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(54) **A method and system for in-vehicle collision avoidance.**

(57) A system for in-vehicle collision avoidance comprising:
- means (20) for detecting the presence of an obstacle vehicle having an heading direction which intersects a heading direction of a host vehicle;
- means (30) for determining a host vehicle collision avoidance effort value representing an effort for a host vehicle to avoid a collision with the obstacle vehicle, and a method for in-vehicle collision avoidance.

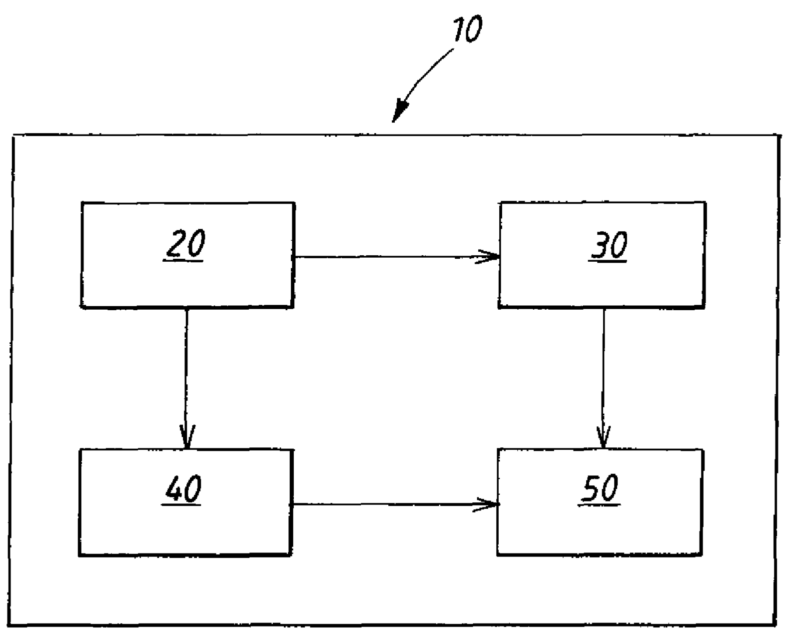


FIG.4

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## Description

### TECHNICAL FIELD

**[0001]** The invention relates to a method for in-vehicle collision avoidance according to the preamble of claim 1. The invention furthermore relates to a system for in-vehicle collision avoidance according to the preamble of claim 8. In particular the invention relates to a method performed for analysing the threat level for a host vehicle carrying means for performing analyses of a traffic scenario including the host vehicle and other objects including an obstacle vehicle. Correspondingly the invention also relates to a system present in a host vehicle, which system includes means for analysing the threat level for a host vehicle, which system includes means for performing analyses of a traffic scenario including the host vehicle and other objects including an obstacle vehicle.

### BACKGROUND ART

**[0002]** A current trend in the automotive industry is to introduce active safety systems for avoiding or mitigating collisions. One type of system, with a potentially large positive impact on accident statistics, is a forward collision avoidance system (FCAS). An FCAS uses sensors such as RADAR (RAdio Detection And Ranging), LIDAR (LIght Detection And Ranging) and cameras to monitor the region in front of the host vehicle. In the FCAS a tracking algorithm is used to estimate the state of the objects ahead and a decision algorithm uses the estimated states to determine any action, e.g. warning the driver, autonomous braking or steering. An example of a forward collision avoidance system is provided in EP1717778.

**[0003]** Even though the forward collision avoidance system disclosed in EP 1717778 is a generally well working system, there is a continuous need for improvement in the field of collision avoidance systems, in particular for systems to be operable in complex traffic situations in a manner where unnecessary interventions are avoided.

### DISCLOSURE OF INVENTION

**[0004]** The object of the invention is thus to further improve a method for in-vehicle collision avoidance and a collision avoidance system in a manner such that the risk for unnecessary intervention is reduced. The decision algorithms in most automotive forward collision systems continuously evaluate the threat for a collision with an obstacle ahead. A standard approach is to evaluate if any manoeuvres exist that avoid a collision with current obstacles. For example one can evaluate the lateral and longitudinal acceleration required to avoid collision with an obstacle. However in current systems the possibility that a driver of an obstacle vehicle can avoid a possible collision is not considered. According to the invention a method for in vehicle collision avoidance and a collision avoidance system are improved by considering the possibility that a driver of an obstacle vehicle can avoid a possible collision are accounted for by determining an obstacle vehicle collision avoidance effort value representing an effort for the obstacle vehicle to avoid a collision with the host vehicle. The risk for unnecessary intervention is reduced by determining a host vehicle intervention based on a retrieved host vehicle collision avoidance effort value and the determined obstacle vehicle collision avoidance effort value.

**[0005]** According to the invention the collision threat is evaluated by first evaluating the effort required by the host vehicle to avoid a collision assuming that the obstacle maintains a constant maneuver. Secondly the effort for the obstacle vehicle to avoid the host vehicle, assuming a constant maneuver for the host, is evaluated. The threat of a having a collision is based on the effort both of the host and of the obstacle to avoid a collision when the other vehicle keeps a constant maneuver. The possibility of calculating the joint effort for both vehicles to avoid a collision by a coordinated avoidance maneuver may preferably disregarded, since it is difficult to predict a joint action taken by both the host vehicle driver and obstacle vehicle driver with good accuracy.

**[0006]** The invention is particularly suitable for any situation where there is a large probability that the driver of the obstacle vehicle is observing of the host vehicle. This also includes, but is not limited to, scenarios where the relative heading angle is not large, e.g. traffic situations where the obstacle vehicle is in the host's blind spot.

**[0007]** The invention is however applicable for evaluating the collision threat in scenarios where there is a large relative heading angle, typically larger than 45 deg., where 0 deg. means vehicle traveling in the same direction and 180 deg. the opposite direction between the host vehicle, which carries the collision avoidance system and the obstacle vehicle. A suitable range for the relative heading angle $\alpha$ is $30^\circ < \alpha < 150^\circ$ or $-150^\circ < \alpha < -30^\circ$, preferably $45^\circ < \alpha < 135^\circ$ or $-135^\circ < \alpha < -45^\circ$.

### BRIEF DESCRIPTION OF DRAWINGS

**[0008]** Embodiments of the invention will be described in further detail below with references to appended drawings, where

Fig. 1 discloses a traffic scenario where two solutions are present for a host vehicle to pass an obstacle vehicle, one is for passing to the right of the obstacle and the other one is for passing to the left of the obstacle,

Fig. 2 illustrates a crossing traffic scenario,

Fig. 3 illustrates a block scheme of a method according to the invention,

Fig. 4 shows a schematic drawing of a system for in-vehicle collision avoidance according to the invention, and

Fig. 5 shows the drawing of fig. 4 in more detail.

EMBODIMENT(S) OF THE INVENTION

**[0009]** According to the invention the collision threat in an accident scenario is determined by evaluating the effort for both the host vehicle and the obstacle vehicle to avoid a collision. In a preferred embodiment an alarm should be issued if this effort is high for both vehicles. An alarm, here, may implicate any /or a combination of the following actions: warning to the driver, warning the driver of the obstacle, autonomous braking, autonomous steering or other actions to reduce the probability of injury.

**[0010]** The theory behind the invention as well as preferred embodiments thereof will be described in detail below.

**[0011]** Generally the effort for the host vehicle to avoid a collision is defined as $E_1 \geq 0$ and the effort for the other vehicle is defined as as $E_2 \geq 0$. Note, that the evaluation of the effort $E_1$ and $E_2$ may include other objects and information about infrastructure.

**[0012]** In a preferred embodiment an alarm is issued if $min(E_1, E_2) > E_{th}$, where $E_{th}$ defines a threshold value for when a collision is considered to be imminent.

**[0013]** In a preferred embodiment of the invention the determination of a host vehicle intervention based on said a host vehicle collision avoidance effort value and obstacle vehicle collision avoidance effort value is applied for Constant Acceleration Maneuvers as is explained in the following example.

**[0014]** Here we propose a specific implementation of this idea for the case where the motion of all objects is considered to have constant acceleration. The effort to avoid a collision is measured in terms of how much longitudinal or lateral acceleration is required to avoid a collision.

**[0015]** Lateral acceleration

**[0016]** A common metric to measure the collision threat is to calculate the lateral acceleration required to avoid collision, i.e. evaluation of the possibility to avoid collision by means of steering. The lateral acceleration capability is limited by tire-to-road friction. The maximum lateral acceleration for a passenger car is typically 1 g ≈ 9.8 m/s$^2$. Thus the set of feasible maneuvers is given by [-9.8 9.8] m/s$^2$, in this case.

**[0017]** We assume that both the host and the obstacle move with constant acceleration both in the longitudinal and lateral direction. This is described in (1).

$$x(t) = x_0 + \dot{x}_0 t + \frac{\ddot{x}_0 t^2}{2} \qquad (1)$$

**[0018]** The lateral acceleration needed to avoid an obstacle can be calculated as

$$\ddot{x}^{host}_{lat,needed} = \ddot{x}^{obstacle}_{lat,0} + \frac{-\tilde{x}_{lat,0} \pm \left(\frac{w^{host}}{2} + \frac{w^{obstacle}}{2}\right) - \tilde{\dot{x}}_{lat,0} TTC}{TTC^2}$$

(2)

$$TTC = \begin{cases} \frac{\tilde{x}_{long,0}}{\tilde{\dot{x}}_{long,0}}, \tilde{\ddot{x}} = 0 \\ \frac{-\tilde{\dot{x}}_{long,0}}{\tilde{\ddot{x}}_{long,0}} - \frac{\sqrt{\tilde{\dot{x}}^2_{long,0} - 2\tilde{x}_{long,0}\tilde{\ddot{x}}_{long,0}}}{\tilde{\ddot{x}}_{long,0}}, \tilde{\ddot{x}} \neq 0 \end{cases}$$

(3)

**[0019]** Where:

$\ddot{x}_{needed}$ needed acceleration to avoid a collision (m/s$^2$)

$x^j_{i,0}$ lateral or longitudinal position for obstacle or host vehicle (m)

$\dot{x}^j_0$ velocity for obstacle or host (m/s)

$\ddot{x}^j_0$ acceleration for obstacle or host (m/s$^2$)

$w^j$ vehicle width for obstacle or host (m)

**[0020]** Subscript "lat" and "long" denotes lateral and longitudinal motion respectively and superscript "host" and "obstacle" denotes host or the obstacle vehicle.

$\tilde{x} = x^{obstacle} - x^{host}$ relative distance (m) (4)

$\tilde{\dot{x}} = \dot{x}^{obstacle} - \dot{x}^{host}$ relative velocity (m/s) (5)

$\tilde{\ddot{x}} = \ddot{x}^{obstacle} - \ddot{x}^{host}$ relative acceleration (m/s$^2$) (6)

**[0021]** As can be observed (2) gives the possible lateral accelerations to avoid a collision. Two solutions are yielded by (2) one is for passing to the right of the obstacle and the other one is for passing to the left of the obstacle, see Figure 1.

**[0022]** The required lateral acceleration to avoid an obstacle is calculated as

$$\ddot{x}^{host}_{lat,needed} = \min\left(\left|\max\left(\ddot{x}^{host}_{left,needed}, 0\right)\right|, \left|\min\left(\ddot{x}^{host}_{right,needed}, 0\right)\right|\right)$$

(7)

**[0023]** This is normalized by the maximum possible lateral acceleration according

$$STN^{host} = \frac{\ddot{x}^{host}_{lat,needed}}{\ddot{x}_{lat,\max}},$$

(8)

to obtain a steering threat number which indicate that a collision is imminent when STN =1.The obstacles steering threat number ($STN^{obstacle}$), i.e. the effort for the obstacle to avoid the host, is calculated correspondingly.

Longitudinal acceleration

**[0024]** Another common metric to evaluate the collision threat is by the longitudinal acceleration to avoid collision, this is often considered to correspond to how much braking is required to avoid a collision. A simple way of calculating the longitudinal acceleration to avoid an in path object is to assume constant acceleration and solve (1). This yield

$$\ddot{x}^{host}_{long,needed} = \ddot{x}^{obstacle}_{long,0} - \frac{\dot{\tilde{x}}^{2}_{long,0}}{2\tilde{x}_{long,0}}.$$

(9)

**[0025]** For a crossing vehicle however there are other possibilities i.e. the host vehicle may speed up in order to move out of the crossing vehicles path. Also when braking it is not always required to reduce the relative velocity to 0. It suffices to brake hard enough for the other vehicle to move out of the host's path. Thus, when talking about a longitudinal acceleration to avoid collision this includes both positive and negative acceleration values.

**[0026]** Figure 2 illustrates a crossing scenario. Considering host longitudinal motion in a crossing scenario the host can either accelerate to pass before the obstacle or brake sufficiently hard for the obstacle to pass through the host path before a collision occurs. In the crossing scenario an obstacle vehicle 1 having a heading direction 2 which intersects the heading direction 3 of a host vehicle is shown. The relative heading angle that is the angle between the respective heading direction is denoted by $\alpha$.

**[0027]** The time for an object to enter the host vehicle path, $t_{EnterPath}$, is given by the solution to

$$\frac{w^{host}}{2} + \frac{w^{obstacle}}{2} = \tilde{x}_{lat,0} + \dot{\tilde{x}}_{lat,0}t + \frac{\ddot{\tilde{x}}_{lat,0}t^2}{2}$$

(10)

**[0028]** Which is

$t_{EnterPath} = 0$ if $\tilde{x}_{lat,0} < \frac{w^{host}}{2} + \frac{w^{obstacle}}{2}$ (i.e the object is already in the host vehicles path)

else

$$t_{EnterPath} = \infty \text{ if } \dot{\tilde{x}}_{lat,0} = 0 \;\&\; \ddot{\tilde{x}}_{lat,0} \geq 0$$

or

$$\tilde{\ddot{x}}_{lat,0} \neq 0 \,\&\, \min(\tilde{x}_{lat,0}, \tilde{x}_{lat,0} + \tilde{\dot{x}}_{lat,0} t + \frac{\tilde{\ddot{x}}_{lat,0} t^2}{2}) \geq \frac{w^{host}}{2} + \frac{w^{obstacle}}{2} \tag{11}$$

where $t = -\frac{\tilde{\dot{x}}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}}$ (i.e the obstacle will never enter the host vehicles path).

else

$$t_{EnterPath} = \frac{\frac{w^{host}}{2} + \frac{w^{obstacle}}{2} - \tilde{x}_{lat,0}}{\tilde{\dot{x}}_{lat,0}} \quad \text{if } \tilde{\ddot{x}}_{lat,0} = 0 \tag{12}$$

else

$$t_{EnterPath} = -\frac{\tilde{\dot{x}}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}} - \sqrt{\left(\frac{\tilde{\dot{x}}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}}\right)^2 - \frac{2\tilde{x}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}}} \quad \text{if } \tilde{\ddot{x}}_{lat,0} > 0 \tag{13}$$

$$t_{EnterPath} = -\frac{\tilde{\dot{x}}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}} + \sqrt{\left(\frac{\tilde{\dot{x}}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}}\right)^2 - \frac{2\tilde{x}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}}} \quad \text{if } \tilde{\ddot{x}}_{lat,0} < 0 \tag{14}$$

**[0029]** The calculations of $t_{EnterPath}$ above are valid only if $\tilde{\dot{x}}_{lat,0} \leq 0$.

**[0030]** If $\tilde{\dot{x}}_{lat,0} > 0$, the calculations are valid if the signs of $\tilde{x}_{lat,0} \,\&\, \tilde{\dot{x}}_{lat,0} \,\&\, \tilde{\ddot{x}}_{lat,0}$ are changed first.

**[0031]** Similarly the time for the object to pass the host vehicles path, $t_{PassPath}$, is given by the solution to

$$-\frac{w^{host}}{2}-\frac{w^{obstacle}}{2}=\tilde{x}_{lat,0}+\tilde{\dot{x}}_{lat,0}t+\frac{\tilde{\ddot{x}}_{lat,0}t^2}{2} \tag{15}$$

**[0032]** Which is

$t_{PassPath}=\infty$ if $\tilde{x}_{lat,0}<-\frac{w^{host}}{2}-\frac{w^{obstacle}}{2}$ (i.e the object will never enter the host vehicles path).

$$t_{PassPath}=0 \quad \text{if} \quad \tilde{\dot{x}}_{lat,0}=0\ \&\ \tilde{\ddot{x}}_{lat,0}=0\ \&-\frac{w^{host}}{2}-\frac{w^{obstacle}}{2}<\tilde{x}_{lat,0}<\frac{w^{host}}{2}+\frac{w^{obstacle}}{2} \tag{16}$$

else

$$t_{PassPath}=-\frac{\frac{w^{host}}{2}+\frac{w^{obstacle}}{2}+\tilde{x}_{lat,0}}{\tilde{\dot{x}}_{lat,0}} \quad \text{if} \quad \tilde{\ddot{x}}_{lat,0}=0 \tag{17}$$

else

$$t_{PassPath}=-\frac{\tilde{\dot{x}}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}}-\sqrt{\left(\frac{\tilde{\dot{x}}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}}\right)^2-\frac{2\left(\frac{w^{host}}{2}+\frac{w^{obstacle}}{2}+\tilde{x}_{lat,0}\right)}{\tilde{\ddot{x}}_{lat,0}}} \quad \text{if} \quad \tilde{\ddot{x}}_{lat,0}>0 \tag{18}$$

$$t_{PassPath} = -\frac{\tilde{\dot{x}}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}} + \sqrt{\left(\frac{\tilde{\dot{x}}_{lat,0}}{\tilde{\ddot{x}}_{lat,0}}\right)^2 - \frac{2\left(\frac{w^{host}}{2} + \frac{w^{obstacle}}{2} + \tilde{x}_{lat,0}\right)}{\tilde{\ddot{x}}_{lat,0}}} \quad \text{if } \tilde{\ddot{x}}_{lat,0} < 0 \tag{19}$$

**[0033]** The calculations of $t_{EnterPath}$ above are valid only if $\tilde{\dot{x}}_{lat,0} \leq 0$.

**[0034]** if $\tilde{\dot{x}}_{lat,0} > 0$, the calculations are valid if the signs of $\tilde{x}_{lat,0}$ & $\tilde{\dot{x}}_{lat,0}$ & $\tilde{\ddot{x}}_{lat,0}$ are changed first.

**[0035]** To calculate the acceleration to clear the objects path before it crosses the host path one must solve

$$0 = \tilde{x}_{long,0} + l^{host} + l^{obstacle} + \tilde{\dot{x}}_{long,0} t_{EnterPath} + \frac{\tilde{\ddot{x}}_{long,needed} t_{EnterPath}^2}{2} \tag{20}$$

yielding

$$\tilde{\ddot{x}}_{long,needed}^{ATN} = -\frac{2\left(\tilde{x}_{long,0} + l^{host} + l^{obstacle} + \tilde{\dot{x}}_{long,0} t_{EnterPath}\right)}{t_{EnterPath}^2}. \tag{21}$$

**[0036]** Note that (21) does not always have a valid solution. For the case when the object does not enter the host's path ($t_{EnterPath}$ = infinity) one has

$$\tilde{\ddot{x}}_{long,needed}^{ATN} = 0, \tag{22}$$

and in the cases where the host is already in the host path ($t_{EnterPath}$ = 0)

$$\tilde{\ddot{x}}_{long,needed}^{ATN} = \infty. \tag{23}$$

**[0037]** Similarly the acceleration required to let the object cross the host's path without a collision is given by

$$\ddot{\tilde{x}}^{BTN}_{long,needed} = -\frac{2\left(\tilde{x}_{long,0} + \dot{\tilde{x}}_{long,0} t_{PassPath}\right)}{t^2_{PassPath}}. \quad (24)$$

**[0038]** The solution (22) is only valid if

$$t_{PassPath} < t_{Impact} \quad (25)$$

where $t_{Impacet}$ is the smallest positive solution for t off

$$0 = x_0 + \dot{x}_0 t + \frac{\ddot{x}^{host}_{long,needed} t^2}{2}. \quad (26)$$

**[0039]** Since the relative acceleration is given by Equation (6). The host vehicle required acceleration to avoid a collision is

$$\ddot{x}^{host,ATN}_{long,needed} = \ddot{x}^{obstacle}_{long} - \ddot{\tilde{x}}^{ATN}_{long,needed}. \quad (27)$$

$$\ddot{x}^{host,BTN}_{long,needed} = \ddot{x}^{obstacle}_{long} - \ddot{\tilde{x}}^{BTN}_{long,needed}. \quad (28)$$

**[0040]** The above longitudinal accelerations are then normalized with the available acceleration. This yields an acceleration threat number according to

$$ATN^{host} = \begin{cases} 0, & if \quad \ddot{x}^{host,ATN}_{long,needed} \le 0 \\ \dfrac{\ddot{x}^{host,ATN}_{long,needed}}{\ddot{x}_{long,\max}}, & else \end{cases} \quad (29)$$

and a brake threat number according to

$$BTN^{host} = \begin{cases} 0, & if \quad \ddot{x}^{host,BTN}_{long,needed} \geq 0 \\ \dfrac{\ddot{x}^{host,BTN}_{long,needed}}{\ddot{x}_{long,\min}}, & else \end{cases} \tag{30}$$

**[0041]** Then the minimum of ATN and BTN is chosen to describe the longitudinal effort to avoid a collision by braking or accelerating.

**[0042]** As for the lateral acceleration required to avoid collision the longitudinal acceleration to avoid collision is calculated both for the host ($\ddot{x}^{host}_{needed,long}$) and the obstacle ($\ddot{x}^{obstacle}_{needed,long}$).

**[0043]** The effort for the host and the obstacle to avoid each other can now be stated in a more general threat number, given by

$$TN^{host} = \min(ATN^{host}, BTN^{host}, STN^{host}) \tag{31}$$

and

$$TN^{obstacle} = \min(ATN^{obstacle}, BTN^{obstacle}, STN^{obstacle}) \tag{32}$$

**[0044]** Here $TN^{host}$ represents a host vehicle collision avoidance effort value indicating an effort for a host vehicle to avoid a collision with the obstacle vehicle and $TN^{obstacle}$ represents an obstacle vehicle collision avoidance effort value indicating an effort for an obstacle vehicle to avoid a collision with the host vehicle.

**[0045]** The threat estimation is based on the host vehicles possibilities to avoid the collision as well as the other vehicles possibilities to avoid the collision. This is captured by taking

$$TN^{joint} = \min(TN^{host}, TN^{obstacle}) \tag{33}$$

, thus an alarm is issued when $TN^{joint} > TN_{th}$ where $TN_{th}$ is a threshold that determines when a collision is considered to be imminent in terms of normalized acceleration values of the host and obstacle.

**[0046]** In figure 3 a block scheme of a method according to the invention is illustrated. In a first method step S10 the presence of an obstacle vehicle having a heading direction which intersects a heading direction of a host vehicle is detected. The method step S10 utilises input data from sensor means such as a radar, lidar, camera or the like which are capable of detecting an obstacle vehicle. The sensor means furthermore determines the speed of the obstacle vehicle relative to the host vehicle and optionally the acceleration of the obstacle vehicle. A future path estimator estimates a future path of the obstacle vehicle from the input data collected by the sensor means. The future path may be determined based on the assumption that the obstacle vehicle will progress under a constant manoeuvre with constant acceleration or optionally that the obstacle vehicle will deviate from a constant manoeuvre based on assumed behaviours that a driver may undertake. Different behaviour may be assigned with different probability weights. The future path estimator suitable utilises a Kalman filtering process to assign probable future path of the obstacle vehicle. Future path estimators are well known in the art.

**[0047]** Suitable future path estimators are described in A. Eidehall, Tracking and threat assessment for automotive collision avoidance, . PhD thesis, Linköping University, Linköping, Sweden, 2005. Linköping Studies in Science and Technology. Dissertations No. 1066 or J. Jansson. Collision Avoidance Theory with Application to Automotive Collision Mitigation. PhD thesis, Linköping University, Linköping, Sweden, 2005. Linköping Studies in Science and Technology. Dissertations No. 950.

**[0048]** An obstacle vehicle is defined as a vehicle having a heading direction which intersects a heading direction of a host vehicle. Vehicles which do not have a future path having a heading direction which intersects a heading direction of a host vehicle are not considered as potential hazardous objects.

**[0049]** In a second method step S20 a host vehicle collision avoidance effort value representing an effort for a host vehicle to avoid a collision with the obstacle vehicle is determined. Determination of vehicle collision avoidance effort values are well known in the art. In the broadest aspect of the invention any known method for determining a host vehicle collision avoidance effort value may be used. A suitable method is described above, where the host vehicle collision avoidance value is determined under the assumption that the obstacle vehicle performs a constant manoeuvre under a constant acceleration. According to this method determination of the host vehicle collision avoidance effort value includes determination of required longitudinal acceleration of the host vehicle in order to avoid collision with the obstacle vehicle, when assuming that the obstacle vehicle performs a constant manoeuvre. Furthermore, the determination of the obstacle vehicle collision avoidance effort value may include determination of required longitudinal acceleration of the obstacle vehicle in order to avoid collision with the host vehicle, when assuming that the host vehicle performs a constant manoeuvre. Further examples of how to establish a host vehicle collision avoidance value are described in A. Eidehall, Tracking and threat assessment for automotive collision avoidance, . PhD thesis, Linköping University, Linköping, Sweden, 2005. Linköping Studies in Science and Technology. Dissertations No. 1066; J. Jansson. Collision Avoidance Theory with Application to Automotive Collision Mitigation. PhD thesis, Linköping University, Linköping, Sweden, 2005. Linköping Studies in Science and Technology. Dissertations No. 950 or A Multilevel Collision Mitigation Approach - Its Situation Assessment, Decision Making, and Performace Tradeoffs, Jörg Hillenbrand, Andreas M. Spieker, and Kristian Kroschel, IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, VOL. 7, NO.4, DECEMBER 2006.

**[0050]** In a third method step S30 an obstacle vehicle collision avoidance effort value representing an effort for the obstacle vehicle to avoid a collision with the host vehicle is determined. A suitable method is described above, where the obstacle vehicle collision avoidance value is determined under the assumption that the host vehicle performs a constant manoeuvre under a constant acceleration. Determination of the obstacle vehicle collision avoidance effort value therefore advantageously includes determination of required longitudinal acceleration of the obstacle vehicle in order to avoid collision with the host vehicle, when assuming that the host vehicle performs a constant manoeuvre. Furthermore, determination of the host vehicle collision avoidance effort value preferably includes determination of required lateral acceleration of the host vehicle in order to avoid collision with the obstacle vehicle, when assuming that the obstacle vehicle performs a constant manoeuvre. The obstacle vehicle collision avoidance value is determined in the host vehicle with use of input data from the sensor system carried by the host vehicle. The method does not require that the obstacle vehicle is equipped with a system for determining an obstacle vehicle collision avoidance effort value since all necessary equipment for performing the method is carried by the host vehicle. In the most general aspect of the invention the obstacle vehicle collision avoidance effort value may be determined using the same principles as determining host vehicle collision avoidance effort values by methods known in the art while applying the principles on the obstacle vehicle rather than on the host vehicle.

**[0051]** Finally in a fourth method step S40 a host vehicle intervention based on said a host vehicle collision avoidance effort value and obstacle vehicle collision avoidance effort value is determined. The intervention can consist in activation of forced steering, activation of brakes or simply alerting the driver by indicator means. Suitable means for performing the interventions are well known in the art. Such means are for instance disclosed in the following references: US 6607255, US 6559762, US 6659572, US 6655749, US 6517172, US 6523912, US 6560525, or US 6677855.

**[0052]** In a preferred embodiment intervention is made in the event an intervention is made in the event the minimum of the host vehicle collision avoidance effort value and the obstacle vehicle collision avoidance effort value exceeds a threshold value. This embodiment is particularly suitable since experience has shown that active safety systems tend to underestimate the capacity of drivers to adapt to traffic scenarios. In particular this embodiment is advantageous in at road crossings where one of the roads is a priority road and traffic on the other road has a duty to yield. According to this aspect, in an advantageous embodiment of the invention method for in-vehicle collision avoidance is restricted to traffic scenarios where a relative heading angle $\alpha$ between the host vehicle and the obstacle vehicle is such that $30^\circ < \alpha < 150^\circ$ or $-150^\circ < \alpha < -30^\circ$, preferably $45^\circ < \alpha < 135^\circ$ or $-135^\circ < \alpha < -45^\circ$.

**[0053]** In figure 4 a schematic drawing of a system 10 for in-vehicle collision is shown. The system for in-vehicle collision avoidance comprises avoidance:

- means 20 for detecting the presence of an obstacle vehicle having an heading direction which intersects a heading direction of a host vehicle;
- means 30 for determining a host vehicle collision avoidance effort value representing an effort for a host vehicle to avoid a collision with the obstacle vehicle;
- means 40 for determining an obstacle vehicle collision avoidance effort value representing an effort for the obstacle vehicle to avoid a collision with the host vehicle; and
- means 50 for determining a host vehicle intervention based on said a host vehicle collision avoidance effort value and obstacle vehicle collision avoidance effort value.

**[0054]** The means 20 for detecting the presence of an obstacle vehicle having a heading direction which intersects a heading direction of a host vehicle includes sensor means 21 such as a radar, lidar, camera or the like which are capable of detecting an obstacle vehicle. The sensor means furthermore determines the speed of the obstacle vehicle relative to the host vehicle and optionally the acceleration of the obstacle vehicle. A future path estimator 22 for the obstacle vehicle estimates a future path of the obstacle vehicle from the input data collected by the sensor means. The future path of the obstacle vehicle may preferably be determined based on the assumption that the obstacle vehicle will progress under a constant manoeuvre with constant acceleration as is explained in detail above or optionally that the obstacle vehicle will deviate from a constant manoeuvre based on assumed behaviours that a driver may undertake. Different behaviour may be assigned with different probability weights. Such a future path estimator suitable utilises a Kalman filtering process to assign probable future path of the obstacle vehicle.

**[0055]** Suitable future path estimators for the obstacle vehicle which may be used in the system disclosed herein is disclosed in the references A. Eidehall, Tracking and threat assessment for automotive collision avoidance, . PhD thesis, Linköping University, Linköping, Sweden, 2005. Linköping Studies in Science and Technology. Dissertations No. 1066; J. Jansson. Collision Avoidance Theory with Application to Automotive Collision Mitigation. PhD thesis, Linköping University, Linköping, Sweden, 2005. Linköping Studies in Science and Technology. Dissertations No. 950 . A future path estimator 23 for the host vehicle estimates a future path of the obstacle vehicle from the input data collected by sensor means. The sensor means preferably includes input from an on board speedometer, and vehicle yaw rate sensors. An input sensor from accelerometers may also be used. The future path of the host vehicle may be determined based on the assumption that the obstacle vehicle will progress under a constant manoeuvre with constant acceleration or optionally that the obstacle vehicle will deviate from a constant manoeuvre based on assumed behaviours that a driver may undertake. Different behaviour may be assigned with different probability weights. Such a future path estimator suitable utilises a Kalman filtering process to assign probable future path of the obstacle vehicle. Suitable future path estimators for the obstacle vehicle which may be used in the system disclosed herein are disclosed in the references A. Eidehall, Tracking and threat assessment for automotive collision avoidance, . PhD thesis, Linköping University, Linköping, Sweden, 2005. Linköping Studies in Science and Technology. Dissertations No. 1066; J. Jansson. Collision Avoidance Theory with Application to Automotive Collision Mitigation. PhD thesis, Linköping University, Linköping, Sweden, 2005. Linköping Studies in Science and Technology. Dissertations No. 950.

**[0056]** When the future paths of the host vehicle and obstacle are determined, an assessment is made of whether the heading direction of the host vehicle intersects the heading direction of the obstacle vehicle. This assessment is made in an obstacle vehicle identification block 25.

**[0057]** When the obstacle vehicle is identified a host vehicle collision avoidance effort value representing an effort for a host vehicle to avoid a collision with the obstacle vehicle is determined in the means 30 for determining a host vehicle collision avoidance effort value. The means 30 for determining the host vehicle collision avoidance effort value assess the effort required by the host to avoid a collision with the obstacle vehicle. The effort value is suitably calculated as described above. The means 30 for determination of the host vehicle collision avoidance effort value are preferably arranged to include determination of required longitudinal acceleration of the host vehicle in order to avoid collision with the obstacle vehicle, when assuming that the obstacle vehicle performs a constant manoeuvre, when determining the host vehicle collision avoidance effort value. Said means 30 for determination of the host vehicle collision avoidance effort value may furthermore be arranged to include determination of required lateral acceleration of the host vehicle in order to avoid collision with the obstacle vehicle, under assumption that the obstacle vehicle performs a constant manoeuvre, when determining the host vehicle collision avoidance effort value

**[0058]** Furthermore an obstacle vehicle collision avoidance effort value representing an effort for an obstacle vehicle to avoid a collision with the host vehicle is determined in the means 40 for determining an obstacle vehicle collision avoidance effort value. The means 40 for determining an obstacle vehicle collision avoidance effort value assess the effort required by the obstacle vehicle to avoid a collision with the host vehicle. The effort value is suitably calculated as described above. In a preferred embodiment the means 40 for determination of the obstacle vehicle collision avoidance effort value are thus arranged to include determination of required longitudinal acceleration of the obstacle vehicle in order to avoid collision with the host vehicle, under assumption that the host vehicle performs a constant manoeuvre, when determining the obstacle vehicle collision avoidance effort value. The means 40 for determination of the obstacle vehicle collision avoidance effort value may furthermore be arranged to include determination of required lateral acceleration of the obstacle vehicle in order to avoid collision with the host vehicle, under assumption that the host vehicle performs a constant manoeuvre, when determining the obstacle vehicle collision avoidance effort value.

**[0059]** When the respective effort values are calculated in the means 30, 40 determination of a host vehicle intervention based on said a host vehicle collision avoidance effort value and obstacle vehicle collision avoidance effort value is made by means 50 for determining a host vehicle intervention. The means 50 includes a comparator function block 51 which may compare the collision effort values with threshold values as have been indicated above. Different actions may be performed in dependence of the outcome of the comparison. In one embodiment the means 50 for determining a host vehicle intervention includes means 52 for performing an intervention which are arranged to intervene in the event the minimum of the host vehicle collision avoidance effort value and the obstacle vehicle collision avoidance effort value exceeds a threshold value. The means 50 for determining a host vehicle intervention generates output signals to the brake system, the engine control system, safety equipment or warning indicators depending of how the intervention is made. Suitable systems for control of the intervention are described in US 6607255, US 6559762, US 6659572, US 6655749, US 6517172, US 6523912, US 6560525, or US 6677855.

## Claims

**1.** A method for in-vehicle collision avoidance comprising the following method steps:

- detecting the presence of an obstacle vehicle (1) having an heading direction (2) which intersects a heading direction (3) of a host vehicle (4); (S10)
- determining a host vehicle collision avoidance effort value *($TN^{host}$)* representing an effort for a host vehicle (4) to avoid a collision with the obstacle vehicle (1); (S20)

**characterised in that** the method further includes the step of:

- determining an obstacle vehicle collision avoidance effort value ($TN^{obstacle}$) representing an effort for the obstacle vehicle (1) to avoid a collision with the host vehicle (4); (S30) and
- determining a host vehicle intervention based on said a host vehicle collision avoidance effort value ($TN^{host}$) and obstacle vehicle collision avoidance effort value ($TN^{obstacle}$).(S40)

**2.** A method according to claim 1, **characterised in that** an intervention is made in the event the minimum of the host vehicle collision avoidance effort value ($TN^{host}$) and the obstacle vehicle collision avoidance effort value ($TN^{obstacle}$) exceeds a threshold value (*TNth*).

**3.** A method according to claim 1 or 2, **characterised in that** determination of the host vehicle collision avoidance effort value *($TN^{host}$)* includes determination of required longitudinal acceleration $(\ddot{x}^{host}_{long,needed})$ of the host vehicle (4) in order to avoid collision with the obstacle vehicle (1), when assuming that the obstacle vehicle (1) performs a constant manoeuvre.

**4.** A method according to claim 1, 2 or 3, **characterised in that** determination of the obstacle vehicle collision avoidance effort value ($TN^{obstacle}$) includes determination of required longitudinal acceleration $(\ddot{x}^{obstacle}_{long,needed})$ of the obstacle vehicle (1) in order to avoid collision with the host vehicle (4), when assuming that the host vehicle (4) performs a constant manoeuvre.

**5.** A method according to any of the preceding claims, **characterised in that** determination of the host vehicle collision avoidance effort value ($TN^{host}$) includes determination of required lateral acceleration $(\ddot{x}^{host}_{lat,needed})$ of the host vehicle (4) in order to avoid collision with the obstacle vehicle (1), when assuming that the obstacle vehicle (4) performs a constant manoeuvre.

**6.** A method according to any of the preceding claims, **characterised in that** determination of the obstacle vehicle collision avoidance effort value (*$TN^{obstacle}$*) includes determination of required lateral acceleration $(\ddot{X}^{obstacle}_{lat,needed})$ of the obstacle vehicle (1) in order to avoid collision with the host vehicle (4), when assuming that the host vehicle (4) performs a constant manoeuvre.

**7.** A method according to any of the preceding claims, **characterised in that** the method is restricted to traffic scenarios where a relative heading angle $\alpha$ between the host vehicle (4) and the obstacle vehicle (1) is such that $30^\circ < \alpha < 150^\circ$ or $-150^\circ < \alpha < -30^\circ$, preferably $45^\circ < \alpha < 135^\circ$ or $-135^\circ < \alpha < -45^\circ$.

**8.** A system for in-vehicle collision avoidance comprising:

- means (20) for detecting the presence of an obstacle vehicle (1) having an heading direction (2) which intersects a heading direction (3) of a host vehicle (4);
- means (30) for determining a host vehicle collision avoidance effort value ($TN^{host}$) representing an effort for a host vehicle (4) to avoid a collision with the obstacle vehicle (1);

**characterised in that** system further includes:

- means (40) for determining an obstacle vehicle collision avoidance effort value ($TN^{obstacle}$) representing an effort for the obstacle vehicle (1) to avoid a collision with the host vehicle (1); and
- means (50) for determining a host vehicle intervention based on said a host vehicle collision avoidance effort value ($TN^{host}$) and obstacle vehicle collision avoidance effort value ($TN^{obstacle}$).

**9.** A system according to claim 8, **characterised in that** the system further includes means (52) for performing an intervention which are arranged to intervene in the event the minimum of the host vehicle collision avoidance effort value ($TN^{host}$) and the obstacle vehicle collision avoidance effort value ($TN^{obstacle}$)exceeds a threshold value ($TN_{th}$).

**10.** A system according to claim 8 or 9, **characterised in that** said means (30) for determination of the host vehicle collision avoidance effort value ($TN^{host}$) are arranged to include determination of required longitudinal acceleration $(\ddot{X}^{host}_{long,needed})$ of the host vehicle (4) in order to avoid collision with the obstacle vehicle (1), when assuming that the obstacle vehicle (1) performs a constant manoeuvre, when determining the host vehicle collision avoidance effort value ($TN^{host}$).

**11.** A system according to claim 8, 9 or 10, **characterised in that** said means (40) for determination of the obstacle vehicle collision avoidance effort value ($TN^{obstacle}$) are arranged to include determination of required longitudinal acceleration $(\ddot{X}^{obstacle}_{long,needed})$ of the obstacle vehicle (1) in order to avoid collision with the host vehicle (4), under assumption that the host vehicle (4) performs a constant manoeuvre, when determining the obstacle vehicle collision avoidance effort value ($TN^{obstacle}$).

**12.** A system according to any of claims 8 - 11, **characterised in that** said means (30) for determination of the host vehicle collision avoidance effort value ($TN^{host}$) are arranged to include determination of required lateral acceleration $(\ddot{X}^{host}_{lat,needed})$ of the host vehicle (4) in order to avoid collision with the obstacle vehicle (1), under assumption that the obstacle vehicle (1) performs a constant manoeuvre, when determining the host vehicle collision avoidance effort value ($TN^{host}$).

**13.** A system according to any of claims 8 - 12, **characterised in that** said means (40) for determination of the obstacle vehicle collision avoidance effort value ($TN^{host}$) are arranged to include determination of required lateral acceleration $(\ddot{X}^{obstacle}_{lat,needed})$ of the obstacle vehicle (1) in order to avoid collision with the host vehicle (4), under assumption that the host vehicle (4) performs a constant manoeuvre, when determining the obstacle vehicle collision avoidance effort value ($TN^{host}$).

**14.** A system according to any of claims 8 - 13, **characterised in that** system for in-vehicle collision avoidance is restricted base a decision to intervene from the host vehicle collision avoidance value ($TN^{host}$) and the obstacle vehicle collision avoidance value ($TN^{obstacle}$) to traffic scenarios where a relative heading angle $\alpha$ between the host vehicle (4) and the obstacle vehicle (1) is such that $30^\circ < \alpha < 150^\circ$ or $-150^\circ < \alpha < -30^\circ$, preferably $45^\circ < \alpha < 135^\circ$ or $-135^\circ < \alpha < -45^\circ$.

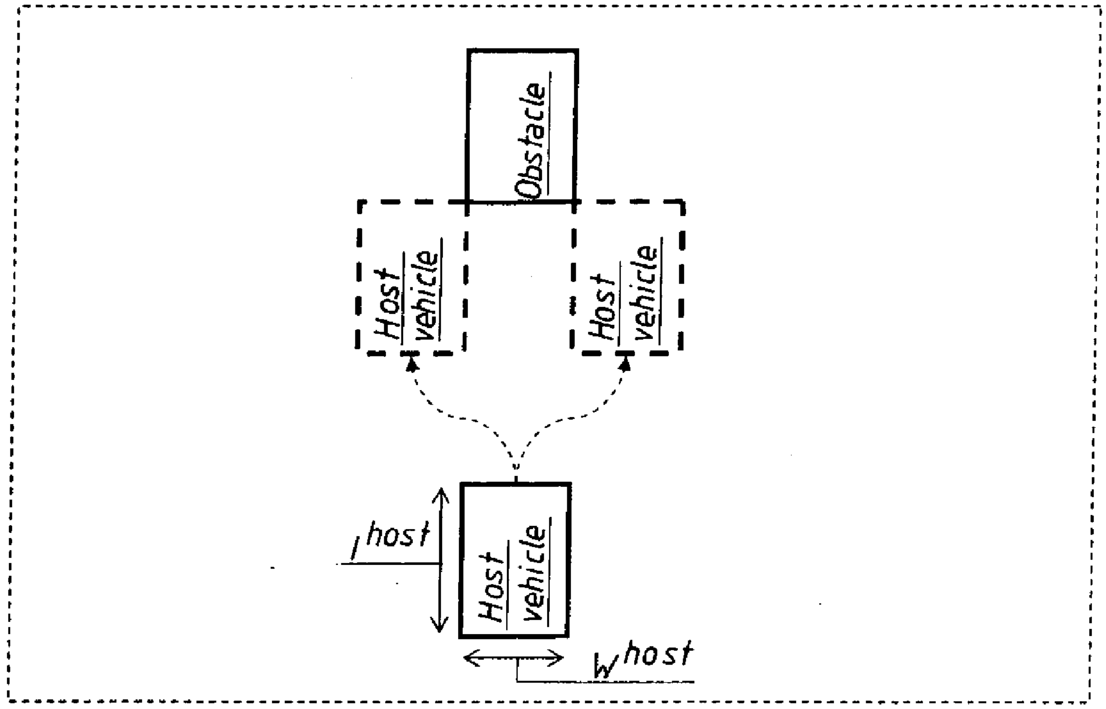
Obstacle
Host vehicle
Host vehicle
host
Host vehicle
whost

FIG.1

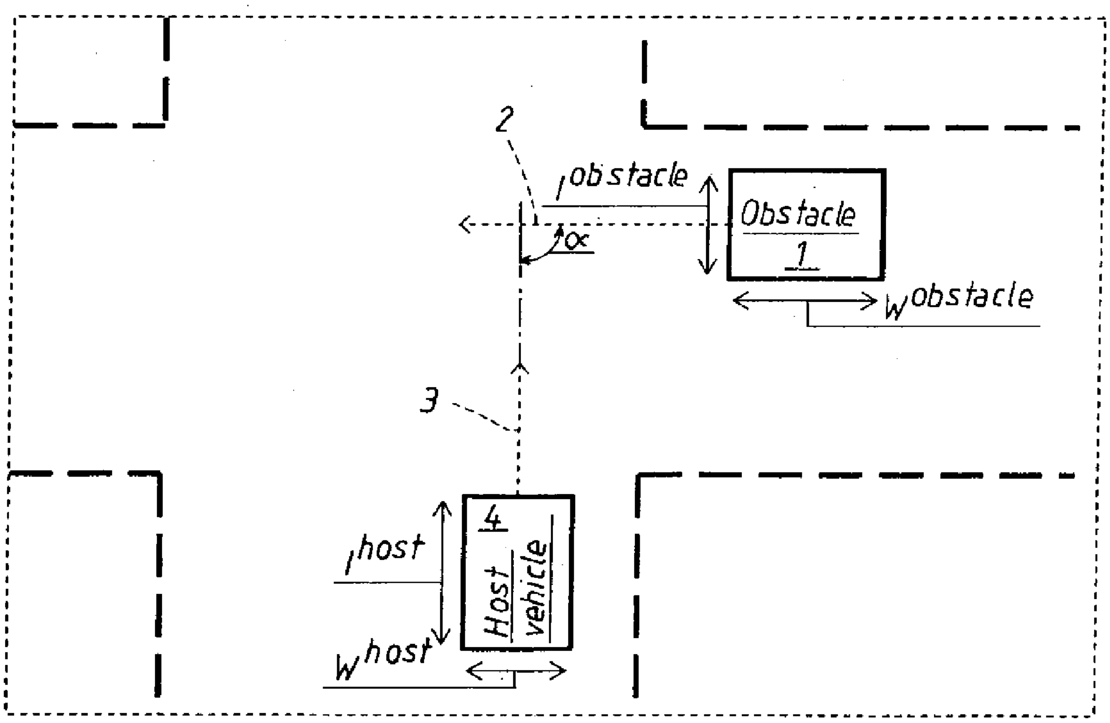
2
lobstacle
Obstacle
1
α
wobstacle
3
4
Host vehicle
lhost
whost

FIG.2

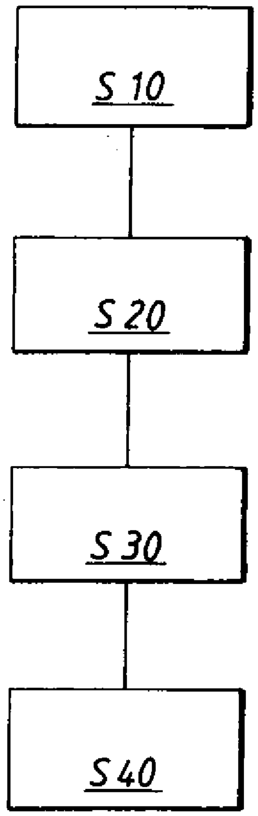


FIG.3

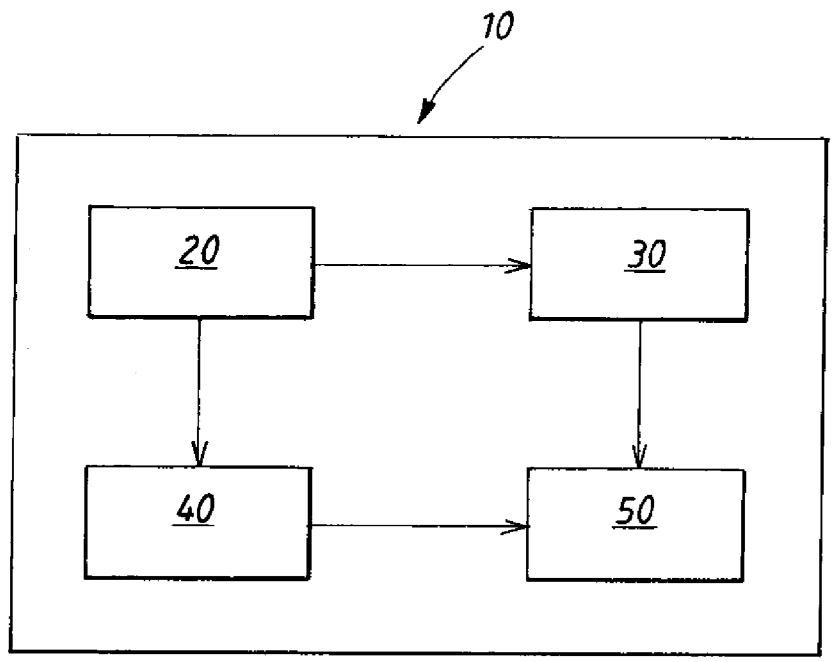


FIG.4

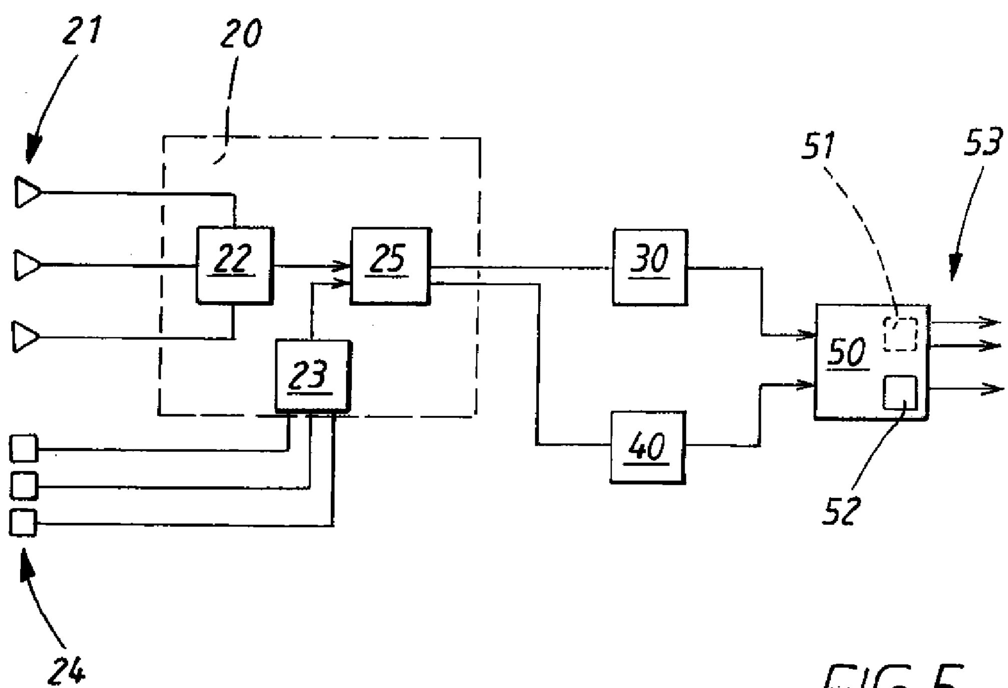


FIG.5

European Patent Office

# EUROPEAN SEARCH REPORT

Application Number
EP 07 10 8940

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
|---|---|---|---|
| X | DE 102 57 842 A1 (BOSCH GMBH ROBERT [DE]) 27 November 2003 (2003-11-27)<br>* column 5, paragraphs 22,24-26 *<br>* column 6, paragraph 28 *<br>----- | 1-14 | INV.<br>G08G1/16<br><br>ADD.<br>G01S13/93 |

| TECHNICAL FIELDS SEARCHED (IPC) |
|---|
| G01S<br>G08G |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 26 October 2007 | Coffa, Andrew |

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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T : theory or principle underlying the invention
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D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

## ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 07 10 8940

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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26-10-2007

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| DE 10257842 A1 | 27-11-2003 | NONE | |

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

## REFERENCES CITED IN THE DESCRIPTION

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- US 6677855 B **[0051] [0059]**

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- **JÖRG HILLENBRAND ; ANDREAS M. SPIEKER ; KRISTIAN KROSCHEL.** *IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS,* November 2006, vol. 7 (4 **[0049]**