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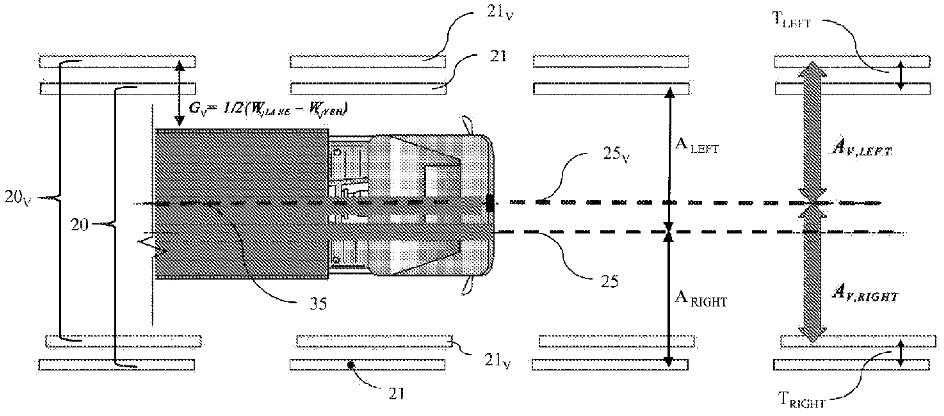

Figure 7

(57) **Abstract:** The method of adaptive drive control in a vehicle comprises the steps of obtaining, by at least one image sensor (40), image data of a road ahead of the vehicle; on the basis of said image data, identifying, by a processor device, lateral boundary lane markers (21) of a lane (20) in which the vehicle (30) is travelling; on the basis of said image data, determining, by the processor device, left and right marker distances (ALEFT, ARIGHT) of the lateral boundary lane markers (21) relative to the origin of a vehicle coordinate system (25) fixed to the vehicle (30); on the basis of the left and right marker distances (ALEFT, ARIGHT), determining, by the processor device, a lane centerline offset (LC) as a distance between a centerline (35) of the vehicle (30) and a centerline (25) of the lane (20); receiving a trigger event by the processor device; generating, by the processor device, a virtual lane model, wherein the virtual lane (20) has virtual lateral boundary lane markers (21v) that are shifted relative to the physical lateral lane markers (21) by left and right offsets (TL, TR), respectively, and wherein the virtual lane (20v) also has a virtual lane centerline (25v) that is shifted relative to the physical lane centerline (25) by an offset (TC), wherein the distances between the left and right lateral boundary lane markers (21v) from the centerline (25v) of the virtual lane (20v) are defined as virtual lateral marker distances (AV,LEFT, AV,RIGHT) and the distance between the vehicle centerline (35) and the virtual lane centerline (25v) is defined as the virtual centerline offset (LCv); generating, by the processor device, an activation signal for one or more of said on- board electronic vehicle control units when one of a set of predefined conditions is satisfied; forwarding said activation signal, by the processor device, to one or more onboard electronic

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vehicle control units for activating said unit(s).

System and method for adaptive drive control in a vehicle

TECHNICAL FIELD

The present invention relates to a system and a method for adaptive drive control in a vehicle.

BACKGROUND ART

The Lane Departure Warning (LDW), the Lane Departure Avoidance (LDA) and the Lane Keeping Assist (LKA) systems have been developed to assist in the orderly navigation of thoroughfares by vehicle drivers. The Lane Departure Warning (LDW) system assists drivers in maintaining proper lane alignment by alerting the driver to a possible unintentional lane departure, the Lane Departure Avoidance (LDA) system operates the steering wheel to keep the vehicle in its lane, and the Lane Keeping Assist (LKA) system helps the driver in maintaining safe travel within a marked lane. Furthermore, various traffic safety systems are also well known, which can respond to the variation in traffic situations.

The document US 7388475 B2 describes an improved Lane Departure Warning (LDW) system with different algorithm adjustments. The LDW system determines the distance between the vehicle and at least one lane marker (or the time till the expected lane crossing) and alerts the driver when the distance or the time till the expected lane crossing is less than a predetermined warning threshold. The system is configured to automatically reduce or suppress the warning threshold, or otherwise modify the warning algorithm at predefined conditions, for example, if the vehicle is driving in a curved lane, so as to effect timely warning to the driver.

The document US 2018/0229768 A1 describes a Lane Keeping Assist (LKA) system, wherein the system determines an offset position of the vehicle based on the lane markers, a clearance between the host-vehicle and the lane markers based on the offset position, and an adaptive threshold based on the lane width. The system also detects narrowing or widening of the lanes, and increases or reduces the adaptive threshold values.

The document EP 2010425 B1 describes a driver assistance system, in which the system is focused on the steering of the vehicle, and the warning depends on the deviation of the steering position from the actual road curvature. The relation between the deviation and the curvature is represented with a characteristic curve, and the warning thresholds are adjusted on the basis of the characteristic curve.

The document US 7765066 B2 describes a lane keeping system, in which the vehicle is slightly diverted to the left relative to the centerline of the lane when passing an object, for example, another vehicle in the neighbouring lane on the right in order to thereby allow a greater safety distance from the vehicle being passed.

The above described systems can assist a driver through lane departure warning, lane departure avoidance and/or lane keeping separately, but currently, there is no common calculating process to integrate the benefits of the individual driver assistant systems into one combined traffic safety system.

There is need for an adaptive drive control system that is capable of automatically changing the warning threshold and /or the lane centerline control offset in order to reduce or suppress the warning threshold, or otherwise modify the warning or the lane keep assist control algorithm at predefined conditions

SUMMARY OF INVENTION

These and other objects of the present invention are achieved by providing a method for adaptive drive control in a vehicle as defined by claim 1, and a system for adaptive drive control in a vehicle as defined by claim 4. Various preferred embodiments of the method and the system of the invention are defined by the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in detail with reference to the attached drawings.
Figure 1 schematically illustrates the geometry of a physical lane with a vehicle travelling therein.
Figure 2 schematically illustrates the geometrical parameters of a physical lane with a vehicle

travelling in the middle of the lane.

Figure 3 schematically illustrates the geometrical parameters of a physical lane with a vehicle travelling close to the left-side lane marker.

Figure 4 schematically illustrates the geometrical parameters of a physical lane with a vehicle travelling close to the right-side lane marker.

Figure 5 schematically illustrates the line marker tolerances for the ego lane probability calculation according to the invention.

Figure 6 schematically illustrates the geometry of the lane center-based calculation according to the invention.

Figure 7 schematically illustrates the parameters of the virtual lane model according to the invention.

Figure 8 is an exemplary graph of prolonged drive sensitivity levels used in an embodiment of the method according to the invention.

Figure 9 is a block diagram of the adaptive drive control system of the invention.

Figure 10 is a flow diagram of the adaptive drive control method of the invention.

DETAILED DESCRIPTION

The present invention relates to an adaptive drive control system for use in a vehicle. Although the present invention will be described in relation with a road vehicle, the method and the system of the invention may also be used for watercrafts and aircrafts with appropriate adaptations.

Figure 1 schematically shows the geometry of a physical lane 20 with a vehicle 30 travelling therein. The physical lane 20 is defined by boundary lane markers 21 on two sides of the lane 20. The vehicle 30 shown in Fig. 1 travels slightly offset from a lane centerline 25, so in this situation, the longitudinal centerline 35 of the vehicle 30 is not in align with the centerline 25 of the physical lane 20. Thus there is a lateral offset δ between the vehicle centerline 35 and the lane centerline 25.

As used herein, the term “lane marker” may include visible marks such as highly reflective paint or thermoplastic stripes (either continuous or dashed line-type), curbs, medians, reflectors, and otherwise distinguishable edges of pavement.

As shown in Fig. 1, on the front of the vehicle 30, preferably at the middle of the vehicle 30, at least one image sensor 40, preferably a camera, is mounted for providing image data on the road and its environment ahead of the vehicle 30. The image data includes information relating at least to the boundary lane markers 21 of the physical lane 20. Optionally, the image data may further include information relating to other lane markers, symbols painted on the lane, traffic lights, traffic signs, etc.

The vehicle 30 is further equipped with a processor device 42 that analyses the image data provided by the image sensor(s) 40, and allows high-performance real-time image processing of various objects of the road, such as the boundary lane markers 21 of the physical lane 20.

The at least one image sensor 40 and the processor device 42 form part of the adaptive drive control system 10 of the invention as shown in Fig. 9.

In one embodiment of the adaptive drive control system 100 according to the invention, the processor device 42 may also assign a confidence level to the detection of a lane marker 21. The value of the detection confidence level may range from 1 to 4, wherein

- Level 1 represents "low detection confidence",
- Level 2 represents "medium detection confidence",
- Level 3 represents "high detection confidence",
- Level 4 represents "extra high detection confidence".

Figure 2 schematically illustrates the geometrical parameters of a physical lane 20 with a vehicle 30 travelling in the middle of the physical lane 20. Based on the image data obtained from the at least one image sensor 40, the processor device 42 determines a left marker distance A_{LEFT} and a right marker distance A_{RIGHT} that are the lateral distances between the origin of a vehicle coordinate system 45 and the lane markers 21 on both sides of the vehicle 30. The vehicle coordinate system 45 has a fixed location with respect to the vehicle 20. Preferably, the origin of the vehicle coordinate system 45 is fixed along the centerline 35 of the vehicle 30 as shown in Fig. 1. In the following description, it will be assumed that the vehicle coordinate system 45 is fixed along the centerline 35 the vehicle 30 in order make the calculations easier. It is, however, obvious for a skilled person how to modify the below calculations for adapting it to a vehicle coordinate system fixed at another point of the vehicle 30 not aligning with the centerline 35 of the vehicle 30.

As long as the vehicle centerline 35 is between the boundary lane markers 21, the values of the left marker distance A_{LEFT} is positive and the right marker distance A_{RIGHT} is negative in the vehicle coordinate system 45:

$$A_{LEFT} > 0$$

$$A_{RIGHT} < 0$$

The sum of the absolute values of the left and right marker distances A_{LEFT}, A_{RIGHT} gives the lane width W_{LANE}:

$$W_{LANE} = |A_{LEFT}| + |A_{RIGHT}|$$

When the vehicle 30 is located exactly in the middle of the lane 20, as shown in Figure 2, $|A_{LEFT}| = |A_{RIGHT}|$, it also means that:

$$A_{LEFT} + A_{RIGHT} = 0$$

If the vehicle 30 is shifted towards either side of the lane 20, as shown in Figs. 3 and 4, the lateral deviation δ from the physical lane centerline 25 can be calculated in the vehicle coordinate system 45 as follows:

$$\delta = \frac{(A_{LEFT} + A_{RIGHT})}{2}$$

The lateral deviation δ corresponds to a lane centerline offset LC along the y-axis in the vehicle coordinate system 45. If the value of the lane centerline offset LC is negative in the vehicle coordinate system 45, i.e. $|A_{LEFT}| < |A_{RIGHT}|$, then the vehicle 30 is shifted towards the left side of the lane 20, as shown Figure 3. If the value of the lane centerline offset LC is positive in the vehicle coordinate system 45, i.e. $|A_{LEFT}| > |A_{RIGHT}|$, then the vehicle 30 is shifted to the right, as shown Figure 4. If the value of the lane centerline offset LC is zero in the vehicle coordinate system 45, i.e. $|A_{LEFT}| = |A_{RIGHT}|$, then the vehicle 30 is exactly in the middle of the physical lane 20.

EGO LANE PROBABILITY CALCULATION

As shown in Fig. 9, the adaptive control system 10 of the invention may comprise an ego lane probability calculating unit 60 that calculates an ego lane probability for each of the lane markers 21. The ego lane probability is defined as the probability of a plausible lane detection by the at least one image sensor 40. The ego lane probability is calculated on the basis of the image data obtained from the at least one image sensor 40, and forwarded to the processor device 42. The ego lane probability calculation is based on:

- preset values of minimum and maximum tolerances $A_{LEFT,MIN}$, $A_{LEFT,MAX}$, $A_{RIGHT,MIN}$, $A_{RIGHT,MAX}$ of the left and right boundary lane markers 21, respectively, as shown in Figure 5;
- checking if the left and right marker distances A_{LEFT}, A_{RIGHT} are between the respective minimum and maximum tolerances $A_{LEFT,MIN}$, $A_{LEFT,MAX}$, $A_{RIGHT,MIN}$, $A_{RIGHT,MAX}$; and
- checking if the detection confidence of each of the lane markers 21 equals to or greater than a minimum detection confidence level.

For the minimum and maximum tolerances $A_{LEFT,MIN}$, $A_{LEFT,MAX}$, $A_{RIGHT,MIN}$, $A_{RIGHT,MAX}$, the following relation stands in the vehicle coordinate system 45:

$$A_{RIGHT,\,MIN} < A_{RIGHT,\,MAX} < A_{LEFT,\,MIN} < A_{LEFT,\,MAX}$$

The ego lane probability calculating unit 60 receives image data from the at least one image sensor 40 and provides the ego lane probability value for the processor device 42.

THEORETICAL TOLERANCES

In order to calculate the minimum and maximum tolerances $A_{LEFT,MIN}$, $A_{LEFT,MAX}$, $A_{RIGHT,MIN}$, $A_{RIGHT,MAX}$, minimum and maximum theoretical tolerances A_{MIN}, A_{MAX} are first determined.

The minimum theoretical tolerance A_{MIN} of the marker distance A (for both left and right directions) is the half of the vehicle width W_{VEH}, because if the vehicle 30 is shifted all the way to either side of the lane 20, where the outer edge of the respective front tire is on the lane marker 21, then the distance between the origin of the vehicle coordinate system 45 and the lane marker 21 is exactly the half of the vehicle width W_{VEH}:

$$A_{MIN} = \frac{W_{VEH}}{2}$$

The maximum theoretical tolerance A_{MAX} of the marker distance A (for both left and right directions) is the half of the lane width W_{LANE}, because if the vehicle 30 is in the middle of the physical lane 20, then the lane marker 21 accommodates exactly by a distance equal to the half of the lane width W_{LANE} from the origin of the vehicle coordinate system 45:

$$A_{MAX} = \frac{W_{LANE}}{2}$$

For compensating detection inaccuracy and for taking different lane geometries into consideration, for example, a widening lane before a lane split, an additional fixed tolerance f is added to the maximum theoretical tolerance A_{MAX} to extend the acceptable tolerance range:

$$A_{MAX} = \frac{W_{LANE}}{2} + f$$

The minimum and maximum theoretical tolerances A_{MIN}, A_{MAX} may have different values depending on which side the vehicle 30 is shifted towards within the physical lane 20.

THEORETICAL TOLERANCE COMPENSATION

When the vehicle 30 is getting shifted towards either side of the lane 20, the maximum value of the shift-direction theoretical tolerance needs to be reduced in order to count for the loss of the lateral area in the direction of the shift. In contrast, the opposite-side minimum and maximum theoretical tolerances A_{MIN}, A_{MAX} need to be extended in order to compensate for the area gained by the shift. In this way, even if the vehicle 30 is shifted to either side of the lane 20, the lane markers 21 will remain within the acceptable tolerance ranges, up to the point where the vehicle 30 crosses the lane marker 21.

TOLERANCES IN CASE OF A LEFT SHIFT

When the vehicle 30 is shifted to the left side of the physical lane 20, the left-side minimum tolerance $A_{LEFT,MIN}$ is equal to the minimum theoretical tolerance A_{MIN}:

$$A_{\mathrm{LEFT,\,MIN}} = \frac{W_{\mathrm{VEH}}}{2}$$

The left-side maximum tolerance $A_{LEFT,MAX}$ is based on the maximum theoretical tolerance A_{MAX} as well, but the physical lane centerline offset LC is also added to the equation:

$$A_{\mathrm{LEFT,\,MAX}} = \frac{W_{\mathrm{LANE}}}{2} + \mathrm{f} + \mathrm{LC}$$

The reason for adding the physical lane centerline offset LC to the maximum theoretical tolerance A_{MAX} is to compensate for the vehicle 30 getting further away from the lane centerline 25 in the left direction. The lane centerline offset LC has a negative value in the case of a left shift, therefore by adding the lane centerline offset LC to the maximum theoretical tolerance A_{MAX} will gradually reduce the left-side maximum tolerance $A_{LEFT,MAX}$ value. This reduction is saturated when its value reaches the minimum tolerance:

$$\left(A_{\mathrm{LEFT,\,MAX}}\right)_{\mathrm{MIN}} = A_{\mathrm{LEFT,\,MIN}} = \frac{W_{\mathrm{VEH}}}{2}$$

The right-side minimum and maximum tolerances $A_{RIGHT,MIN}$, $A_{RIGHT,MAX}$ can be calculated in a similar way, and therefore those details are omitted here.

Calculation of the Ego Lane Probability

The ego lane probability is calculated using the following equation:

$$\mathrm{pEgoLane} = \frac{w_{LEFT}R_{LEFT} + w_{RIGHT}R_{RIGHT}}{\max(w_{LEFT}, w_{RIGHT})}$$

where:

w: weighing factor, equals to the amount of high confidence samples in all the sampled loops

R: the ratio of the high confidence and in-range samples / total samples

Sample number (n)

The ego lane probability is calculated to a certain distance (H which stands for history in meters), which is a fixed parameter. The total number of samples (n_{total}) depends on the vehicle speed (v_{VEH}). To get the number, the division must be multiplied by the cycle time of the calculation (T_{ts}):

$$n_{total} = \frac{H[m]}{v_{VEH}[m/s]} \cdot T_{ts}[s]$$

Weighing factor (*w*)

Modern cameras detect not only the lane boundary markers, but also assign a confidence level to the detection. For example, the confidence levels may be scaled as

- Low
- Medium
- High
- Extra high

The weighing factor (w) in the ego lane probability calculation is the number of "good-confidence" A parameter samples ($n_{A,conf}$) from the image sensor in the total set (n_{total}):

$$w = \frac{n_{A,conf}}{n_{total}}$$

"Good confidence" means that the detection confidence of the A parameter is greater than a predefined confidence threshold, e.g. greater than, or equal to medium.

Ratio (*R*)

The ratio represents the number of high confidence and in-range samples in the total set:

$$R = \frac{n_{A,conf,in-range}}{n_{total}}$$

One sample of the A parameter is in-range, if the value is between the tolerances detailed above.

The ego lane probability can be calculated by calculating these variables for both the left and right sides and substituting them into the original equation.

General, lane center-based calculations

As described earlier, the lane centerline offset LC in the vehicle coordinate system 45 is:

$$LC = \frac{(A_{LEFT} + A_{RIGHT})}{2}$$

Virtual lane model

In lateral control systems, three attributes of the lane 20 are the most important: the location of the lane centerline 25, and the left and right lane boundary markers 21.

- In a passive system (e.g. lane departure warning), the left and right lane boundaries are the relevant information, i.e. system shall issue a warning if the lane boundary is reached. Also, there can be multiple levels defined for how strict the warning threshold shall be, i.e. how far the warning threshold is from the actual lane centerline.
- In an active system, the lane centerline is relevant, which is used as a steering control target.

As Figure 7 shows, a virtual lane model is introduced, which includes all these three attributes of a lane:

- virtual lane centerline 25v
- virtual lane marker distances $A_{V,LEFT}$, $A_{V,RIGHT}$ measured from the virtual lane centerline 25v:

The goal of the virtual lane centerline 25v is to make the passive and active lateral systems flexible, and adaptable to different environmental and traffic situations. For example, the virtual lane can be narrowed, widened, or shifted, based on the traffic scenario. The virtual lane 20v has the same attributes as the physical lane 20, i.e. left and right lane boundaries and lane centerline, but the advantage is that these are parameters, and all three can be adapted to traffic situation or other factors.

The advantage of the virtual lane model – beyond the flexibility of the control – is that it has the same attributes as the real traffic lanes, therefore all the lateral control algorithms can remain the same. Another benefit is that this model is independent of the lane representation, e.g. it works just as well with 2nd or 3rd order polynomial representations.

Virtual lane center

The virtual lane centerline 25v can be shifted towards either side of the physical lane centerline 25.

As mentioned earlier, the vehicle centerline position, i.e. the centerline offset can be calculated using the left and right lane marker distances:

$$LC = \frac{A_{LEFT} + A_{RIGHT}}{2}$$

The virtual lane centerline offset LC_V is calculated using an offset T_C parameter, which represents a lateral distance between the physical and virtual lane centerlines:

$$LC_V = \frac{A_{LEFT} + A_{RIGHT}}{2} + T_C$$

Virtual lane boundaries

The virtual lane boundaries are the left and right virtual marker distances $A_{V,LEFT}$, $A_{V,RIGHT}$ measured from the virtual lane centerline 25v. These are based on the physical lane boundaries, but shifted by using a compensation factor T_L, T_R on both sides:

$$A_{V,LEFT} = A_{LEFT} + T_L$$

$$A_{V,RIGHT} = A_{RIGHT} + T_R$$

In normal operation, these parameters are the same as A_{LEFT} and A_{RIGHT}, meaning that:

$$T_L = 0$$

$$T_R = 0$$

Calculations using the virtual lane model

In a passive system, like the Lane Departure Warning system, this virtual lane centerline 25v can be utilized by measuring the warning threshold not from the lane boundaries, but from the virtual lane boundary markers 21v.

In case of an LDW system, the virtual lane centerline 25v can be the same as the physical lane centerline 25, that is:

$$LC_V = LC$$

whereas the virtul lane marker distances $A_{V,LEFT}$, $A_{V,RIGHT}$ can be modified according to the traffic scenario.

In an active system, like the Lane Keeping Assist system, the final goal is to reduce the distance between the vehicle centerline 35 and the virtual lane centerline 25v to zero:

$$LC_V \to 0$$

Additionally, similar to the lane departure warning algorithm, there can be a tolerance T applied for how strictly the virtual lane center must be targeted:

$$|LC_V| \leq T$$

These calculations will now be introduced in detail.

As seen in Figure 6, the ideal gap G between the outer edge of the vehicle and the lane boundary is equal to:

$$G = \frac{W_{LANE} - W_{VEH}}{2}$$

The lane departure warning algorithm formula can be calculated using this gap G, because the lateral deviation from the lane centerline 25 must be less than this gap G in either direction.

Since the lane centerline offset LC can be either positive or negative (depending on the direction), the acceptable range calculation uses the absolute value of the lane centerline offset LC. This value must be no more than this gap G:

$$|LC| \leq G$$

Substituting the variables with their equations:

$$|LC| \leq \frac{W_{LANE} - W_{VEH}}{2}$$

$$\left|\frac{A_{LEFT} + A_{RIGHT}}{2}\right| \leq \frac{W_{LANE} - W_{VEH}}{2}$$

Simplifying the equation gives:

$$|A_{LEFT} + A_{RIGHT}| \leq W_{LANE} - W_{VEH}$$

The lane width W_{LANE} can be calculated from the "A" parameters, as shown earlier:

$$W_{LANE} = |A_{LEFT}| + |A_{RIGHT}|$$

If we substitute the parts into the original equation ($|LC| \leq G$), then we get the general formula for calculating if the vehicle is inside the lane boundaries (1. Equation):

$$|A_{LEFT} + A_{RIGHT}| \leq |A_{LEFT}| + |A_{RIGHT}| - W_{VEH}$$

In an active system, like the Lane Keeping Assist system the final goal is to reduce the distance between the vehicle centerline 35 and the physical lane centerline 25 to zero:

$$LC \to 0$$

Substituting the lane boundary parameters, we get:

$$\frac{A_{LEFT} + A_{RIGHT}}{2} \to 0$$

Lane Departure Warning (LDW) algorithm

Warning condition

As mentioned above, the general lane departure formula is:

$$|A_{LEFT} + A_{RIGHT}| \leq |A_{LEFT}| + |A_{RIGHT}| - W_{VEH}$$

This basic LDW equation is utilized with the virtual lane model boundaries to extend or reduce the acceptable range of the lane boundary relative to the vehicle, therefore making the warning threshold adaptable to different scenarios:

$$\left|A_{V,LEFT} + A_{V,RIGHT}\right| \leq \left|A_{V,LEFT}\right| + \left|A_{V,RIGHT}\right| - W_{VEH}$$

This relation is true, if the vehicle is inside the acceptable range. However, if the relation is no longer true, that indicates a lane departure. Therefore, the lane departure warning condition using the virtual lane model is the following:

$$\left|A_{V,LEFT} + A_{V,RIGHT}\right| > \left|A_{V,LEFT}\right| + \left|A_{V,RIGHT}\right| - W_{VEH}$$

If this condition is true, system shall issue a lane departure warning.

Lane marker detection confidence

As mentioned above, modern cameras not only detect a lane boundary marker, but also assign a confidence level to the detection. In order for the warning algorithm to accept the detected lane boundary as valid, the detection needs to have a certain confidence level.

A basic approach would be to require a fix confidence level, e.g. “high”, in order to issue a warning, if otherwise the warning condition is fulfilled.

However, this application uses a variable confidence requirement, based on ego lane probability level. Since the ego lane probability already requires a certain confidence level for the lane detection, and it calculates an average for a history, it is a good indicator how reliable the current lane boundary detection is. Therefore, when the ego lane probability is high, it is enough to have a temporary lower confidence for the current detection.

Example of variable confidence level lookup-table:

Ego Lane Probability Range	**Required confidence**
50-70%	Extra high
70-80%	High
80-90%	Medium
90-100%	Low

Table 1

If the ego lane probability is lower than 50% then system cannot issue a warning, because then the detection is not reliable enough.

Warning direction

Then system 100 of the invention issues a warning based on the departure direction, which is established based on the sign of the lane centerline offset LC.

As stated earlier:

- left shift: $LC = \frac{(A_{V,LEFT} + A_{V,RIGHT})}{2} < 0$
- right shift: $LC = \frac{(A_{V,LEFT} + A_{V,RIGHT})}{2} > 0$

To summarize the lane departure warning conditions:

- the lane center gets out of the acceptable range, which is true if the the warning condition equation is true,
- the ego lane probability is above the acceptance threshold.

If both conditions are true, system shall issue a lane departure warning in the direction based on lane center sign.

Lane Departure Avoidance (LDA) algorithm

The previously described approach may also be used for lane departure avoidance control methods, where the aim is to keep the vehicle 30 inside the lane boundaries by applying a corrective steering intervention if the outer edge of either of the front tires reaches the lane marker 21 on the corresponding side.

This happens when the lane centerline 25 has a distance from the vehicle centerline 35 in either direction exactly equal to the width of the gap G:

$$|LC| = G$$

Here, again, the virtual lane model is used to make the algorithm adaptable to different scenarios. Thereefore, the lane departure condition is:

$$|LC_V| = G$$

The above expression can substituted into the equation based on the formula used at the lane departure warning chapter. Consequently, the vehicle's front tire reaches the lane boundary, if:

$$|A_{V,LEFT} + A_{V,RIGHT}| = |A_{V,LEFT}| + |A_{V,RIGHT}| - W_{VEH}$$

If the above condition is true, then a steering intervention is necessary, because this is the moment when the front tire of the vehicle touches the virtual lane boundary.

Lane Keep Assist (LKA) algorithm

The previously described approach may also be used for lane keep assist control methods, where the aim is to maintain continuous lane centering control.

The lane keeping algorithm is also based on the previous lane center calculations. The goal is to reduce the lateral offset of the vehicle 30 from the virtual lane centerline 25v, which means that the virtual lane centerline offset LC_V in the vehicle coordinate system 45 must converge to zero:

$$LC_V = \frac{A_{V,LEFT} + A_{V,RIGHT}}{2} \rightarrow 0$$

This is the basic equation for lane centering, using the virtual lane model.

In terms of lateral control, a certain tolerance can be allowed: $|LC_V| \leq T$

Adaptive control characteristics

The adaptive behavior is realized using the virtual lane model, which consists of lane boundary and lane center modifications.

Virtual lane model

As mentioned above, in lane departure warning systems the warning threshold, which is generally the lane marker distance A_{LEFT}, A_{RIGHT}, can be shifted using the virtual lane model. In lane centering applications, the control offset parameter is measured relative to the lane center.

The virtual lane model equations are:

$$A_{V,LEFT} = A_{LEFT} + T_L$$

$$A_{V,RIGHT} = A_{RIGHT} + T_R$$

$$|LC_V| = LC + T_C$$

Here, the T_L and T_R are the left and right corrections that can be adaptive tolerances, and T_C is the lane centerline correction tolerance.

By using the virtual lane model, the physical lane-center based calculation are modified based on multiple driver behaviour-related factors.

There can be multiple tolerance levels defined; for example: using low, medium, and high sensitivity tolerance compensations, which can be added to the basic warning threshold, or to the physical lane centerline offset LC:

- low: T_L
- medium: T_M
- high: T_H

Asymmetric control

If an object is too close to the vehicle 30, the system 100 of the invention sets the warning threshold closer to the vehicle 30 on the side where the other vehicle is approaching, setting an asymmetrical threshold (by keeping the opposite side tolerance unchanged), to minimize the risk of collision.

In a lane keep assist system, the same method is used to change the control target in the lane by slightly shifting away from the vehicle travelling in the neighboring lane, offsetting the virtual lane centerline 25v.

Vehicle operator driving characteristics

The system 100 of the invention may also monitor the lateral swinging of the vehicle 30 in-lane, which is the change of the virtual lane centerline offset LC_V over time. For this purpose, the system records a fixed number (n) of A parameter samples, calculates the expected value (mean) of the lane center coordinate (E_{LC}):

$$E_{LC} = \frac{\sum\left[\left(A_{V,LEFT} + A_{V,RIGHT}\right)/2\right]_i}{n} = \frac{\sum LC_{V,i}}{n}$$

Using the mean value, the standard deviation can be calculated:

$$\sigma_{LC} = \sqrt{\frac{\sum\left(LC_{V,i} - E_{LC}\right)^2}{n-1}}$$

Based on the amplitude of the lane center deviation, the system sets the lane departure warning sensitivity to low, medium, or high by setting the lane center-based tolerance value (T) for low, medium or high. The tolerance levels are chosen from a predefined set of thresholds, for example the values listed in Table 2.

As mentioned earlier, the lane departure warning condition is:

$$\left|A_{V,LEFT} + A_{V,RIGHT}\right| > \left|A_{V,LEFT}\right| + \left|A_{V,RIGHT}\right| - W_{VEH}$$

The aim of the lane keep assist control is:

$$|LC_V| \leq T$$

which means that the center of the vehicle 30 cannot deviate from the virtual lane centerline 25v by more than a predetermined threshold T.

LDW / LKA Control sensitivity	**Lane center deviation based on driving style**	**Virtual lane model tolerances T_L, T_R, T_C $[m]$**
Low	$\sigma_{LC} = 0 \dots 0.25m$	T_L
Medium	$\sigma_{LC} = 0.25 \dots 0.4m$	T_M
High	$\sigma_{LC} > 0.4m$	T_H

Table 2

TRAFFIC SITUATION

Based on the actual traffic situation, the adaptive control system 10 of the invention may update at least one warning threshold in the Lane Departure Warning (LDW) and Lane Departure Avoidance (LDA) process if the vehicle 30 is approaching a neighbouring lane. The actual traffic situation may include sensor/perception information, e.g., object data from at least one ADAS sensor, and/or external traffic information, e.g., from V2X, V2I.

ASYMMETRIC CONTROL

If an object is too close to the vehicle 30, system 100 sets the warning threshold to a lower value, i.e. decreases the maximum tolerance $A_{LEFT,MAX}$ and $A_{RIGHT,MAX}$ on the side of the vehicle 30 where the vehicle 30 is approaching the object by setting an asymmetrical threshold by keeping the opposite side tolerance unchanged in order to minimize risk of collision with the object.

In a lane keep assist system, the same method may be used to change the target centerline to a virtual centerline 25v in order to slightly shifting the vehicle 30 away from another vehicle in the neighboring lane.

ENVIRONMENT

The adaptive control system 10 of the invention may be configured to set different warning thresholds for each side of the vehicle 30, depending on the actual traffic situation. For example, different warning thresholds may be applied when there is an opposite direction traffic in the neighbouring lane. Other factors, such as period of the day, existence of a curb, existence of an emergency lane, etc. may also result in different warning thresholds for the left and right sides of the vehicle 30.

Furthermore, based on road surface properties, the properties of the load of a truck, etc., at least one warning threshold may be set to a stricter level in order to increase vehicle stability.

PROLONGED DRIVE

Another basis for setting the control sensitivity is the driving duration. The idea behind this logic is that the alertness of the driver decreases over time as fatigue sets in. To increase safety, after a long drive, the lane departure alarm shall be issued for an increasingly narrower virtual lane as compared to the beginning of the drive when the driver was watchful enough. In the present invention, the adaptive control system 10 of the invention may monitor the ignition cycle and the vehicle speed v_{VEH} and may calculate the length of the actual driving time $T_{current}$.

The timer starts when the ignition is turned on and the vehicle speed v_{VEH} is greater than zero, i.e. when the vehicle 30 starts moving. As the driving time $T_{current}$ increases, the Lane Departure Warning sensitivity also increases, i.e. the adaptive control system 10 sets the warning sensitivity to higher sensitivity levels by setting the tolerance threshold T to a higher level, see Table 2. Figure 8 shows an example of the relationship between driving time $T_{current}$ and the LDW sensitivity levels.

In case of a short break in driving, the driving time $T_{current}$ is not completely reset to zero, to avoid bypassing this logic with short breaks. If the vehicle 30 has stopped, the last driving timestamp is saved. At the next start, the difference between the last stop and the current start is subtracted from the current driving time $T_{current}$ counter. In this way, the current driving time $T_{current}$ sets back to zero only after a long break.

INTEGRATED ADAPTIVE DRIVE CONTROL

Based on the above detailed calculations, the adaptive drive control method according to the present invention is described below with reference to Fig. 10, which shows a flow diagram of the main steps of the method. The method is used in a vehicle equipped with on-board electronic vehicle control units adapted, upon specific conditions, for generating an alarm signal for the driver and/or an activating signal for automatically intervening into the vehicle's operation.

First, in step 100, image data of the road ahead of the vehicle 30 is obtained by at least one image sensor 40 mounted on the vehicle 30. The image sensor 40 may be a camera or other sensor, e.g. infra sensor.

Next, in step 110, lateral boundary lane markers 21 of the physical lane 20, in which the vehicle 30 is travelling, are identified by the processor device 42 on the basis of said image data of the at least one image sensor 40. Identification of the lane markers 21 may be performed using common image processing algorithms that produce position information of the lane markers 21 in the vehicle coordinate system 45.

In step 120 the left and right marker distances A_{LEFT}, A_{RIGHT} of the lateral boundary lane markers 21 are determined, by the processor device 42, relative to the origin of the vehicle coordinate system 25 fixed to the vehicle 30.

Then, in step 130, the lane centerline offset LC is determined as a distance between the centerline 25 of the lane 20 and the centerline 35 of the vehicle 30 by means of the processor device 42, on the basis of the left and right marker distances A_{LEFT}, A_{RIGHT}.

In the next step 140, a trigger event is received using the processor device 42. The trigger event may include several various traffic situation or environmental event, for, example an obstacle within the lane of the vehicle 30, another vehicle travelling in the same lane 20 ahead of the vehicle 30, another vehicle approaching the vehicle 30 from the opposite direction in a neighbouring lane, etc.

In step 150, upon receiving a trigger event, a virtual lane mode is generated by the processor device 42. The virtual lane 20v has virtual lateral boundary lane markers 21v, that are shifted relative to the physical lateral lane markers 21 by left and right offsets T_L, T_R, respectively. The virtual lane 20v also has a virtual lane centerline 25v that is shifted relative to the physical lane centerline 25 by an offset T_C. The distances between the left and right lateral boundary lane markers 21v from the centerline 25v of the virtual lane 20v are defined as the virtual lateral marker distances $A_{V,LEFT}$, $A_{V,RIGHT}$ and the distance between the vehicle centerline 35 and the virtual lane centerline 25v is defined as the virtual centerline offset LC_V. Accordingly, the virtual lane model may be described by the following equations:

$$A_{V,LEFT} = A_{LEFT} + T_L$$
$$A_{V,RIGHT} = A_{RIGHT} + T_R$$
$$|LC_V| = LC + T_C$$

Next, in step 160, an activation signal is generated by the processor device 42 for one or more of said on-board electronic vehicle control units when one of the following conditions is satisfied:

i) $|A_{V,LEFT} + A_{V,RIGHT}| > |A_{V,LEFT}| + |A_{V,RIGHT}| - W_{VEH}$

wherein W_{VEH} is the width of the vehicle;

ii) $|A_{V,LEFT} + A_{V,RIGHT}| = |A_{V,LEFT}| + |A_{V,RIGHT}| - W_{VEH}$

wherein W_{VEH} is the width of the vehicle;

iii) $\left|\frac{A_{V,LEFT}+A_{V,RIGHT}}{2}\right| \leq T$

wherein T is a predetermined tolerance range.

In this step 160, condition i) relates to the lane departure warning process, condition ii) relates to the lane departure avoidance process, and condition iii) relates to the lane keep assist process.

Finally, in step 170, the activation signal is forwarded by the processor device 42 to one or more of said onboard electronic vehicle control units for activating said unit(s).

It is preferred that the vehicle coordinate system 45 is fixed along the longitudinal centerline 35 of the vehicle 30. It is also preferred that the image data of the road is obtained through a camera arranged on the front side of the vehicle 30, along the centerline 35 of the vehicle.

LIST OF REFERENCE SIGNS

- 10 – adaptive control system
- 20 – lane
    - 21 – physical lane marker
    - 25 – physical lane centerline
- 20v – virtual lane
    - 21v – virtual lane marker
    - 25v – virtual lane centerline
- 30 – vehicle
    - 35 - vehicle centerline
- 40 – image sensor
    - 42 – processor device
    - 45 – vehicle coordinate system
- 60 – ego lane probability calculating unit

Claims

1. A method of adaptive drive control in a vehicle equipped with on-board electronic vehicle control units adapted, upon specific conditions, for generating warning signals and/or for automatically intervening into the vehicle's operation,

a) obtaining (100), by at least one image sensor (40), image data of a road ahead of the vehicle,

b) on the basis of said image data, identifying (110), by a processor device (42), lateral boundary lane markers (21) of a lane (20) in which the vehicle (30) is travelling,

c) on the basis of said image data, determining (120), by the processor device, left and right marker distances (A_{LEFT}, A_{RIGHT}) of the lateral boundary lane markers (21) relative to the origin of a vehicle coordinate system (25) fixed to the vehicle (30),

d) on the basis of the left and right marker distances (A_{LEFT}, A_{RIGHT}), determining (130), by the processor device (42), a lane centerline offset (LC) as a distance between a centerline (35) of the vehicle (30) and a centerline (25) of the lane (20),

e) receiving (140) a trigger event by the processor device (42),

f) generating (150), by the processor device 42, a virtual lane model, wherein the virtual lane (20) has virtual lateral boundary lane markers (21v) that are shifted relative to the physical lateral lane markers (21) by left and right offsets (T_L, T_R), respectively, and wherein the virtual lane 20v also has a virtual lane centerline (25v) that is shifted relative to the physical lane centerline (25) by an offset (T_C), wherein the distances between the left and right lateral boundary lane markers (21v) from the centerline (25v) of the virtual lane (20v) are defined as virtual lateral marker distances ($A_{V,LEFT}$, $A_{V,RIGHT}$) and the distance between the vehicle centerline (35) and the virtual lane centerline (25v) is defined as the virtual centerline offset (LCv),

g) generating (160), by the processor device (42), an activation signal for one or more of said on-board electronic vehicle control units when one of the following conditions is satisfied:

i) $|A_{V,LEFT} + A_{V,RIGHT}| > |A_{V,LEFT}| + |A_{V,RIGHT}| - W_{VEH}$

wherein W_{VEH} is the width of the vehicle;

ii) $|A_{V,LEFT} + A_{V,RIGHT}| = |A_{V,LEFT}| + |A_{V,RIGHT}| - W_{VEH}$

wherein W_{VEH} is the width of the vehicle;

iii) $\left|\frac{A_{V,LEFT}+A_{V,RIGHT}}{2}\right| \leq T$

wherein T is a predetermined tolerance range;

h) forwarding (170) said activation signal, by the processor device (42), to one or more of said onboard electronic vehicle control units for activating said unit(s).

2. The method of claim 1, wherein the vehicle coordinate system (45) is fixed along the longitudinal centerline (35) of the vehicle (30).

3. The method of claim 1, wherein the image data of the road is obtained through a camera arranged on the front side of the vehicle (30), along the centerline (35) of the vehicle (30).

4. A system (100) for adaptive drive control in a vehicle (30) equipped with on-board electronic vehicle control units adapted, upon specific conditions, for generating warning signals and/or for automatically intervening into the vehicle's operation, the system comprising:

- at least one image sensor (40) for obtaining (100) image data of a road ahead of the vehicle (30), and
- a processor device (42) configured to perform the steps b) to h) of the method of claim 1.

5. The system (100) of claim 4, further comprising an ego lane probability calculating unit (60) for calculating an ego lane probability for each of the physical lane markers (21) on the basis of the image data obtained from the at least one image sensor (40), and for outputting an ago lane probability value for the processor device (42), wherein the ego lane probability is defined as the probability of a plausible lane detection by the at least one image sensor (40).

AMENDED CLAIMS
received by the International Bureau on
02 February 2024 (02.02.2024)

Claims

(Amended under Art. 19 PCT)

1. A method of adaptive drive control in a vehicle equipped with on-board electronic vehicle control units adapted, upon specific conditions, for generating warning signals and/or for automatically intervening into the vehicle's operation,

a) obtaining (100), by at least one image sensor (40), image data of a road ahead of the vehicle,

b) on the basis of said image data, identifying (110), by a processor device (42), lateral boundary lane markers (21) of a lane (20) in which the vehicle (30) is travelling,

c) on the basis of said image data, determining (120), by the processor device, left and right marker distances (A_{LEFT}, A_{RIGHT}) of the lateral boundary lane markers (21) relative to the origin of a vehicle coordinate system (25) fixed to the vehicle (30), wherein $A_{LEFT} > 0$ and $A_{RIGHT} < 0$,

d) on the basis of the left and right marker distances (A_{LEFT}, A_{RIGHT}), determining (130), by the processor device (42), a lane centerline offset (LC) as a distance between a centerline (35) of the vehicle (30) and a centerline (25) of the lane (20),

e) receiving (140) a trigger event by the processor device (42), said trigger event defined as a traffic situation or an environmental event detected by the vehicle (30),

f) generating (150), by the processor device 42, a virtual lane model, wherein the virtual lane (20) has virtual lateral boundary lane markers (21v) that are shifted relative to the physical lateral lane markers (21) by left and right offsets (T_L, T_R), respectively, and wherein the virtual lane (20v) also has a virtual lane centerline (25v) that is shifted relative to the physical lane centerline (25) by an offset (T_C), wherein the distances between the left and right virtual lateral boundary lane markers (21v) from the virtual centerline (25v) of the virtual lane (20v) are defined as virtual lateral marker distances ($A_{V,LEFT}$, $A_{V,RIGHT}$) and the distance between the vehicle centerline (35) and the virtual lane centerline (25v) is defined as the virtual centerline offset (LCv),

g) generating (160), by the processor device (42), an activation signal for one or more of said on-board electronic vehicle control units when one of the following conditions is satisfied:

i) $|A_{V,LEFT} + A_{V,RIGHT}| > |A_{V,LEFT}| + |A_{V,RIGHT}| - W_{VEH}$

wherein W_{VEH} is the width of the vehicle;

ii) $|A_{V,LEFT} + A_{V,RIGHT}| = |A_{V,LEFT}| + |A_{V,RIGHT}| - W_{VEH}$

wherein W_{VEH} is the width of the vehicle;

h) generating (160), by the processor device (42), a continuous activation signal for one or more of said on-board electronic vehicle control units to satisfy the following condition:

iii) $\left|\frac{A_{V,LEFT}+A_{V,RIGHT}}{2}\right| \leq T$

wherein T is a predetermined tolerance range;

i) forwarding (170) said activation signal, by the processor device (42), to one or more of said onboard electronic vehicle control units for activating said unit(s).

2. The method of claim 1, wherein the vehicle coordinate system (45) is fixed along the longitudinal centerline (35) of the vehicle (30).

3. The method of claim 1, wherein the image data of the road is obtained through a camera arranged on the front side of the vehicle (30), along the centerline (35) of the vehicle (30).

4. A system (100) for adaptive drive control in a vehicle (30) equipped with on-board electronic vehicle control units adapted, upon specific conditions, for generating warning signals and/or for automatically intervening into the vehicle's operation, the system comprising:

- at least one image sensor (40) for obtaining (100) image data of a road ahead of the vehicle (30), and
- a processor device (42) configured to perform the steps b) to h) of the method of claim 1.

5. The system (100) of claim 4, further comprising an ego lane probability calculating unit (60) for calculating an ego lane probability for each of the physical lane markers (21) on the basis of the image data obtained from the at least one image sensor (40), and for outputting an ago lane probability value for the processor device (42), wherein the ego lane probability is defined as the probability of a plausible lane detection by the at least one image sensor (40).

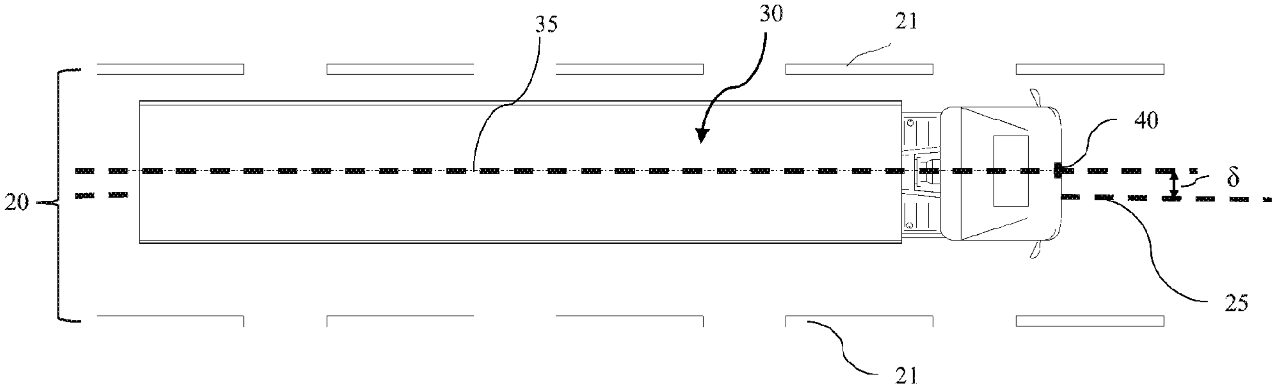

Figure 1

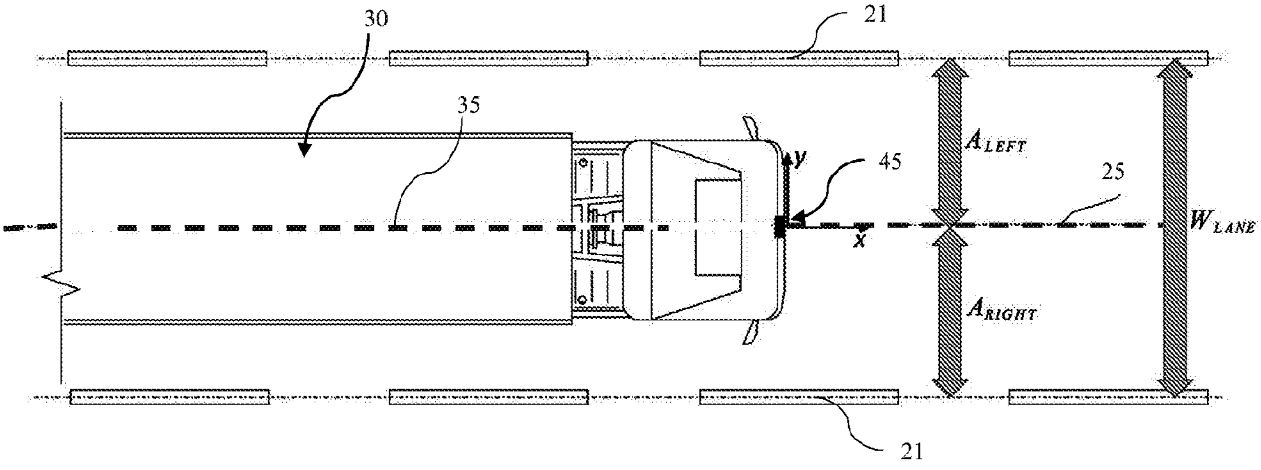

Figure 2

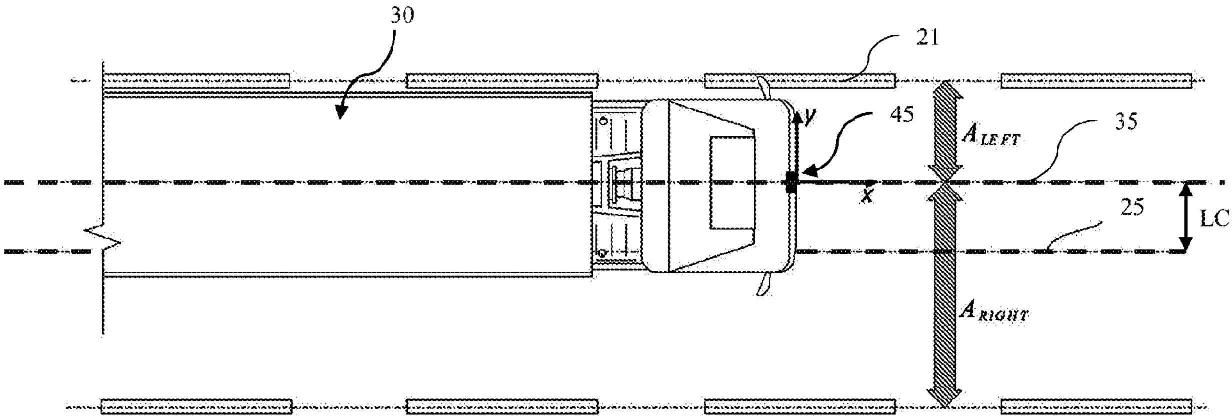

Figure 3

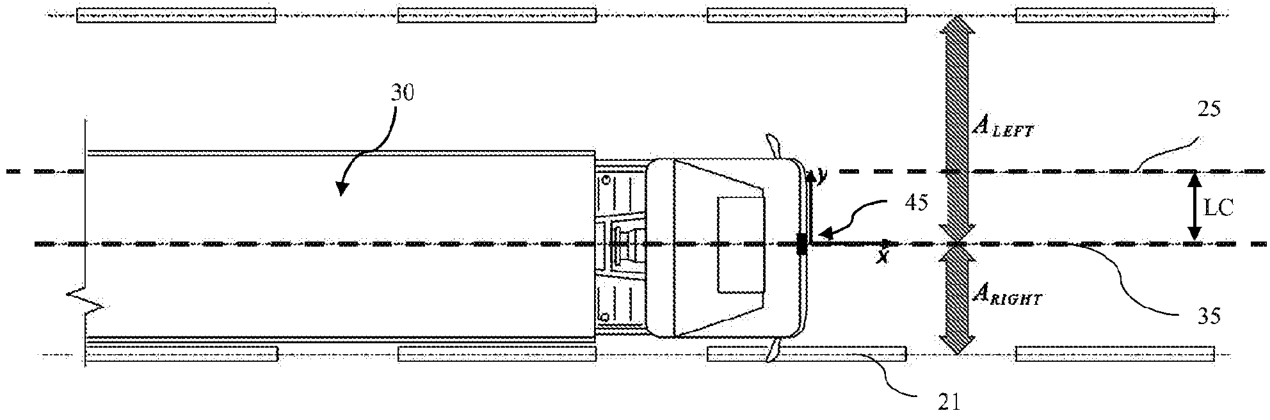

Figure 4

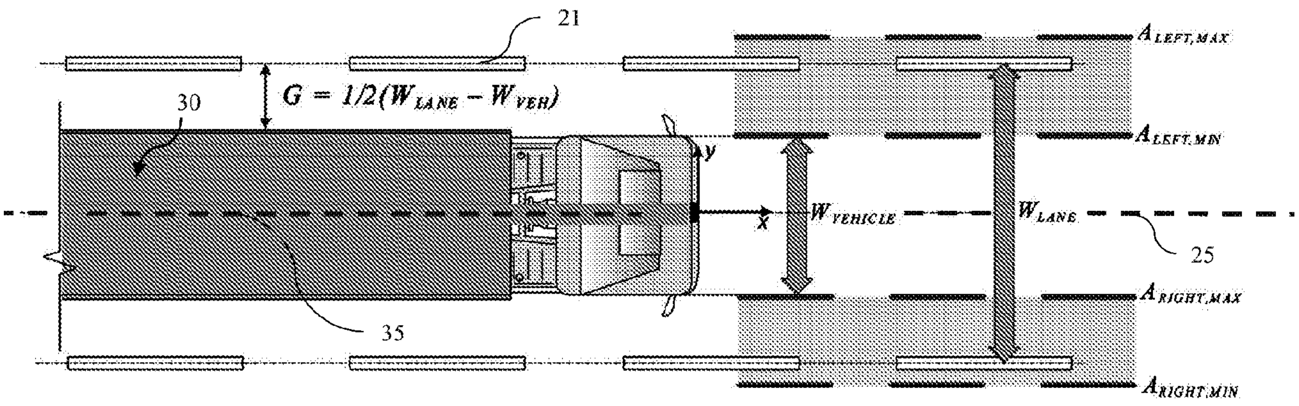

Figure 5

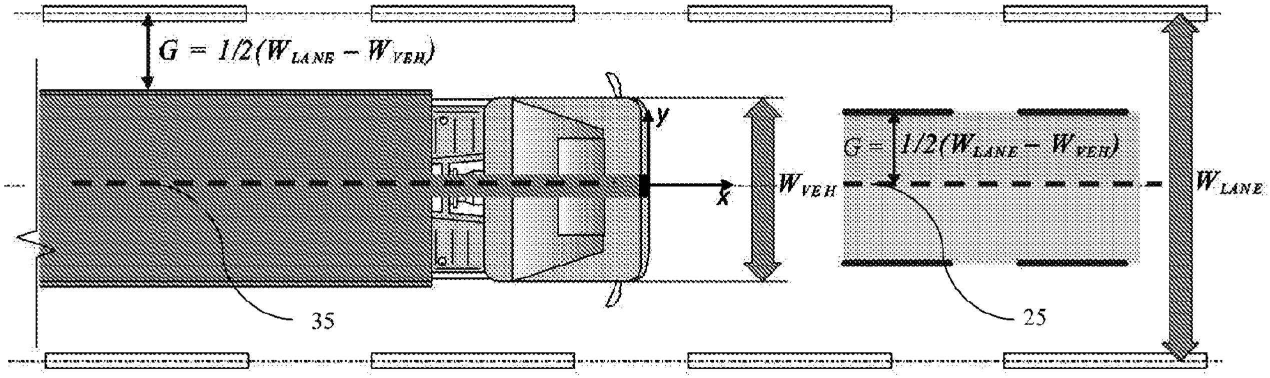

Figure 6

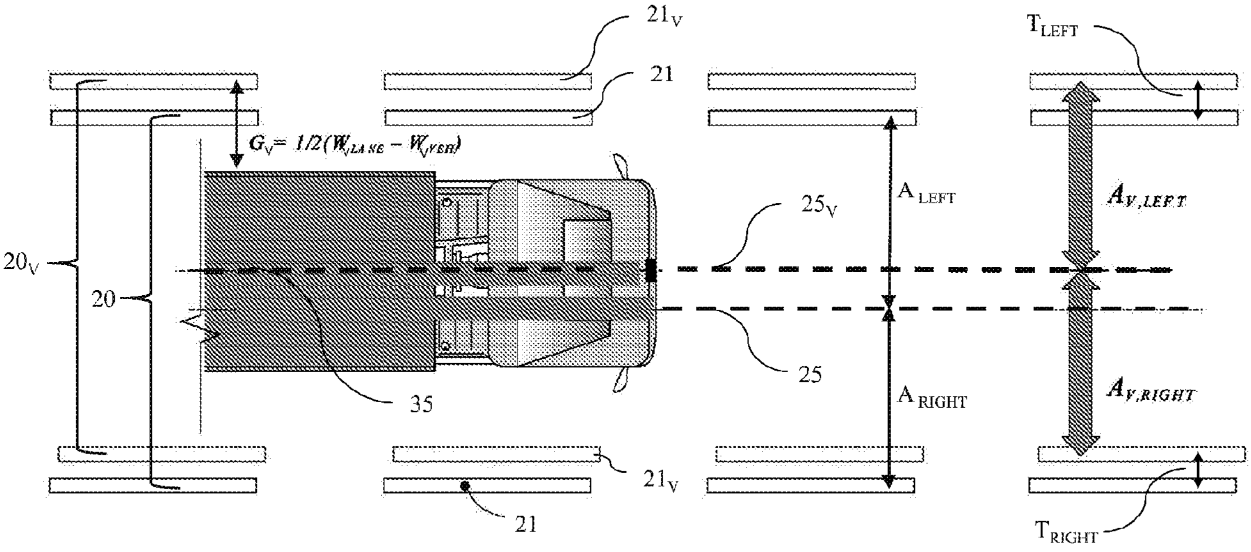

Figure 7

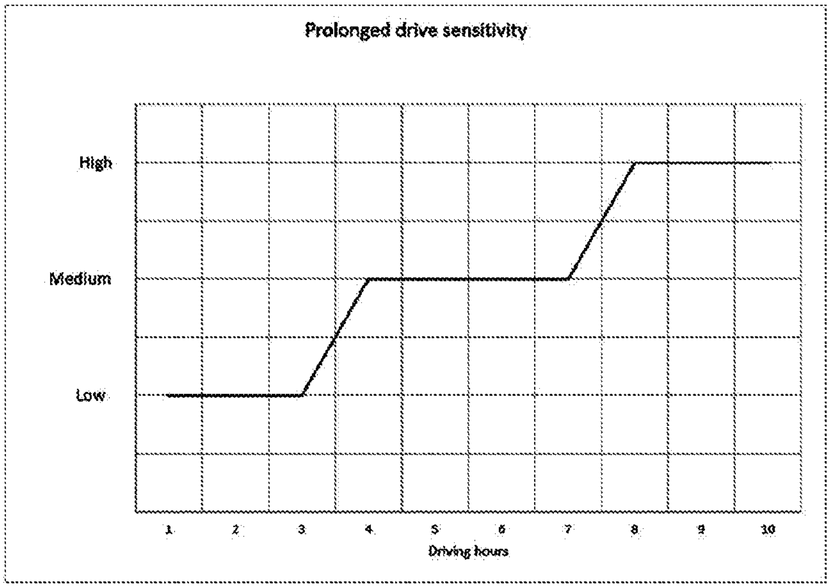

Figure 8

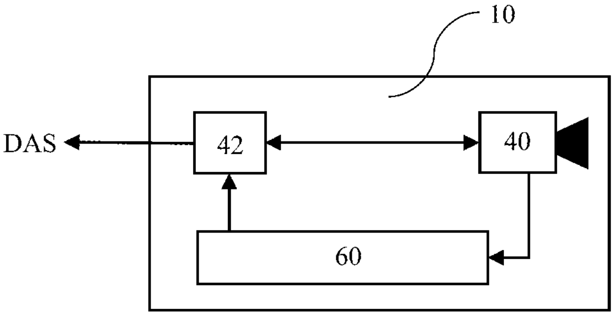

Figure 9

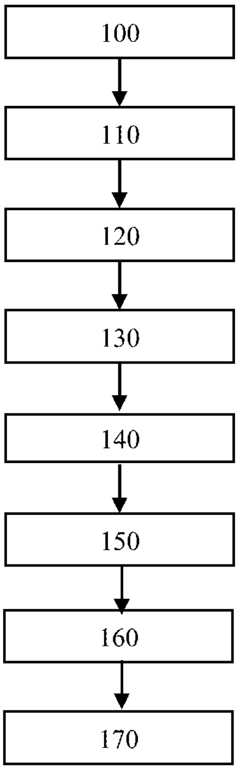

Figure 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/HU2023/050067

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06V20/56
ADD.

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)
G06V

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/022317 A1 (OKITA TOSHINORI [JP]) 27 January 2011 (2011-01-27) paragraphs 1-2, 39, 47, 50, 51; figures 2 and 4 -----	1-5
A	Sandipann P. Narote ET AL: "A review of recent advances in lane detection and departure warning system", , 16 August 2017 (2017-08-16), XP055654052, DOI: 10.1016/j.patcog.2017.08.014 Retrieved from the Internet: URL:https://www.sciencedirect.com/science/article/pii/S0031320317303266 [retrieved on 2019-12-18] section V.B-2 ----- -/--	1-5

☒ 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 24 November 2023	Date of mailing of the international search report 04/12/2023
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Loza, Artur

C(Continuation). **DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	TIDEMAN M ET AL: "A Review of Lateral Driver Support Systems", INTELLIGENT TRANSPORTATION SYSTEMS CONFERENCE, 2007. ITSC 2007. IEEE, IEEE, PI, 1 September 2007 (2007-09-01), pages 992-999, XP031151498, ISBN: 978-1-4244-1395-9 section 10; page 1, right column, 1st paragraph -----	1-5
A	XING YANG ET AL: "Advances in Vision-Based Lane Detection: Algorithms, Integration, Assessment, and Perspectives on ACP-Based Parallel Vision", IEEE/CAA JOURNAL OF AUTOMATICA SINICA, 1 May 2018 (2018-05-01), pages 645-661, XP055906040, ISSN: 2329-9266, DOI: 10.1109/JAS.2018.7511063 Retrieved from the Internet: URL:https://ieeexplore.ieee.org/ielx7/6570654/8332135/08332138.pdf?tp=&arnumber=8332138&isnumber=8332135&ref=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8= [retrieved on 2023-11-24] section IV.C on page 653 -----	1-5

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/HU2023/050067

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		EP 2298626 A1	23-03-2011
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