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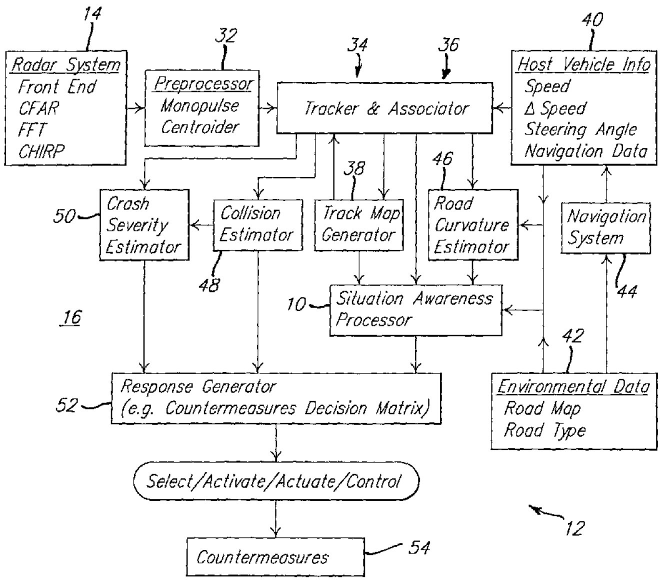

(57) Abstract: A plurality of events (S) representative of a situation in which the host vehicle (16) is operated are selected, including at least one set of related events (S_η). Input data (e_i) is provided to an inference engine from either a first set of data representative of a target (18) in a field of view of the host vehicle (16), a second set of data representative of the position or motion of the host vehicle (16), or a third set of data is representative of an environment (30) of said host vehicle (16). The inference engine operates in accordance with an inference method to generate an output representative of a probability of occurrence of at least one event (S^λ)of the set of events, responsive to the input data (e_i), and possibly to one or more outputs (P_{k-1}) at a past time (k-1). A countermeasure (34) may be invoked responsive to one or more outputs (p_k) from one or more inference engines.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

SITUATION AWARENESS PROCESSOR

In the accompanying drawings:

FIG. 1 illustrates a target in view of a host vehicle in a local coordinate system of the host vehicle;

FIG. 2 illustrates a block diagram system incorporating a situation awareness processor;

FIG. 3 illustrates a block diagram of host vehicle with a system incorporating a situation awareness processor;

FIG. 4 illustrates a general inference process of a situation awareness processor; and

FIG. 5 illustrates an example of an inference process of a situation awareness processor.

There exists a need for an improved predictive collision sensing or collision avoidance system for automotive applications that can sense and identify an environment of a host vehicle with sufficient range and accuracy so that proper countermeasures can be selected and taken sufficiently early to either avoid a collision; or to mitigate injury therefrom either to occupants of the host vehicle, or to pedestrians outside thereof. As used herein, the term predictive collision sensing system will also refer to a collision avoidance system, so as to mean a system that can sense and track targets in the environment of the host vehicle, and then either suggest, or automatically invoke, countermeasures, that would improve safety. Generally, a predictive collision sensing system tracks the motion of the host vehicle relative to its environment, or vice versa, for example, using a radar system with an associated target tracker. The environment may include both stationary and moving targets. An automotive environment is distinguished from other target tracking environments -- for example, that of air or sea vessels – in that automotive vehicles are primarily operated in an environment that is constrained by roadways. There are, of course, exceptions to this, for example, parking lots or off-road driving conditions, but these exceptions generally account for a relatively small percentage of vehicular operating time, or for a relatively small risk of collisions for which there would be benefit from a predictive collision sensing system.

Referring to **Figs. 1-3**, a **situation awareness processor 10** is illustrated in a **radar processing system 12** that processes radar data from a **radar system 14** incorporated in a

host vehicle 16. Generally, the **host vehicle 16** incorporates a sensor for sensing **targets 18** in the environment thereof, and incorporates a system for actuating and/or controlling associated countermeasures responsive to the relative motion of the **host vehicle 16** with respect to one or more targets. The sensor for sensing **targets 18** is, for example, a radar or lidar sensor system that senses and tracks the location of **targets 18** relative to the **host vehicle 16**, and predicts if a collision between the **host vehicle 16** and a **target 18** is likely to occur, for example, as disclosed in commonly owned **U.S. Patent No. 6,085,151** that is incorporated herein by reference.

Referring to **Fig. 1**, the **host vehicle 16** is seen traveling in the **X**-direction at a **host speed 20** in the environment of one or more **targets 18**, each at an associated **bearing 22** and **distance 24** relative to the **host vehicle 16**, each having an associated **target speed 26** at an associated **heading 28**. Generally, the **targets 18** may be either stationary, or moving, relative to the **environment 30** of the **host vehicle 16**.

Fig. 2 illustrates a block diagram of the **radar processing system 12**, wherein each block in the block diagram comprises associated software modules that receive, prepare and/or process data provided by a **radar system 14** mounted in the host vehicle. Data from the **radar system 14** is preprocessed by a **preprocessor 32** so as to generate radar data, for example, range, range rate, and azimuth angle, suitable for target tracking. The radar data typically covers a relatively wide field of view forward of the host vehicle, at least +/- 5 degrees from the host vehicle's longitudinal axis, and possibly extending to +/- 180 degrees, or larger, depending upon the radar and associated antenna configuration. A present exemplary system has a field of view of +/- 55 degrees.

A **tracker 34** converts radar output data (range, range rate & azimuth angle) into target speed and X-Y coordinates specifying the location of a target. For example, the system of **U.S. Patent No. 6,085,151** discloses a system for tracking multiple targets, and for clustering associated radar data for a single target. An **associator 36** relates older track data to that from the latest scan, compiling a track history of each target.

A **track map generator 38** generates a track map comprising a grid of heading and quality information from the track data as a record of the evolution of target motion relative to the host vehicle. The track map is updated with track data from subsequent **targets 18** that enter the field-of-view of the **host vehicle 16**, and old data fades from the map with time. Accordingly, the track map provides a representation of the paths followed by **targets 18** relative to the **host vehicle 16**, which paths are normally constrained by the associated roadways in the **environment 30** of the **host vehicle 16**. For example, a **track map generator 38** is disclosed in a separately filed U.S. Application Serial No. 09/_______, entitled *Track Map Generator*, filed on June 8, 2001.

A **situation awareness processor 10** uses 1) the track map, 2) data acquired indicative of the position and/or motion of the **host vehicle 16**, i.e. **host vehicle information 40**, and possibly 3) **environment data 42**, to determine the most likely or appropriate driving situation from a set of possible driving situations. For example, the **environment data 42** can include navigation data from a **navigation system 44**, digital maps, real-time wireless inputs of highway geometry and nearby vehicles, and data from real-time transponders such as electromagnetic or optical markers built into highways; and can be used -- along with target tracking data from the **tracker 34/associator 36** -- by a **road curvature estimator 46** to provide an estimate of road curvature to the **situation awareness processor 10**. For example, navigation data such as the location and direction of a vehicle can be measured by a GPS receiver; by a dead reckoning system using measurements of vehicle heading from a compass or directional gyroscope, and vehicle distance and heading from wheel speed or rotation measurements, in conjunction with a map matching algorithm; or a combination thereof.

The **situation awareness processor 10** stores and interprets the track map from the **track map generator 38**, and compares the progress over time of several target tracks. Evaluation of the relative positions and progress of the tracked targets permits identification of various driving situations, for example a location situation, a traffic situation, a driving maneuver situation, or the occurrence of sudden events. Several approaches can be used to identify the situation, for example set theoretic reasoning (using for example random set theory or evidential reasoning); Bayesian inference; or a neural network.

Examples of location situations include a divided or undivided highway, an intersection, a freeway entrance or exit, a parking lot or off-highway situation, and a stopped object on the left or right of the host vehicle. Examples of traffic situations include crowded traffic, loose traffic, or normal traffic. Examples of driving maneuver situations include target cut-in, host vehicle lane or speed changing, or target speed changing.

The situation estimated by the **situation awareness processor 10**, together with collision and crash severity estimates from a **collision estimator 48** and a **crash severity estimator 50** respectively, are used as inputs to a **response generator 52** to select an appropriate **countermeasure 54**, for example, using a decision matrix. The decision of a particular response by the **response generator 52** may be based on, for example, a rule-based system (an expert system), a neural network, or another decision means.

Examples of **countermeasures 54** that can be activated include, a warning device to warn the driver to take corrective action, for example 3D audio warning (for example, as disclosed in commonly owned **U.S. Patent No. 5,979,586** that is incorporated by reference herein); various means for taking evasive action to avoid a collision, for example the engine throttle, the vehicle transmission, the vehicle braking system, or the vehicle steering system; and various means for mitigating injury to an occupant if a collision is unavoidable, for example a motorized safety belt pretensioner, or internal or external airbags. The particular one or more **countermeasures 54** selected, and the manner by which that one or more **countermeasures 54** are activated, actuated, or controlled, depends up the situation identified by the **situation awareness processor 10**, and upon the collision and crash severity estimates. By way of example, one potential scenario is that the response to encroachment into the host's lane of travel would be different depending upon whether the target is coming from the opposite direction or going the same way as the **host vehicle 16**, but cutting into the lane thereof. By considering the traffic situation giving rise to the threat, the **countermeasures 54** can be better adapted to mitigate that threat. By using a radar system, or generally a predictive collision sensing system, to sense targets within range of the host vehicle, the **countermeasures 54** may be implemented prior to an actual collision so as to either avoid a collision, or to mitigate occupant injury therefrom.

Referring to **Fig. 3**, the **radar system 14** and **radar processing system 12** are seen incorporated in **host vehicle 16**, wherein the **host vehicle information 40** is provided by associated sensors, for example, operatively connected to a **vehicle processor 56** that provides the resulting **host vehicle information 40** to the **situation awareness processor 10**. For example, one or more **wheel speed sensors 58** can provide wheel speed measurements from one or more associated wheels of the vehicle, the average of which, for laterally opposed wheels, provides a measure of vehicle speed; the difference of which provides a measure of yaw rate. Alternately, or additionally, the vehicle speed may be measured from the rotation of a transmission output shaft. A **steering angle sensor 60** operatively connected to the steering shaft provides a measure of steering angle responsive to the turning of the steering wheel by the driver. The yaw rate of the **host vehicle 16** may alternately, or additionally, be sensed by a **gyro 62**, wherein the integration of yaw rate provides a measure of the heading of the **host vehicle 16**.

The **situational awareness processor 10** transforms the sensor information collected by various sensors into a coherent understanding of the driving environment, such that a more proper response can be invoked responsive to an emergency. Stated in another way, the **situational awareness processor 10** interprets the meaning of sensor data. The inputs to the **situational awareness processor 10** are transformed from a "state" domain into an "event" domain. Whereas variables in state domain are usually represented numerically, the variables in event domain are commonly represented as events and by a confidence of the occurrence thereof. The **situational awareness processor 10** identifies an "event" corresponding to particular a "situation". **Tables 1-3** provide examples, and associated definitions, of various events.

Inputs for identifying relevant events are obtained by processing the original sensor reports including radar reports, host vehicle speed and yaw rate, GPS host location report and digital map report. These inputs include, but are not limited to, those listed in **Table 4**, the information of which, except for host absolute location, type of road and approaching road structure, is interrelated by the coordinate system of **Fig. 1**. Host absolute location is defined in the coordinate system of the digital map, and the type of road and approach road structures are expressed in terms of events.

Table 1

Event ID	**Events Related to Host Vehicle Location**	
A1	ivided Highway	Traffic on the opposite direction is separated relatively far away
A2	ndivided ighway	There is traffic on the opposite direction nearby, with most traffic parallel and at a relatively high speed
A3	ntersection	Traffics with different, intersecting directions
A4	reeway	Divided Highway with no Intersection, and a relatively higher speed than for a Highway
A5	reeway Entrance	Connection into a freeway from another highway of any type
A6	reeway Exit	Connection out of a freeway into another highway of any type
A7	arking Lot	Place where there is a collection of stopped vehicles, in some cases located irregularly, and where the host vehicle is required to perform tight maneuvers
A8	ff-Highway	Place where the surrounding environment is irregular, and where the host vehicle may perform almost any kind of maneuver

Table 2

Event ID	Events Related to Traffic	
B1	rowded Traffic	A higher volume of traffic for a particular type of location
B2	oose Traffic	A lower volume of traffic for a particular type of location
B3	ormal Traffic	A standard volume of traffic for a particular type of location
B4	raffic on Left	Another moving object on the left of the host
B5	raffic on Right	Another moving object on the right of the host
B6	raffic in Lane	Another moving object within the lane of the host
B7	topped Traffic on Left	A stopped object on the left of the host
B8	topped Traffic on Right	A stopped object on the right of the host
B9	topped Traffic in Lane	A stopped object within the lane of the host

Table 3

Event ID	Events Related to Relative Position Change	
C1	Left Traffic Cut-in	An object is cutting-in the host's lane from the left
C2	Right Traffic Cut-in	An object is cutting-in the host's lane from the right
C3	Host Lane Changing to Left Lane	The host vehicle is moving into the left lane
C4	Host Lane Changing to Right Lane	The host vehicle is moving into the right lane
C5	Left Traffic Accelerating	An object to the left of the host increases its speed
C6	Right Traffic Accelerating	An object to the right of the host increases its speed
C7	Lead Traffic Accelerating	An object in the front of the host increases its speed
C8	Left Traffic Decelerating	An object to the left of the host decreases its speed
C9	Right Traffic Decelerating	An object to the right of the host decreases its speed
C10	Lead Traffic Decelerating	An object in the front of the host decreases its speed
C11	Host Accelerating	The host speed increases
C12	Host Decelerating	The host speed decreases
C13	Traffic Turn Left	An object changes its heading to the left relative to host
C14	Traffic Turn Right	An object changes its heading to the right relative to host
C15	Host Turn Left	The host changes its heading to the left
C16	Host Turn Right	The host changes its heading to the right

Table 4

Inputs to Situation Awareness Processor		
Type	**Input**	**Source of Information**
Target Related Information	Number of Targets	Obtained from processing forward looking sensor(s), such as radar, lidar, or camera, with tracking algorithm
	Target Heading	
	Target Speed	
	Target Location Relative to Host	
Host Related Information	Host Speed	Vehicle speed sensor in the transmission, or wheel speed sensors, of host vehicle
	Host Yaw Rate	Gyro, or differential wheel speed
	Host Heading	GPS, compass, gyro and/or differential wheel speed
	Host Absolute Location	Host navigation system: GPS; or dead reckoning from compass and wheel rotation; with map matching
Environment Information	Track Map	A recording of previously obtained target trajectories into grids covering the field-of-view, wherein information carried by previous tracks is saved in a smoothed manner
	Road Curvature	Obtained from digital map, or processing of host yaw rate and target information
	Type of Road	Obtained from a digital map through matching with the host absolute location
	Approaching Road Structure	

The output of the **situational awareness processor 10** comprises a list of identified events, and associated confidence levels. The events collectively define the current driving situation. The confidence can be represented in several ways, such as probability and possibility, each generated by a different inference (reasoning) mechanism, as discussed further hereinbelow. The outputs are determined by an inference process, which is a recursive decision making process that correlates events with their associated and corresponding inputs. A decision is given in terms of a confidence for the occurrence of a particular event. A general formula for calculating the confidence of an event can is given as:

$$p_k = f(p_{k-1}, e_1, e_2, \ldots, e_n) \qquad (1)$$

where p_k is the confidence level, and e_i are the inputs, at time k.

Various methods can be used in the inference engines that specify the recursive updating mechanism. Among them, the most widely used are 1) Dempster-Shafer Evidential Reasoning, 2) Fuzzy Logic Reasoning, 3) Bayesian Inference, and 4) Neural Network. Random set theory can also used in place of the evidential reasoning or fuzzy logic reasoning as a more general approach.

In preparation for using a particular inference engine, the above-described events are first grouped into several classes, each containing a number of mutually exclusive atomic events. Inference is made within each class, although the output of one inference engine can be fed back as an input to another inference engine. A decision on the nature of the current driving situation is made responsive to the collective output of all inference engines. For example, **Table 5** lists a set of reorganized event classes based upon the events listed in **Tables 1-3.**

The decision process based on the reorganized events essentially forms a networked inference engine, which is illustrated generally in **Fig. 4**, and which is illustrated more specifically in **Fig. 5**.

By way of example, the decision process is now illustrated by deriving a Bayesian inference of Approaching Road Structure. The Bayesian formula is given by:

$$p(A_i \mid B) = \frac{p(B \mid A_i)p(A_i)}{p(B)} = \frac{p(B \mid A_i)p(A_i)}{\sum_{j=1}^{n} p(B \mid A_j)p(A_j)}$$

Denoting e_κ, $\kappa = a, b, \Lambda\ k$, as all the information available to the inference engine, and $\{e_\kappa\}$ as the collection of all available inputs, e_a collectively refers to all the information carried by the track map, which can be further decomposed into a set of G grids, i.e. $e_a = \{e_{ah}^{\xi}, e_{aq}^{\xi}, \xi = 1,2,\Lambda\ G\}$, where e_{ah}^{ξ} and e_{aq}^{ξ} are heading and quality information of grid ξ, respectively. For N targets, then $e_e = N$. Superscripts can be used to distinguish targets, e.g. e_b^r, e_c^r and e_d^r represent speed, heading, and location of target *r*, *r*=1,2...*N*, respectively. Of the target information, each e_d^r contains two elements, defining a target's location in X and Y coordinates, i.e. $e_d^r = (x^r, y^r)$. Road type and approaching road structure are events in nature. Each event is from a class of possible events as defined earlier. Generally, a superscript can be used to differentiate an event from peers in its class, e.g. e_i^α and e_j^β specifies a road type and an approaching road structure, respectively.

Table 5

Class ID	Class Name	Events in Class	Event ID(s)
CA	Approaching Road Structure	Intersection	A3
		Freeway Entrance	A5
		Freeway Exit	A6
		Unknown	
CB	Road Type	Divided Highway	A1
		Undivided Highway	A2
		Freeway	A4
		Parking Lot	A7
		Off-Highway	A8
		Unknown	
CC	Traffic Volume	Crowded	B1
		Loose	B2
		Normal	B3
		Unknown	
CD	Traffic Location	Left	B4
		Right	B5
		In Lane	B6
		Unknown	
CE	Stopped Object Location	Left	B7
		Right	B8
		In Lane	B9
		Unknown	
CF	Traffic Maneuver	Cut-in From Left	C1
		Cut-in From Right	C2
		Turn Left	C13
		Turn Right	C14
		Straight Acceleration	C5, C6, C7
		Straight Deceleration	C8, C9, C10
		Nonmaneuver	
CG	Host Maneuver	Lane Changing to Left	C3
		Lane Changing to Right	C4
		Turn Left	C15
		Turn Right	C16
		Straight Acceleration	C11
		Straight Deceleration	C12
		Nonmaneuver	

The output of the inference network comprises the seven events from the seven classes defined earlier, wherein event is denoted as S, subscripts are used to denote the class of an event, and superscript are used to denote the intended event of the class specified by the subscript. Accordingly, S_η^λ is an output event for class η and event λ in the class. For example, if $\eta = 1, \lambda = 2$, then S_η^λ means freeway entrance.

Given the above definitions, the Bayesian inference for Approaching Road Structure can be derived as follows. Under Bayesian framework, the outcome of an inference is the posterior probability of a given event. For approaching road structures, the probabilities to be evaluated are S_1^λ, $\lambda = 1, 2, 3, 4$, given the collection of evidence $\{e_\kappa\}$ and knowledge of a related event in class S_2, are given by:

$$p(S_1^\lambda \mid S_2^{\lambda_0}, \{e_\kappa\}) = \frac{p(\{e_\kappa\} \mid S_1^\lambda, S_2^{\lambda_0}) p(S_1^\lambda \mid S_2^{\lambda_0})}{\sum_{\lambda_1=1}^{4} p(\{e_\kappa\} \mid S_1^{\lambda_1}, S_2^{\lambda_0}) p(S_1^{\lambda_1} \mid S_2^{\lambda_0})}$$

wherein, $\lambda_0 = 1, 2, \Lambda\ 6$ is the index for events belonging to the road type class.

Using the previously obtained $p(S_1^\lambda \mid S_2^{\lambda_0}, \{e_\kappa\})$ to approximate current $p(S_1^\lambda \mid S_2^{\lambda_0})$, provides the following recursive probability updating equation:

$$p_k(S_1^\lambda \mid S_2^{\lambda_0}, \{e_\kappa\}) = \frac{p(\{e_\kappa\} \mid S_1^\lambda, S_2^{\lambda_0}) p_{k-1}(S_1^\lambda \mid S_2^{\lambda_0}, \{e_\kappa\})}{\sum_{\lambda_1=1}^{4} p(\{e_\kappa\} \mid S_1^{\lambda_1}, S_2^{\lambda_0}) p_{k-1}(S_1^{\lambda_1} \mid S_2^{\lambda_0}, \{e_\kappa\})}$$

wherein $p(\{e_\kappa\} \mid S_1^\lambda, S_2^{\lambda_0})$ is the probability density of set $\{e_\kappa\}$ given the condition that events S_1^λ and $S_2^{\lambda_0}$ are true. Considering the individual elements in $\{e_\kappa\}$ gives:

$$\begin{aligned} p(\{e_\kappa\} \mid S_1^\lambda, S_2^{\lambda_0}) &= p(e_a, \{e_b^r, e_c^r, e_d^r\}, e_f, e_i^\alpha, e_j^\beta \mid S_1^\lambda, S_2^{\lambda_0}) \\ &= p(e_a \mid S_1^\lambda, S_2^{\lambda_0}) p(e_f \mid S_1^\lambda, S_2^{\lambda_0}) p(e_i^\alpha \mid S_1^\lambda, S_2^{\lambda_0}) p(e_j^\beta \mid S_1^\lambda, S_2^{\lambda_0}) \\ &\times \prod_{r=1}^{N} p(e_b^r \mid S_1^\lambda, S_2^{\lambda_0}) p(e_c^r \mid S_1^\lambda, S_2^{\lambda_0}) p(e_d^r \mid S_1^\lambda, S_2^{\lambda_0}) \end{aligned}$$

wherein individual conditional probabilities/probability densities can be found as:

(1) $p(e_a \mid S_1^\lambda, S_2^{\lambda_0})$

$$\begin{aligned} p(e_a \mid S_1^\lambda, S_2^{\lambda_0}) = \prod_{\xi=1}^{G} [&p(e_{ah}^\xi \mid S_1^\lambda, S_2^{\lambda_0}, \xi = \text{TRUE}) p(\xi = \text{TRUE} \mid S_1^\lambda, S_2^{\lambda_0}) \\ &+ p(e_{ah}^\xi \mid S_1^\lambda, S_2^{\lambda_0}, \xi = \text{FALSE}) p(\xi = \text{FALSE} \mid S_1^\lambda, S_2^{\lambda_0})] \end{aligned}$$

As $p(\xi = \text{TRUE} \mid S_1^\lambda, S_2^{\lambda_0})] = e_{aq}^\xi$ and $p(\xi = \text{FALSE} \mid S_1^\lambda, S_2^{\lambda_0})] = 1 - e_{aq}^\xi$, then

$$p(e_a \mid S_1^{\lambda}, S_2^{\lambda_0}) = \prod_{\xi=1}^{G} [p(e_{ah}^{\xi} \mid S_1^{\lambda}, S_2^{\lambda_0}, \xi = \text{TRUE}) e_{aq}^{\xi} + p(e_{ah}^{\xi} \mid S_1^{\lambda}, S_2^{\lambda_0}, \xi = \text{FALSE})(1 - e_{aq}^{\xi})].$$

A suitable way to model $p(e_{ah}^{\xi} \mid S_1^{\lambda}, S_2^{\lambda_0}, \xi = \text{TRUE})$ is to a use Guassian mixture, i.e. an approximation involving a summation of several Guassian distributions:

$$p(e_{ah}^{\xi} \mid S_1^{\lambda}, S_2^{\lambda_0}, \xi = \text{TRUE}) = \frac{1}{N_f} \sum_{i=1}^{N_f} \frac{1}{2\pi\sigma_i} e^{\frac{(e_{ah}^{\xi} - \mu_i)^2}{2\sigma_i^2}}$$

where N_f is the number of features selected for an approaching road structure. For example, the following parameters may be chosen for an intersection: $N_f = 3$, $\mu_1 = 0°$, $\mu_2 = 90°$, $\mu_3 = 90°$, and $\sigma_1 = \sigma_2 = \sigma_3 = 10°$.

The distribution $p(e_{ah}^{\xi} \mid S_1^{\lambda}, S_2^{\lambda_0}, \xi = \text{FALSE})$ may be modeled as a uniform distribution, e.g.,

$$p(e_{ah}^{\xi} \mid S_1^{\lambda}, S_2^{\lambda_0}, \xi = \text{FALSE}) = \frac{1}{180°}.$$

(2) $p(e_b^r \mid S_1^{\lambda}, S_2^{\lambda_0})$, $p(e_c^r \mid S_1^{\lambda}, S_2^{\lambda_0})$, $p(e_d^r \mid S_1^{\lambda}, S_2^{\lambda_0})$ and $p(e_f \mid S_1^{\lambda}, S_2^{\lambda_0})$ can be handled similar to $p(e_a \mid S_1^{\lambda}, S_2^{\lambda_0})$.

(3) $p(e_i^{\alpha} \mid S_1^{\lambda}, S_2^{\lambda_0})$:

Probability of event-type input e_i^{α} can be decided as

$$p(e_i^{\alpha} \mid S_1^{\lambda}, S_2^{\lambda_0}) = \begin{cases} p(e_i^{\alpha} = \text{TRUE}), & \text{if } S_2^{\lambda_0} = e_i^{\alpha} \\ 1 - p(e_i^{\alpha} = \text{TRUE}), & \text{if } S_2^{\lambda_0} \neq e_i^{\alpha} \end{cases}$$

Where $p(e_i^{\alpha} = \text{TRUE})$ can be obtained by the quality measure of GPS/map matching.

(4) $p(e_i^{\beta} \mid S_1^{\lambda}, S_2^{\lambda_0})$ can be handled similar to $p(e_i^{\alpha} \mid S_1^{\lambda}, S_2^{\lambda_0})$.

The actual forms and parameters of above probability terms would be obtained based on experiments, with simplification to reduce computational burden.

The above inference engine can be replaced by any of the other three widely used reasoning techniques, namely fuzzy logic reasoning, Dempster-Shafer evidential reasoning and neural networks. Particularly, a collection of atomic events can be specified based on the classes of events to be recognized, for example, as are illustrated in **Table 6**.

Table 6

Set ID	Set Name	Events in Set		Event ID(s)	Definition
		ID	Name		
SA	Approaching Road Structure	SA1	Intersection	3	Traffics at different directions meet each other
		SA2	Entrance	5	A road connected into the host's road in a near parallel manner
		SA3	Exit	6	A road connected out of the host's road in a near parallel manner
SB	Road Type	SB1	Divided Road	1	Road with only one direction of traffic
		SB2	Undivided Road	2	Traffic with opposite direction is close
		SB3	Highway	1, A2	Road of any type with higher speed and traffics are parallel
		SB4	Parking Lot	7	Same as A7
		SB5	Off-Highway	8	Same as A8
SC	Traffic Volume	SC1	Crowded	1	Same as B1
		SC2	Loose	2	Same as B2
		SC3	Normal	3	Same as B3
SD	Traffic Location	SD1	Left	4, B7	An object is on the left of the host
		SD2	Right	5, B8	An object is on the right of the host
		SD3	In Lane	6, B9	An object is in the same lane of the host
SE	Object Nature	SE1	Moving		The location of an object is changing relative to the ground
		SE2	Stopped		The location of an object is not changing relative to the ground
SF	Traffic Maneuver	SF1	Turn Left	13	Heading of the velocity of an object changes to the left of the host
		SF2	Turn Right	14	Heading of the velocity of an object changes to the right of the host
		SF3	Acceleration	5, C6, C7	Object speed increases
		SF4	Deceleration	8, C9, C10	Object speed decreases
SG	Host Maneuver	SG1	Turn Left	15	Heading of the velocity of host changes to the left of the host
		SG2	Turn Right	16	Heading of the velocity of host changes to the right of the host
		SG3	Acceleration	11	Host speed increases
		SG4	Deceleration	12	Host speed decreases
		SG5	Lane Change	3, C4	Host moves to another lane

Note that the defined atomic events are not exactly the same as the situations. Some are intersections of several events, some are unions of events, some are actually part of a situation, and some have not been defined. However, these atomic sets collectively can represent the situations defined earlier.

Given the defined sets of atomic events, the output events can be obtained by joining the atomic events, as illustrated in **Table 7**.

Table 7

A1 = (SB1, SB3)	*B1 = (SC1)*	*C1 = (B4, SF1)*
A2 = (SB2, SB3)	*B2 = (SC2)*	*C2 = (B5, SF2)*
A3 = (SA1)	*B3 = (SC3)*	*C3 = (SG1, SG5)*
A4 = (SB1, SB2, SA1)	*B4 = (SD1, SE1)*	*C4 = (SG2, SG5)*
A5 = (A4, SA2)	*B5 = (SD2, SE1)*	*C5 = (SF3, B4)*
A6 = (A4, SA3)	*B6 = (SD3, SE1)*	*C6 = (SF3, B5)*
A7 = (SB4)	*B7 = (SD1, SE2)*	*C7 = (SF3, B6)*
A8 = (SB5)	*B8 = (SD2, SE2)*	*C8 = (SF4, B4)*
	B9 = (SD3, SE2)	*C9 = (SF4, B5)*
		C10 = (SF4, B6)
		C11 = (SG3)
		C12 = (SG4)
		C13 = (SF1)
		C14 = (SF2)
		C15 = (SG1)
		C16 = (SG2)

The Dempster-Schafer mass functions assigned to the events can be obtained based on experiments. Mass updating can also obtained based on evidential reasoning theory.

While specific embodiments have been described in detail in the foregoing detailed description and illustrated in the accompanying drawings, those with ordinary skill in the art will appreciate that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention, which is to be given the full breadth of the appended claims and any and all equivalents thereof.

WE CLAIM:

1. A method of identifying a situation in which a host vehicle is operated, comprising:
   a. selecting a plurality of events, wherein each event of said plurality of events is representative of a situation in which the host vehicle is operated, and at least two of said events are different from one another;
   b. selecting at least one set of said events that are related to a situation in which the host vehicle is operated;
   c. providing for a set of data from at least one of a first set of data, a second set of data and a third set of data, wherein said first set of data is representative of a target in a field of view of the host vehicle, said second set of data is representative of the position or motion of the host vehicle, and said third set of data is representative of an environment of said host vehicle;
   d. selecting an inference method for a first inference engine, wherein said inference engine comprises at least one input and an output;
   e. selecting as a first input to said inference engine at least one element of said first set of data, said second set of data and said third set of data; and
   f. generating a first output from said first inference engine responsive to said first input, wherein said first output is representative of a probability of occurrence of at least one event of said set of said events.
2. A method of identifying a situation in which a host vehicle is operated, as recited in claim 1, wherein a plurality of said events are related to a location of the host vehicle.
3. A method of identifying a situation in which a host vehicle is operated, as recited in claim 2, wherein each of said plurality of said events related to said location of the host vehicle is a situation selected from an operation of the host vehicle in a vicinity of a divided or undivided highway; an operation of the host vehicle in a vicinity of an intersection, an operation of the host vehicle in a vicinity of a freeway, an operation of the host vehicle in a vicinity of an entrance or exit to a freeway entrance; an operation of the host vehicle in a vicinity of a parking lot; and an operation of the host vehicle in an off-highway environment.

4. A method of identifying a situation in which a host vehicle is operated, as recited in claim **1**, wherein a plurality of said events are related to a traffic situation.

5. A method of identifying a situation in which a host vehicle is operated, as recited in claim **4**, wherein each of said plurality of said events related to a traffic situation comprises operation of the host vehicle in an environment selected from crowded, loose or normal traffic; a moving or stationary object to the left or right of the host vehicle; and a moving or stationary object in a lane of the host vehicle.

6. A method of identifying a situation in which a host vehicle is operated, as recited in claim **1**, wherein a plurality of said events are related to a relative position change of a target with respect to the host vehicle.

7. A method of identifying a situation in which a host vehicle is operated, as recited in claim **6**, wherein each of said plurality of said events related to a relative position change of a target with respect to the host vehicle is selected from an object cutting in a lane of the host vehicle from the left or right of the host vehicle; the host vehicle changing lanes to the left or right; a change in speed of traffic to the left or right of the host vehicle; a change in speed of traffic in the same lane as the host vehicle; a change in speed of the host vehicle; a change in direction of traffic to the left or right; and a change in direction of the host vehicle to the left or right.

8. A method of identifying a situation in which a host vehicle is operated, as recited in claim **1**, wherein at least two events of said set of events are mutually exclusive.

9. A method of identifying a situation in which a host vehicle is operated, as recited in claim **1**, wherein said first set of data is selected from a count of targets in a field of view of the host vehicle, a target heading, a target speed, and a target location relative to the host vehicle, and at least a portion of said first set of data is generated by a tracker operatively coupled to a radar system.

10. A method of identifying a situation in which a host vehicle is operated, as recited in claim **1**, wherein said second set of data is selected from a speed of the host vehicle, a yaw rate of the host vehicle, a heading of the host vehicle, and a location of the host vehicle.

11. A method of identifying a situation in which a host vehicle is operated, as recited in claim **10**, further comprising providing for reading said location of the host vehicle from a navigation system.

12. A method of identifying a situation in which a host vehicle is operated, as recited in claim **1**, wherein said third set of data is selected from a track map representative of a composite path of targets in an environment of the host vehicle, a curvature or type of a road upon which the host vehicle is operated, data representative of a fixed structure in the field of view of the host vehicle, and a digital map of a road surface, wherein said track map is generated by a track map generator from data is generated by a tracker operatively coupled to a radar system.

13. A method of identifying a situation in which a host vehicle is operated, as recited in claim **1**, wherein said inference method is selected from a Dempster-Shafer evidential reasoning method, a fuzzy logic reasoning method, a Bayesian inference method, a neural network and a reasoning method based on random set theory.

14. A method of identifying a situation in which a host vehicle is operated, as recited in claim **1**, further comprising:

a. selecting as a second input to said inference engine an output from an inference engine, wherein said output is at a past time relative to said first input; and

b. generating an output from said first inference engine responsive to said first and second inputs.

15. A method of identifying a situation in which a host vehicle is operated, as recited in claim **1**, further comprising selecting a countermeasure responsive to at least one said output of at least one said inference engine.

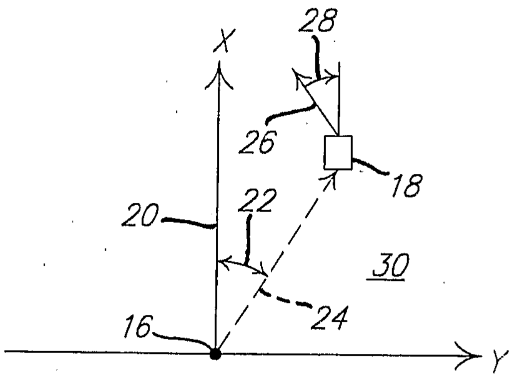

FIG. 1.

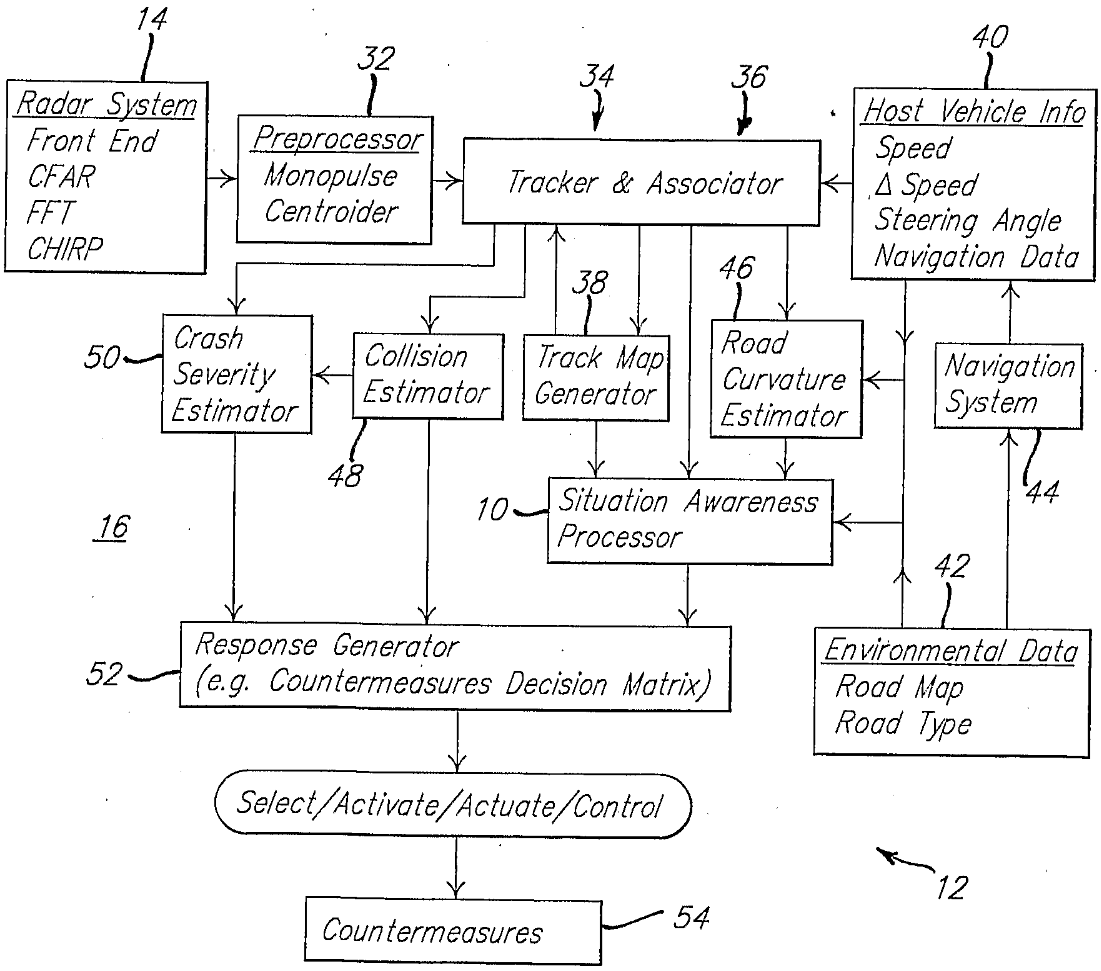

FIG. 2.

SUBSTITUTE SHEET (RULE 26)

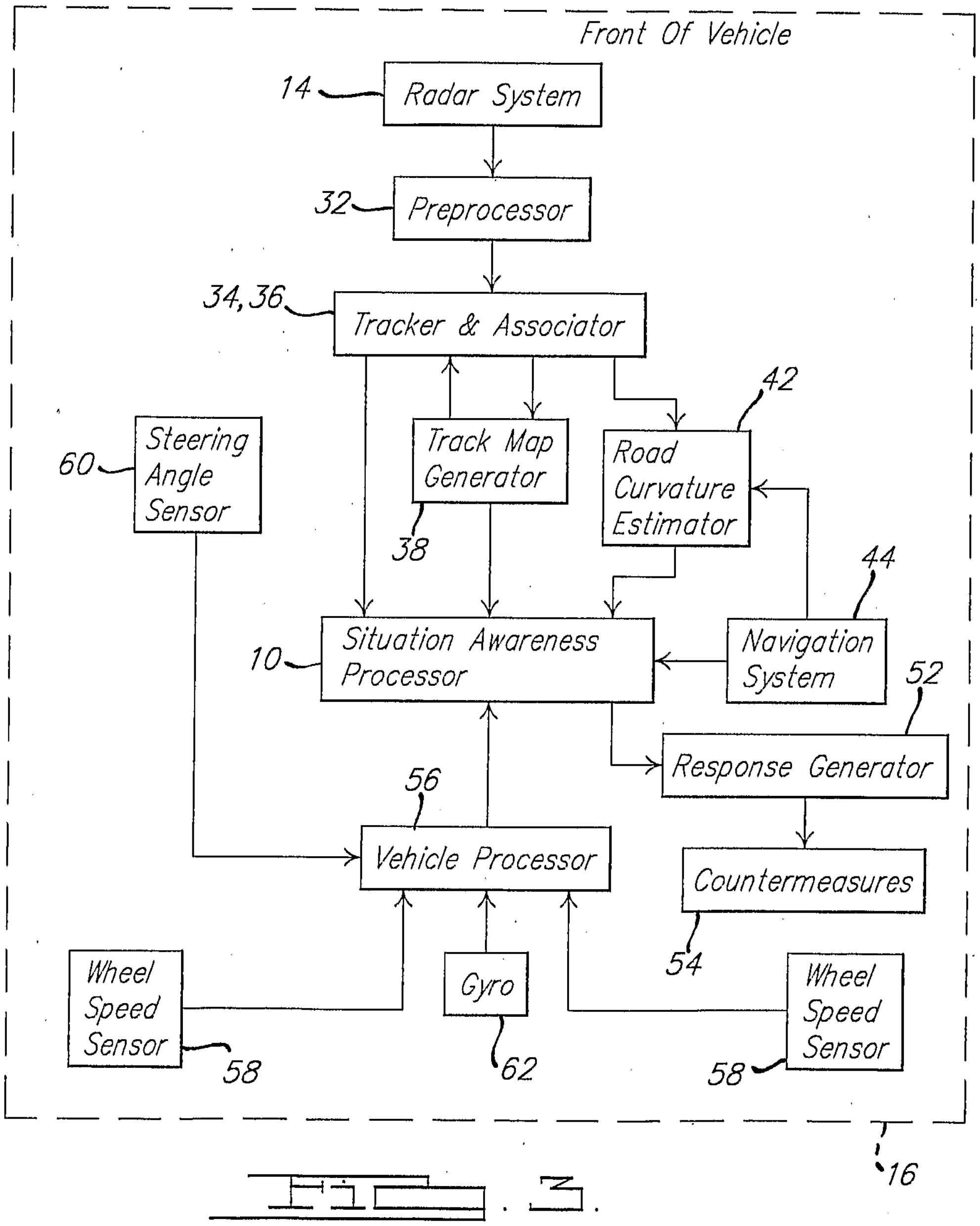
Front Of Vehicle
14
Radar System
32
Preprocessor
34,36
Tracker & Associator
42
Steering Angle Sensor
60
Track Map Generator
38
Road Curvature Estimator
44
10
Situation Awareness Processor
Navigation System
52
Response Generator
56
Vehicle Processor
Countermeasures
54
Wheel Speed Sensor
58
Gyro
62
Wheel Speed Sensor
58
16

FIG. 3.

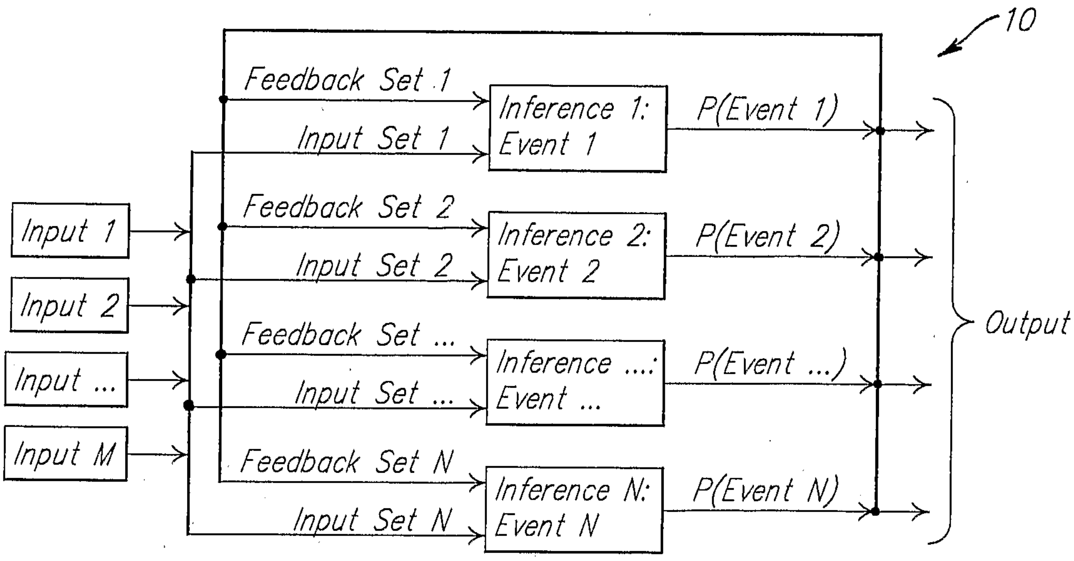
10
Input 1
Input 2
Input ...
Input M
Feedback Set 1
Input Set 1
Inference 1: Event 1
P(Event 1)
Feedback Set 2
Input Set 2
Inference 2: Event 2
P(Event 2)
Feedback Set ...
Input Set ...
Inference ...: Event ...
P(Event ...)
Feedback Set N
Input Set N
Inference N: Event N
P(Event N)
Output

FIG. 4.

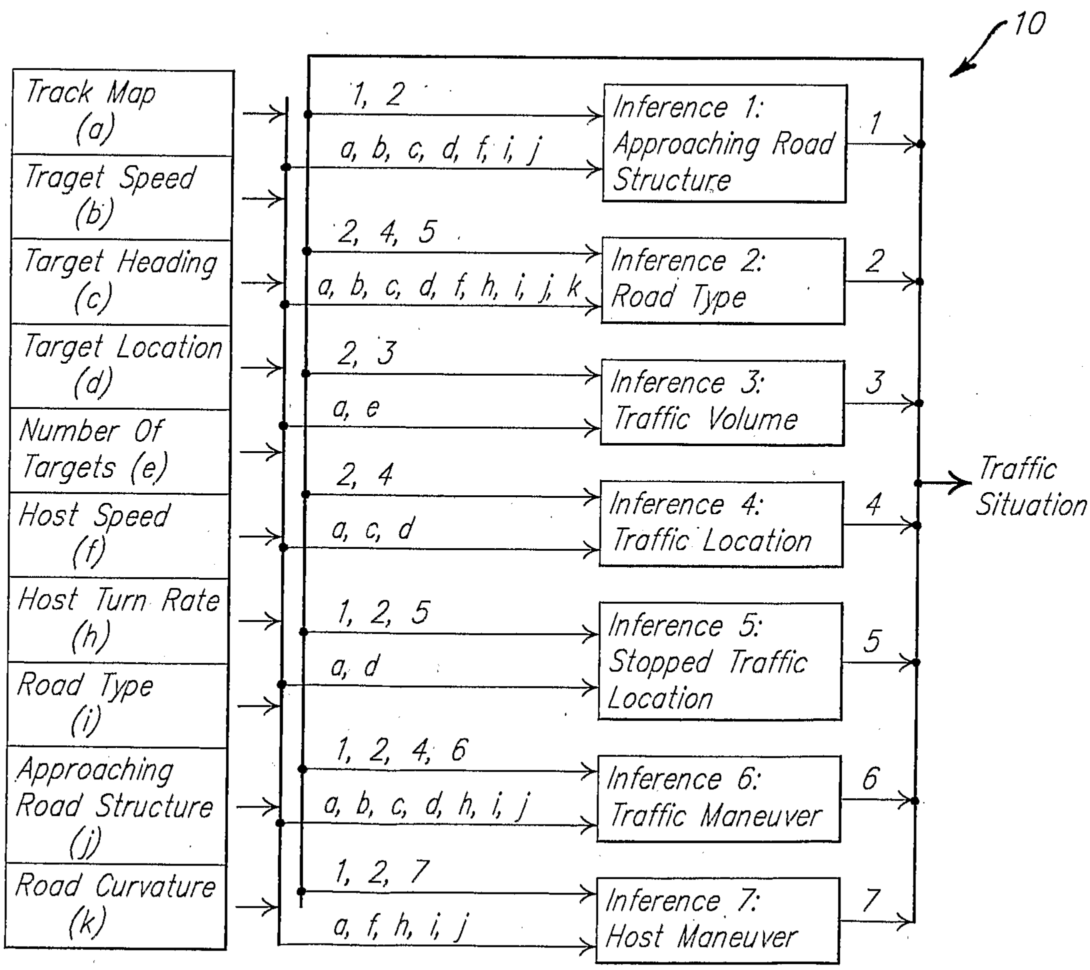
10
Track Map (a)
Traget Speed (b)
Target Heading (c)
Target Location (d)
Number Of Targets (e)
Host Speed (f)
Host Turn Rate (h)
Road Type (i)
Approaching Road Structure (j)
Road Curvature (k)
1, 2
a, b, c, d, f, i, j
Inference 1: Approaching Road Structure
1
2, 4, 5
a, b, c, d, f, h, i, j, k
Inference 2: Road Type
2
2, 3
a, e
Inference 3: Traffic Volume
3
2, 4
a, c, d
Inference 4: Traffic Location
4
1, 2, 5
a, d
Inference 5: Stopped Traffic Location
5
1, 2, 4, 6
a, b, c, d, h, i, j
Inference 6: Traffic Maneuver
6
1, 2, 7
a, f, h, i, j
Inference 7: Host Maneuver
7
Traffic Situation

FIG. 5.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/18717

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :Please See Extra Sheet.
US CL :Please See Extra Sheet.
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)

U.S. : 701/301, 96, 117, 118, 119; 340/903, 905, 435, 436, 438, 441;180/168, 169, 170, 443, 409, 422

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

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

STN
Search terms: Traffic, collision, radar, steering, map, navigation, inference

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, P	US 6,161,071 A (SHUMAN et al) 12 December 2000 (12.12.2000), figures 4-8 and the related text.	1-15
Y, P	US 6,226,389 B1 (LEMELSON et al) 01 May 2001 (01.05.2001), figure 1, 2, 6 and the related text.	1-15
A, E	US 6,275,231 B1 (OBRADOVICH) 14 August 2001 (14.08.2001), entire patent.	1-15
A, E	US 6,275,773 B1 (LEMELSON et al) 14 August 2001 (14.08.2001), entire patent.	1-15

☐ 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

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"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
18 AUGUST 2001

Date of mailing of the international search report
13 SEP 2001

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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER:
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G06F 17/00; G01C 21/26; G08G 1/04, 1/0968, 1/0969, 1/097; G06G 7/76, 7/78

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

701/301, 96, 117, 118, 119; 340/903, 905, 435, 436, 438, 441;180/168, 169, 170, 443, 409, 422