

(51) International Patent Classification:
G06K 9/00 (2006.01)(21) International Application Number:
PCT/EP2017/072902(22) International Filing Date:
12 September 2017 (12.09.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
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kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

(54) Title: A VISION SYSTEM AND METHOD FOR A MOTOR VEHICLE

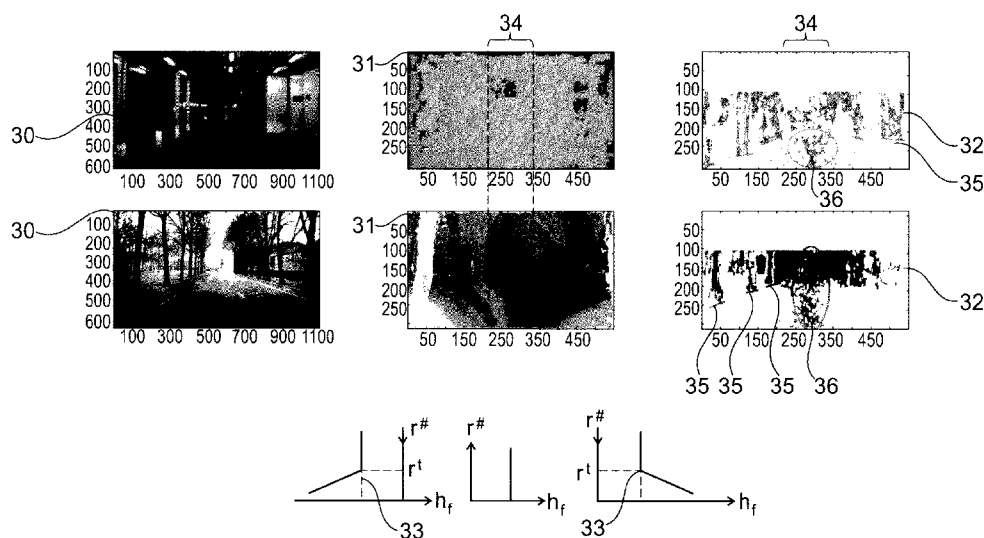


Fig. 2

(57) **Abstract:** A vision system for detecting free space in front of a motor vehicle comprises a mono imaging apparatus (11) adapted to capture images (30) from the surrounding of a motor vehicle, and an electronic processing device (14) adapted to perform image processing of images (30) captured by said mono imaging apparatus (11) in order to detect objects in the surrounding of a motor vehicle. The electronic processing device (14) is adapted to calculate a horizontal component of the optical flow (31), and to determine transitions (33, 35) between regions of essentially constant horizontal optical flow and regions of essentially non-constant horizontal optical flow.



TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

A vision system and method for a motor vehicle

5 The invention relates to a vision system for detecting free space in front of a motor vehicle, comprising a mono imaging apparatus adapted to capture images from the surrounding of a motor vehicle, and an electronic processing device adapted to perform image processing of images captured by said mono imaging apparatus in order to detect objects in the surrounding of
10 a motor vehicle. The invention also relates to a corresponding vision method.

US 7,437,243 B2 discloses a vision system for a motor vehicle
15 with a controller adapted to calculate a side direction velocity component from captured images, to detect a road boundary based upon the calculated side direction velocity component, and to detect a moving direction of an object in the captured images based upon a relationship between the road boundary and
20 the object.

It is of interest, in mono camera systems for cars, to detect whether the area in front of the car is empty and therefore drivable or not.

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Prior art approaches involve either reconstructing 3D point cloud, i.e. structure-from-motion, or comparing the optical flow with a theoretical value for a flat surface. The structure-from-motion approach requires the target objects to be
30 stationary. The approach involving comparing the optical flow with a theoretical value for a flat surface is not always reliable.

The object underlying the present invention is to provide a vision system and method which provides a simple but reliable solution for detecting whether the area in front of the car is drivable or not in a mono camera setup.

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The invention solves the above objective with the features of the independent claims. According to the invention, transitions between regions of essentially constant horizontal optical flow and regions of essentially non-constant horizontal optical flow are determined. The invention uses the fact that the horizontal component of optical flow is constant along a column in the region of a target on the road, regardless of whether the target is moving or stationary, whereas the horizontal component of optical flow is changing in image parts corresponding to the road itself. The invention does not require a prior flat surface in front of the car, or related information.

In many applications of the invention, it is advantageous to determine the world distance of the vehicle to a structure formed by said transitions, in order to have information how far the vehicle can go until it would reach a raised structure, or in other words, how much free space there is in front of the vehicle. In some embodiments of the invention, a flat road assumption can be used in the distance determination. In case a flat road assumption turns out to be not accurate enough, road profile information, for example from a satellite navigation system, can be used to determine the above mentioned distance.

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In the following the invention shall be illustrated on the basis of preferred embodiments with reference to the accompanying drawings, wherein:

Fig. 1 shows a schematic diagram of a vision system of the present invention; and

5 Fig. 2 shows raw and processed images for two different vehicle environments in order to illustrate the present invention.

The vision system 10 is mounted in a motor vehicle and comprises an imaging apparatus 11 for capturing images of a region surrounding the motor vehicle, for example a region in front of the motor vehicle. Here, the imaging apparatus 11 is a mono imaging apparatus 11 comprising one optical imaging device 12, in particular a camera, preferably operating in the visible and/or infrared wavelength range, where infrared covers near IR with wavelengths below 5 microns and/or far IR with wavelengths beyond 5 microns.

The imaging apparatus 11 is coupled to a data processing device 14 adapted to process the image data received from the imaging apparatus 11. The data processing device 14 is preferably a digital device which is programmed or programmable and preferably comprises a microprocessor, microcontroller, digital signal processor (DSP), and/or a microprocessor part in a System-On-Chip (SoC) device, and preferably has access to, or comprises, a data memory 25. The data processing device 14 may comprise a dedicated hardware device, like a Field Programmable Gate Array (FPGA) or an Application Specific Integrated Circuit (ASIC), or an FPGA and/or ASIC part in a System-On-Chip (SoC) device, for performing certain functions. The data processing device 14, or part of its functions, can be realized by a System-On-Chip (SoC) device comprising, for example, FPGA, DSP, ARM and/or microprocessor functionality. The data

processing device 14 and the memory device 25 are preferably realised in an on-board electronic control unit (ECU) and may be connected to the imaging apparatus 11 via a separate cable or a vehicle data bus. In another embodiment the ECU and one
5 or more of the imaging devices 12 can be integrated into a single unit, where a one box solution including the ECU and all imaging devices 12 can be preferred. All steps from imaging, image processing to possible activation or control of driver assistance device 18 are performed automatically and
10 continuously during driving in real time.

Image and data processing carried out in the processing device 14 advantageously comprises identifying and preferably also classifying possible objects (object candidates) in front of
15 the motor vehicle, such as pedestrians, other vehicles, bicyclists and/or large animals, tracking over time the position of objects or object candidates identified in the captured images, and activating or controlling at least one driver assistance device 18 depending on an estimation performed with re-
20 spect to a tracked object, for example on an estimated collision probability. The driver assistance device 18 may in particular comprise a display device to display information relating to a detected object. However, the invention is not limited to a display device. The driver assistance device 18
25 may in addition or alternatively comprise a warning device adapted to provide a collision warning to the driver by suitable optical, acoustical and/or haptic warning signals; one or more restraint systems such as occupant airbags or safety belt tensioners, pedestrian airbags, hood lifters and the like;
30 and/or dynamic vehicle control systems such as braking or steering control devices.

In Figure 2, a series of images is shown for explaining the invention in detail, for a situation in a car park (upper three images) and an overland avenue (lower three images). The left images 30 show the raw images as provided by the camera
5 12.

The centre images 31 show the calculated horizontal flow for each pixel of the raw images. From the centre images 31 it can be seen that the horizontal component of the optical flow has
10 a characteristic pattern on the ground when moving forward. For a raised structure, i.e. a structure rising above the road or ground, like a tree or another moving car, the horizontal component of the optical flow is constant for a large part of an image column. The free space area in the image can there-
15 fore be detected by finding, for every image column, the row where the change or transition between constant and non-constant horizontal optical flow occurs.

This is also evident from the diagrams below the lower horizontal flow image 31. The left and right diagrams correspond
20 to two exemplary image columns coinciding with a raised structure on the road or on the side of the road, like a tree in the avenue in the lower scenario of Figure 2. The diagrams show the row number $r\#$ versus the horizontal flow component
25 hf , where the row number in the present example increases from top to bottom. In the left and right diagrams, it can be seen that the value of the horizontal flow changes (increases or decreases, respectively) from the bottom of the image upwards, but at some point remains constant. This point indicated by
30 row number rt corresponds to the transition point 33 between the raised structure and the road.

The middle diagram, however, does not show any transition point because the horizontal optical flow is approximately constant irrespective of a raised structure being present in the centre region of the image or not. Therefore, the algorithm does not produce any meaningful result in the centre region of the image, defined by a pre-determined fraction of all image columns lying in the centre of the image. Consequently, a central image region 34 is preferably disregarded in the determination of the transition points 34. However, this lack of information is only present when the vehicle moves straight. When turning, the problematic central area 34, 36 moves to the left or right side in the image 30, and comes into the coverage of the free space determining algorithm.

As described above, the transitions points 33 are determined in a vertical image direction, preferably along single image columns, and more preferably for each image column, except for excluded image regions, in particular except for the central image region. However, it may be useful to combine the image information from a plurality of adjacent image columns, if the image information from one image column is not sufficient.

Preferably one or more border lines 35 are determined fitting to the determined transitions points 33. This is explained in the following on the basis of the right images 32 in Figure 2. Generally, the border lines 35 may be straight lines, composed of straight lines, or curved lines. It is possible to have one border line 35 extending over the width of the image, or two border lines 35 in the left and right parts of the image.

The right images 32 in Figure 2 show calculated images, which are referred to as discrimination images in the present application. In the discrimination image 32, the value of each pix-

el is a measure of whether this pixel belongs to a region of essentially constant horizontal optical flow, or to a region of essentially non-constant horizontal optical flow. For example, the discrimination image 32 can be a binary or black-white-image, where the pixel value is set to "white" if the algorithm estimates that the pixel belongs to a region of essentially constant horizontal optical flow, and the pixel value is set to "black" if the algorithm estimates that the pixel belongs to a region of essentially non-constant horizontal optical flow.

However, the discrimination image 32 can also for example be a grey-scale image, where each pixel can assume more than two values, giving a more differentiated probability of whether this pixel belongs to a region of essentially constant horizontal optical flow, or to a region of essentially non-constant horizontal optical flow.

An exemplary method for calculating the discrimination image 32 from the horizontal optical flow image 31 could involve, for each pixel, considering a number x of pixels above the pixel under consideration, a number y of pixels below the pixel under consideration, where y can be equal to or different from x , calculating a statistical deviation, like the standard deviation, of the horizontal optical flow values of the group of pixels comprising the x pixels above, the y pixels below and the pixel at the point of the pixel under consideration, and estimating the pixel under consideration to belong to a region of essential constant horizontal optical flow if the calculated standard deviation is below a pre-determined or calculated threshold. Other ways of calculating the discrimination image 32 from the horizontal optical flow image 31 are possible.

In the discrimination image 32, border lines 35 can be easily fitted to the determined transition points 33. In the upper discrimination image 32, three border lines 35 are visible in the left part and two border lines 35 are visible in the right part of the image. In the lower discrimination image 32, three border lines 35 are visible in the left part of the image. The region below the border lines 35 provides a very clear estimate of the free space which is drivable by the vehicle.

Also in the discrimination image 32, the central areas 34, where no meaningful statement regarding transition points 33 or border lines 35 are possible, are marked by oval lines 36.

Furthermore, although it may be advantageous to determine transition points 33 and/or border lines 35 from a discrimination image 32, this is not mandatory. It is for example also possible to determine transition points 33 and/or border lines 35 directly in the horizontal optical flow image 31, for example by fitting curves like shown in the diagrams below the horizontal optical flow images 31 to each individual column or group of columns of the horizontal optical flow image 31. In this case, the calculation of the discrimination image 32 can be dispensed with, which saves corresponding processing resources.

Form the right images 32 of Figure 2 it is evident that it may be advantageous to restrict the determination of transition points 34 and/or border lines 35 to a lower image part, like the part of the image that is below the horizon, or just the lower half of the image, which can save corresponding processing resources.

Claims:

1. A vision system for detecting free space in front of a motor vehicle, comprising a mono imaging apparatus (11)
5 adapted to capture images (30) from the surrounding of a motor vehicle, and an electronic processing device (14) adapted to perform image processing of images (30) captured by said mono imaging apparatus (11) in order to detect objects in the surrounding of a motor vehicle, characterized in that said electronic processing device (14)
10 is adapted to calculate a horizontal component of the optical flow (31), and to determine transitions (33, 35) between regions of essentially constant horizontal optical flow and regions of essentially non-constant horizontal optical flow.
15
2. The vision system as claimed in claim 1, characterized in that said electronic processing device (14) is adapted to determine said transitions (33, 35) in a vertical image
20 direction.
3. The vision system as claimed in claim 1 or 2, characterized in that said electronic processing device (14) is adapted to determine a transition point (33) for each image column.
25
4. The vision system as claimed in any one of the preceding claims, characterized in that said electronic processing device (14) is adapted to determine one or more border
30 lines (35) fitting to the determined transitions.
5. The vision system as claimed in any one of the preceding claims, characterized in that said electronic processing

device (14) is adapted to calculate a discrimination image (32) from a horizontal optical flow image (31), where the value of each pixel of the discrimination image (32) provides a measure on whether the pixel belongs to a region of essentially constant horizontal optical flow or to a region of essentially non-constant horizontal optical flow, and to determine said transitions (33, 35) from said discrimination image (32).

6. The vision system as claimed in claim 5, wherein said discrimination image (32) is calculated by, in the horizontal optical flow image (31), considering a number x of pixels above the pixel under consideration, a number y of pixels below the pixel under consideration, where y can be equal to or different from x , calculating a statistical deviation, like the standard deviation, of the horizontal optical flow values of the group of pixels comprising the x pixels above, the y pixels below and the pixel under consideration, and estimating the pixel under consideration to belong to a region of essential constant horizontal optical flow if the calculated standard deviation is below a pre-determined or calculated threshold.
7. The vision system as claimed in any one of the preceding claims, characterized in that said electronic processing device (14) is adapted to disregard in said transitions determination a central image region (34, 36).
8. The vision system as claimed in any one of the preceding claims, characterized in that said electronic processing device (14) is adapted to restrict said transitions determination to a lower image part.

9. The vision system as claimed in any one of the preceding claims, characterized in that said electronic processing device (14) is adapted to determine the world distance from the vehicle to a structure formed by said transitions (33, 35).
10. The vision system as claimed in claim 9, characterized in that a flat road assumption is used in said distance determination.
11. The vision system as claimed in claim 9 or 10, characterized in that road profile information, for example from a satellite navigation system, is used in said distance determination.
12. A vision method for detecting free space in front of a motor vehicle, comprising capturing images (30) from the surrounding of a motor vehicle using a mono imaging apparatus (11), and performing image processing of captured images (30) in order to detect free space in front of the motor vehicle, characterized by calculating a horizontal component of the optical flow (31), and determining transitions (33, 35) between regions of essentially constant horizontal optical flow and regions of essentially non-constant horizontal optical flow.

1/2

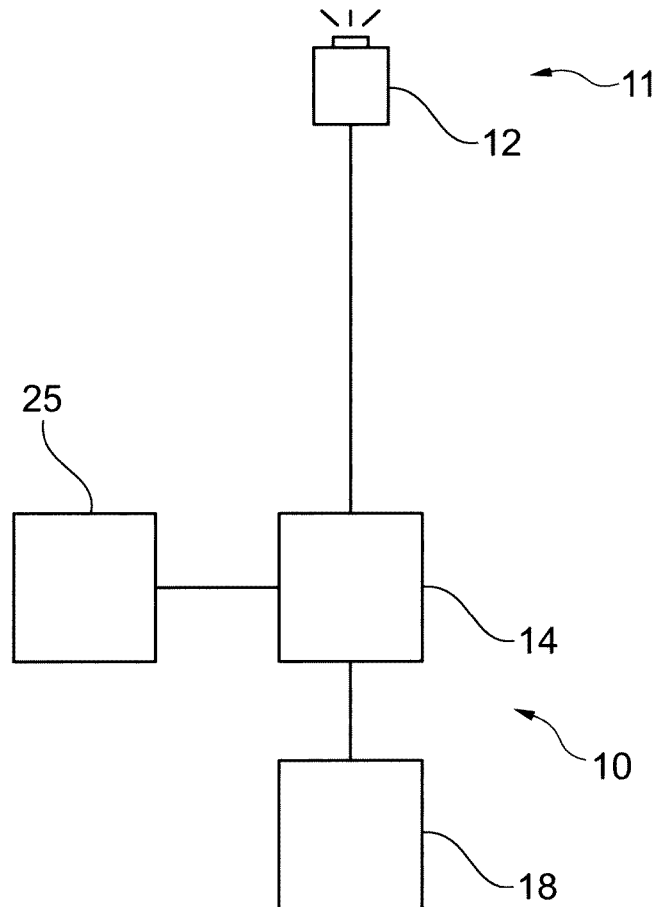


Fig. 1

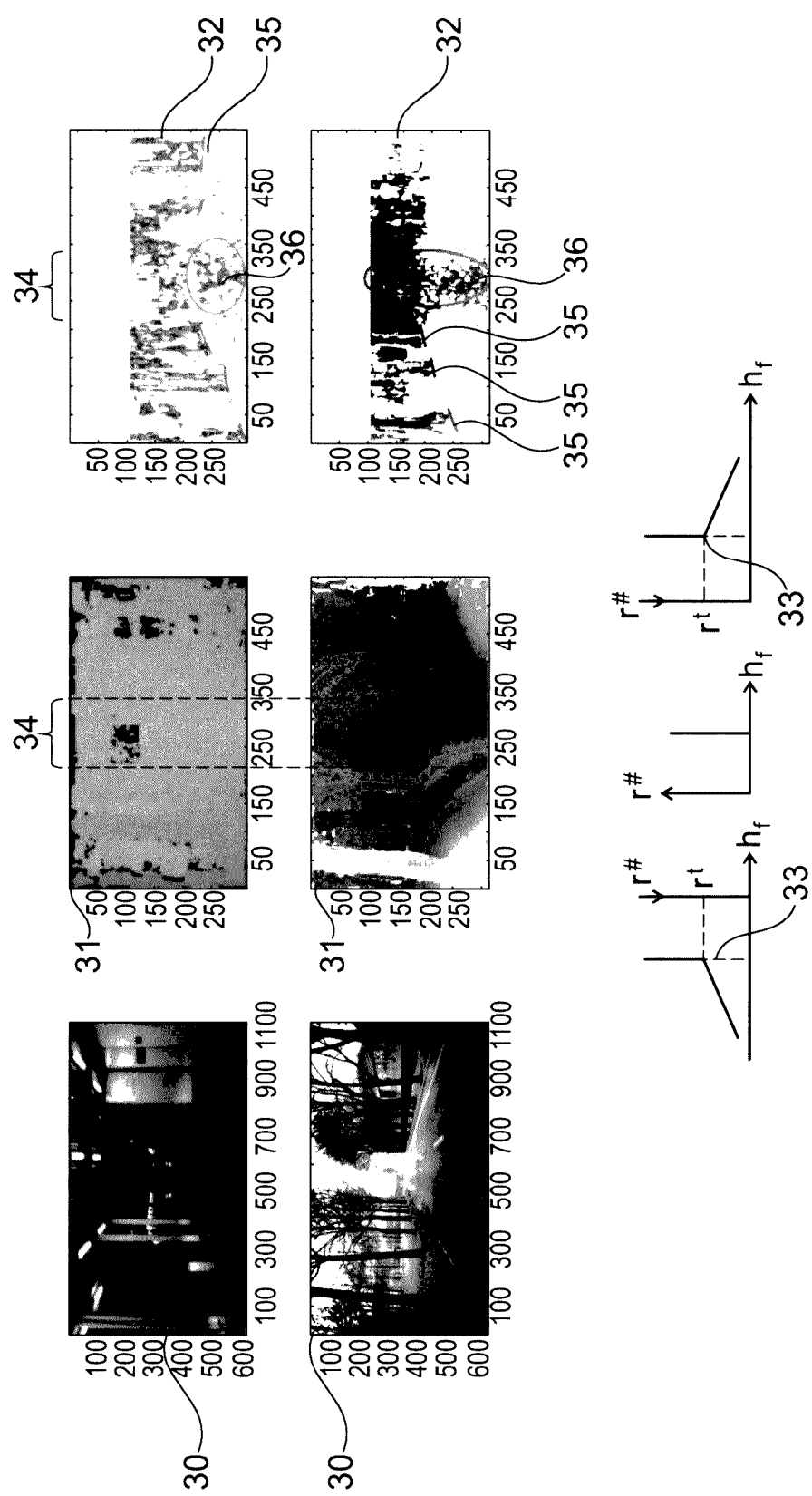


Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/072902

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K9/00
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)
G06K

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.
A	US 2011/311108 A1 (BADINO HERNAN [US] ET AL) 22 December 2011 (2011-12-22) abstract; claims	1-12
A	US 2015/206015 A1 (RAMALINGAM SRIKUMAR [US] ET AL) 23 July 2015 (2015-07-23) abstract paragraph [0011] - paragraph [0014] paragraph [0022] - paragraph [0026] ----- -/-	1-12



Further documents are listed in the continuation of Box C.



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"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

27 November 2017

Date of mailing of the international search report

07/12/2017

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/072902

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DAVID PFEIFFER ET AL: "Efficient representation of traffic scenes by means of dynamic stixels", INTELLIGENT VEHICLES SYMPOSIUM (IV), 2010 IEEE, IEEE, PISCATAWAY, NJ, USA, 21 June 2010 (2010-06-21), pages 217-224, XP031732275, ISBN: 978-1-4244-7866-8 abstract -----	1-12
A	EP 3 002 709 A1 (VALEO SCHALTER & SENSOREN GMBH [DE]) 6 April 2016 (2016-04-06) abstract paragraph [0038] -----	1-12

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/072902

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