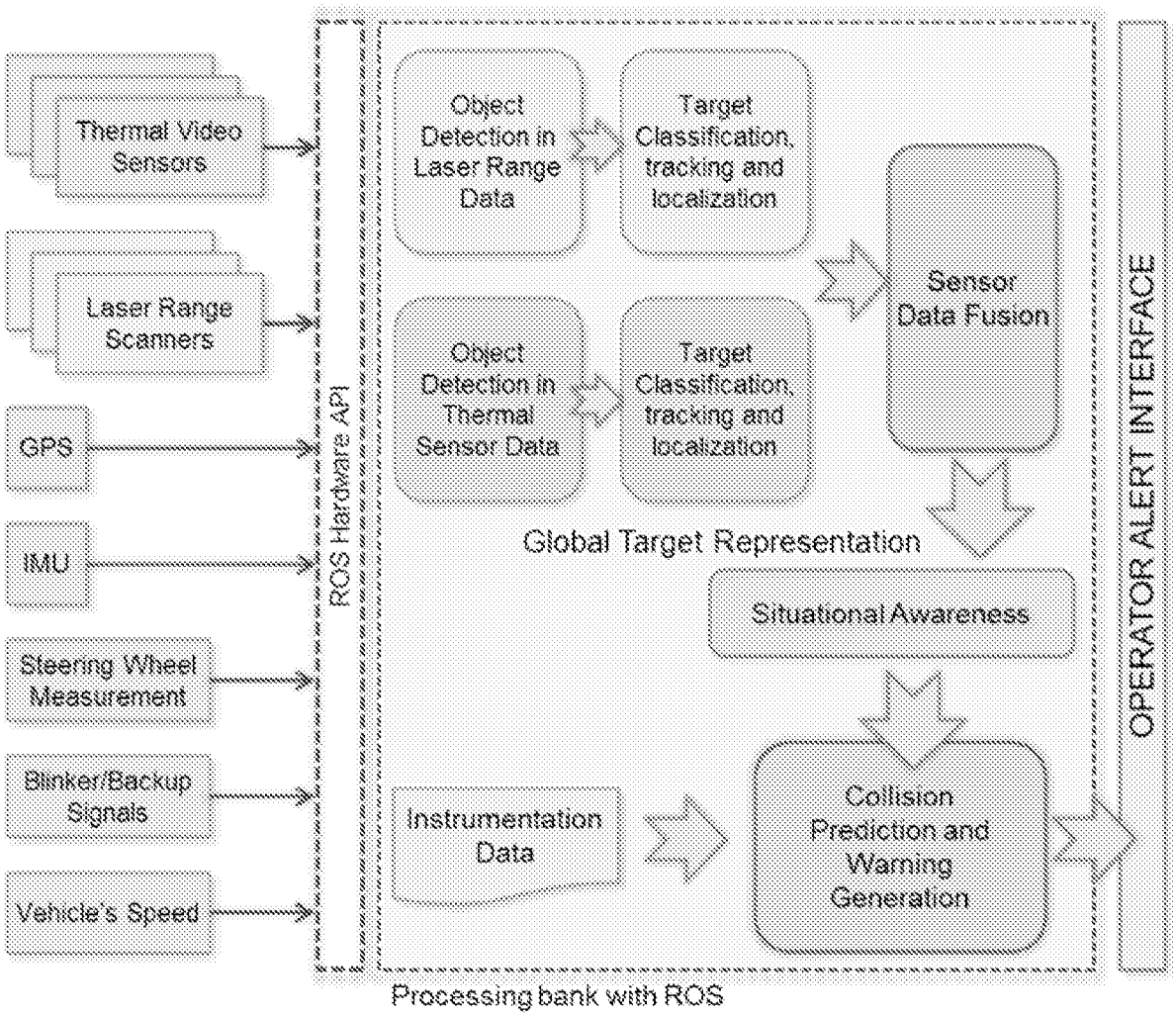

Thermal Video Sensors
Laser Range Scanner (one on each side)
Thermal Video Sensor
Right-side Laser Range Scanner Coverage
Front Laser Range Scanner Coverage
Frontal Laser Range Scanner
Front Thermal Sensor Coverage
Right-side Thermal Sensor Coverage

FIGURE 10


Thermal Video Sensors
Laser Range Scanners
GPS
IMU
Steering Wheel Measurement
Blinker/Backup Signals
Vehicle's Speed
ROS Hardware API
Object Detection in Laser Range Data
Target Classification, tracking and localization
Object Detection in Thermal Sensor Data
Target Classification, tracking and localization
Sensor Data Fusion
Global Target Representation
Situational Awareness
Instrumentation Data
Collision Prediction and Warning Generation
OPERATOR ALERT INTERFACE
Processing bank with ROS

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US17/57350

A. CLASSIFICATION OF SUBJECT MATTER
IPC - G08G 1/16; G01C 22/00; G05D 1/00 (2017.01)
CPC - G08G 1/16; G01C 22/00; G05D 1/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,151,539 A (BERGHOLZ, R et al.) 21 November 2000; figure 4, column 4, lines 53-67; column 5, lines 1-17; column 7, lines 5-17, lines 45-63; column 8, lines 35-51; column 9, lines 16-45	1-18
A	US 6,721,659 B2 (STOPCZYNSKI, L) 13 April 2004; column 3, lines 26-58; column 4, lines 1-27, lines 48-65	1-18
A	EP 3 073 465 A1 (APPLICATION SOLUTIONS ELECTRONICS AND VISION LIMITED) 28 September 2016; paragraph [0033], [0038], [0039], [0043-0044], claim 10	1-18
A	US 6,411,896 B1 (SHUMAN, D et al.) 25 June 2002; entire document	1-18
A	US 2008/0309913 A1 (FALLON, J) 18 December 2008; entire document	1-18

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 December 2017 (06.12.2017)	04 JAN 2018
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (January 2015)