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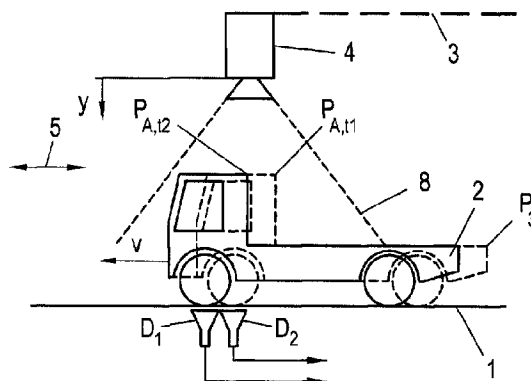
(72) **Inventeurs/Inventors:**
KOTZ, CHRISTIAN, AT;
RAFELSBERGER, OLIVER, AT;
JANNER, CHRISTIAN, AT

(73) **Propriétaire/Owner:**
KAPSCH TRAFFICCOM AG, AT

(74) **Agent:** ROWAND LLP

(54) **Titre :** METHODE DE MESURE UN PROFIL DE HAUTEUR D'UN VEHICULE PASSANT SUR UNE ROUTE

(54) **Title:** METHOD FOR MEASURING A HEIGHT PROFILE OF A VEHICLE PASSING ON A ROAD



(57) **Abrégé/Abstract:**

A method for measuring a height profile of a vehicle passing on a road, said method comprising the following steps: directing a monocular camera from a point above the road onto the road with an angle of aperture that captures a section of the road from above, recording at least a first image of the passing vehicle by means of the camera at a first moment in time, recording at least a second image of the passing vehicle by means of the camera at a second moment in time, generating a movement vector image of the vehicle from an analysis of the optical flow between the first and the second image, and creating the height profile of the vehicle from the movement vector image.

Abstract

A method for measuring a height profile of a vehicle passing on a road, said method comprising the following steps:

5 directing a monocular camera from a point above the road onto the road with an angle of aperture that captures a section of the road from above, recording at least a first image of the passing vehicle by means of the camera at a first moment in time, recording at least a second image of the passing vehicle

10 by means of the camera at a second moment in time, generating a movement vector image of the vehicle from an analysis of the optical flow between the first and the second image, and creating the height profile of the vehicle from the movement vector image.

Method for measuring a height profile of a vehicle passing on a
road

5 The present invention relates to a method for measuring a height profile of a vehicle passing on a road.

The measuring of vehicles as they are travelling is of significance, for example, for height checks of vehicles or for toll road systems, said vehicle having to pay different toll fees depending on the vehicle form, for example vehicle size, body structure (passenger vehicle or lorry), presence of a trailer, number of axles, etc. To this end, a wide range of technologies are currently used, for example laser scanners or stereoscopic (binocular) cameras, in order to create a 3D image of the passing vehicles and to establish therefrom a height profile of the vehicles. Laser scanners are extremely complex however in terms of construction and maintenance, and stereoscopic camera systems require special, complex calibration at all times. The object of the invention is to create a simpler method for measuring the height profile of a vehicle as it is travelling.

This object is achieved by a method of the type mentioned in the introduction, comprising the following steps:

directing a monocular camera from a point above the road onto the road with an angle of aperture that captures a section of the road from above,

recording at least a first image of the passing vehicle by means of the camera at a first moment in time,

recording at least a second image of the passing vehicle by means of the camera at a second moment in time,

30 generating a movement vector image of the vehicle from an analysis of the optical flow between the first and the second image, and

creating the height profile of the vehicle from the movement vector image.

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The invention firstly proposes the use of an optical flow analysis on the starting image flow of a monocular camera for the measurement of the height profile of a vehicle on a road. The establishment of 3D images or, more specifically, 2.5D images from the optical flow between chronologically successive images from relative positions that are therefore different is known *per se* in the art under the slogan "depth from motion" or "shape from video" and utilises the fact that points of an object passing the camera that are close to the camera appear to move more quickly than object points of the same object that are distant from the camera, whereby depth information concerning the object can be obtained.

The basic principles of optical flow analysis are described for example in *Antonin Chambolle et al.*, "An introduction to Total Variation for Image Analysis", Radon Series Comp. Appl. Math 9, 1-78, De Gruyter 2010; *John Dainitith*, "Optical Flow", 2004, retrieved on 5 June, 2012 from encyclopedia.com; *Robert Fisher et al.*, "Dictionary of Computer Vision and Image Processing", John Wiley and Sons, 2005. In traffic monitoring technology, optical flow methods were previously used to examine the movement of traffic flows in separate lanes, for example see *Young Cho et al.*, "Estimating Velocity Fields on a Freeway from Low Resolution Video", IEEE Transactions on Intelligent Transportation Systems, 2006, vol. 7, edition 4, pages 460-469; or *Jens Klappstein*, "Detektion von bewegten Objekten in Straßenverkehrsszenen mittels des optischen Flusses", (detection of moved objects in road traffic by means of optical flow), dissertation for Ruprecht-Karls-Universität Heidelberg, 2008. Individual vehicles were also followed with the aid of 3D representations of the vehicles at crossroads, said 3D representations being generated by optical flow analysis, for example see *Alexander Barth et al.*, "Vehicle Tracking at Urban Intersections Using Dense Stereo", 3rd Workshop on Behaviour Monitoring and Interpretation, BMI, Ghent, 2009; *David Pfeiffer* and *Uwe Franke*, "Efficient Representation of Traffic Scenes by

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Means of Dynamic Stixels", IEEE Intelligent Vehicles Symposium (IV), pages 217-224, San Diego, USA, 2010; L. Dreschler and H.-H. Nagel, "Volumetric Model and 3D-Trajectory of a Moving Car Derived from Monocular TV-Frame Sequences of a Street Scene",
5 IJCAI'81 Proceedings of the 7th International Joint Conference on Artificial Intelligence, pages 692-697. An overview of traffic applications of optical-flow methods is provided by V. Kastrinaki et al., "A Survey of Video Processing Techniques for Traffic Applications", Image and Vision Computing 21, pages
10 359-381, 2003.

The method according to the invention spares costly additional sensors, such as laser scanners, and complex calibration of stereoscopic cameras and makes it possible to implement a height profile measurement of the vehicles with just a single
15 camera directed from above onto the road, which has never been achieved in the prior art.

The camera is preferably directed substantially vertically downwardly onto the road so as to divide shadowing at the front and rear end faces of the vehicle and to thus minimise such
20 shadowing.

The measured height profile may be both a 2.5D height profile (a 2.5D height profile is understood to be a 3D profile that only contains those pieces of image depth information that are clear from the viewing angle and mounting point of the camera) and a 2D height profile ("sectional image"); for the latter,
25 a 2D height profile running parallel to the longitudinal direction of the road is preferably selected: The analysis of the optical flow as the vehicles move in their direction of travel delivers the most meaningful depth information precisely
30 in this direction.

The optical flow is preferably analysed anisotropically in the longitudinal direction of the road for the same reasons. The edges of the passing vehicles transverse to the longitudinal direction of the road hardly change between the two images
35 (provided a vehicle does not change lanes at this time), and

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therefore this can be used as a boundary condition in the analysis of the optical flow.

The height profile is preferably scaled on the basis of the speed of the lowest recorded point of the vehicle or of a shadow of the vehicle on the road in order to produce a correctly dimensioned height profile.

Alternatively, a "self-scaling" of the height profiles to the vehicle speed can be achieved in that the moments in time at which the two images to be evaluated by optical flow analysis are captured are made dependent on a detection of the vehicle at predetermined positions on the road. To this end, the first moment in time is preferably the moment in time at which the vehicle is detected in a first position on the road, and the second moment in time is the moment at which the vehicle is detected in a second position on the road.

The vehicle is particularly preferably detected in the first and the second position with the aid of sensors arranged at the road or by means of an evaluation of the images of the camera itself. The mentioned sensors, for example, may be photoelectric sensors, induction loops in the carriageway, scanners or the like. If the images of the camera itself are used for position detection of the vehicles, for example significant points of the vehicle image, such as a corner in the contour of the vehicle, can be detected at predetermined positions in the image.

In further advantageous embodiments of the invention, the movement vector image, before the height profile is created therefrom, or the created height profile is preferably compensated by the angle of aperture of the camera and is thus rectified.

Any optical-flow method known in the art can be used for the optical flow analysis. Due to the relatively high relative movement of quick vehicles in the image, a total variation optical flow method is preferably used, as is described for example in *T. Brox and J. Malik, "Large Displacement Optical Flow:*

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Descriptor Matching in Variational Motion Estimation", IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 33, edition 3, pages 500-513, 2011, obtainable for the Matlab-program libraries, for example at <http://lmb.informatik.uni-freiburg.de/resources/binaries/>.

The method of the invention may also be used to classify the measured vehicle by comparing the created height profile with reference height profiles of known vehicle classes.

For the method of the invention, any suitable camera can be used, for example a photo camera for taking successive individual images or a video camera. A traffic monitoring camera mounted on a bridge spanning a road is preferably used as the camera, in particular a traffic monitoring video camera, of which the video stream (image output stream) is fed to the optical flow analysis.

The invention will be explained in greater detail hereinafter on the basis of an exemplary embodiment illustrated in the accompanying drawings, in which:

Figs. 1a and 1b show the method of the invention when recording an image of a vehicle passing below a monocular camera at two different moments in time;

Figs. 2a-2d show the method of the invention on the basis of image, vector and profile data occurring therein;

Figs. 3a and 3B show two exemplary movement vector images before (Fig. 3a) and after (Fig. 3b) rectification;

Fig. 4 shows a perspective view of a 2.5D height profile created from the rectified movement vector image from Fig. 3b; and

Fig. 5 shows a 2D height profile or the optional subsequent rectification thereof created from the movement vector image of Fig. 3a or 3b or from the 2.5D height profile of Fig. 4 respectively.

Figs. 1a and 1b show the basic measuring arrangement for carrying out the method in question for measuring a height profile of a vehicle 2 passing on a road 1. The vehicle 2 is shown

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in Figs. 1a and 1b in two different locations or positions, more specifically a first position denoted by dashed lines at the moment in time t_1 and a second position shown with solid lines at a later moment in time t_2 .

5 A camera 4 directed downwardly onto the road 1 is mounted above the road 1 on a stationary support 3, for example a pole with cantilever arm or a bridge spanning the road (gantry), for example at a mounting height of 6 - 7 m. The camera 4 is monoc-
 10 ular, that it to say it has a single, usually square or rectangular, image recording sensor (not shown) and a single lens arranged in front, whereby it has an inverted-pyramidal field of vision 8 with an angle of aperture α as viewed in a plane parallel to the longitudinal direction of the road 5 and an angle
 15 of aperture β (not shown) as viewed in a plane transverse to the longitudinal direction of the road 5. For clearer illustration, the vehicle 2 illustrated here by way of example has a very strongly differentiated and simplified height profile with substantially one roof area 6 close to the camera (high) in the form of a driver's cabin roof and one roof area 7 distant from
 20 the camera (low) in the form of a loading area.

It goes without saying that the camera 4 may also be directed downwardly at an incline onto the road 1, provided the portion of road of interest, on which the vehicle 2 passes, can be seen in part of the field of vision 8 of said camera.

25 As can be seen from Figs. 1a and 1b, a point P_A close to the camera, for example on the roof area 6, moves in a given period of time $\Delta t = t_2 - t_1$ between the first moment in time t_1 and the second moment in time t_2 in the field of vision 8 of the camera 4 seemingly by a movement vector x_A , whereas an im-
 30 age point P_B distant from the camera, for example on the roof area 7, moves in the same period of time Δt between the same (or different) moments in time by the smaller movement vector x_B .

Fig. 2a shows the recorded images (frames) F_1 , F_2 of the
 35 camera 4 corresponding to the recording situations in Figs. 1a

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and 1b at the two moments in time t_1 , t_2 . The two images F_1 , F_2 are fed to an optical flow analysis method. The optical flow analysis method is known in the art, and, for example, on the basis of significant points (feature points) detected in the images F_1 , F_2 , establishes movement vectors x_A , x_B of the significant points (sparse approach). Alternatively, all image points could be taken into consideration in that their sought movement vectors are considered as part of an objective function to be minimised, that is to say the movement vector matrix that best reflects the change of the optical flow F between the images F_1 , F_2 is sought (dense approach). Preferred implementations of the dense approach are the total variation optical flow method, in which the objective function is an energy term to be minimised, which takes into account the changes in brightness and colour between the images. Further terms (of higher order) may also be taken into consideration in order to further improve the results. For details of the optical flow analysis and in particular of the total variation optical flow method, reference is made to the literature mentioned in the introduction T. Brox and J. Malik, "Large Displacement Optical Flow: Descriptor Matching in Variational Motion Estimation", IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 33, edition 3, pages 500-513, 2011; for example, Matlab-C-mex implementation of this method is available from URL:<http://lmb.informatik.uni-freiburg.de/resources/binaries/>.

Here, special smoothness terms can be used as boundary conditions for the total variation optical flow analysis, which include the small or absent movement of the vehicle 2 transverse to the longitudinal direction 5 of the road as a precondition in order to facilitate the solution to the minimisation problem. In order to achieve good separation between different objects (road, vehicle) and so as not to smooth the edge between vehicle and road for example, smoothing is preferably carried out anisotropically (parallel to the edges occurring in the images).

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Since the movement vectors $x(P)$ for slow vehicles are very small and are zero for stationary vehicles, in these situations the temporal distance $t_2 - t_1$ between the two analysed images F_1 and F_2 is preferably increased. For example, images following on from one another directly from the video stream of the camera 4, when this is a video camera, therefore are not necessarily analysed, but instead images recorded accordingly far apart in time. The recording times t_1 and t_2 of the two images F_1 and F_2 are preferably selected such that the vehicle 2 in each case is located in a predetermined position on the road 1, as will be explained later in greater detail. It goes without saying that the camera 4 may also record more than two images F_1 , F_2 at more than two moments in time t_1 , t_2 , and these images may be included in the optical flow analysis.

Fig. 2b shows the result of the optical flow analysis of Fig. 2a in the form of a movement vector image V , which contains a movement vector $x(P)$ for each image point P of the camera image F_1 or F_2 . Fig. 2b is a highly schematic drawing with few movement vectors illustrated symbolically; in fact, the movement vector image V is a matrix or an array, in which each cell or pixel P contains a movement vector $x(P)$.

Fig. 3a shows another form of the illustration of the movement vector image V from Fig. 2b, wherein the absolute values ("speeds") of the movement vectors $x(P)$ have been classified (quantised) in different gradation areas; as can be seen, the roof area 6 (cabin roof) of the vehicle 2 clearly appears with a (seemingly) high speed and the roof area 7 (bay) of the vehicle 2 appears with a (seemingly) low speed.

From the movement vector image V (Figs. 2b and 3a), the respective distance y (Figs. 1a, 1b) of a point of the vehicle 2 from the camera 4 can now be established directly: a high absolute value of the movement vector $x(P)$ indicates a short distance y and vice versa. The movement vector image V thus simultaneously constitutes a height relief or height profile of the

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vehicle 2 passing on the road 1, even if this is "raw" because it is unscaled.

Fig. 4 shows this illustratively in that the absolute values of the movement vectors $x(P)$ of the movement vector image V are assigned distances y and these have been illustrated in a graph. The illustration of Fig. 4 therefore shows a 3D height profile, more specifically: a 2.5D height profile $W_{2.5}$ of the vehicle 2. By creating a section in a plane 9 parallel to the longitudinal direction of the road 5, a 2D height profile W_2 can be produced from the 3D or 2.5D height profile $W_{2.5}$ of Fig. 4 and is illustrated in Fig. 5.

It can be seen from Fig. 5 that the height profile $W_{2.5}$ or W_2 considered until now is distorted in accordance with the angle of aperture α of the camera 4 in the longitudinal direction of the road 5 (and also in accordance with the angle of aperture β transverse thereto). With the aid of a corresponding geometric equalisation, the 2D height profile W_2 of Fig. 5 (or the 2.5D height profile $W_{2.5}$) of Fig. 4 can thus be compensated by the angle of aperture α (and optionally also β) of the camera 4, that is to say rectified, as illustrated schematically by the arrows 10 in Fig. 5; the rectified 2D height profile is denoted in Fig. 5 by W_2' . Figs. 2c and 2d schematically show in detail the step of rectification of a 2D height profile W_2 by the angle of aperture α in the longitudinal direction of the road 5 on the basis of a box-shaped vehicle 2 with vertical end faces 11, 12.

The rectification by the angle of aperture α (and β) can be carried out both directly on the height profiles $W_{2.5}$, W_2 , and already beforehand on the movement vector image V . This is shown in Fig. 3b, which shows the movement vector image V of Fig. 3a after the step of rectification by the angles of aperture α , β ; the rectified movement vector image is denoted by V' . A rectified 2.5D height profile $W_{2.5}'$ or a rectified 2D height profile W_2' may thus also be created directly from the rectified movement vector image V' of Fig. 3b.

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The height profiles $W_{2.5}$, $W_{2.5}'$, W_2 , W_2' may then be used for classification of the vehicle 2, for example in that significant parameters of the vehicle 2, such as height and length, are calculated therefrom or the height profiles are compared with a set of previously stored reference height profiles of known vehicle classes.

If the inherent speed v of the vehicle 2 is known, for example as a result of measurement by means of separate sensors, such as photoelectric sensors, induction loops in the carriageway 1, scanners etc., it can be included directly in the optical flow analysis of Fig. 2a, and the movement vector images V , V' and height profiles $W_{2.5}$, $W_{2.5}'$, W_2 , W_2' contain absolute values, that is to say are scaled, such that, for example, the correct height and length of the vehicle 2 can be deduced therefrom. If the inherent speed v of the vehicle 2 is not known or is measured separately, in particular if only a single camera 4 is provided for carrying out the described optical flow method, a lowest moving point P_3 that is to say a point farthest from the camera, or a shadow of the vehicle 2 on the road 1, can be used in the images F_1 , F_2 as a reference value, and the movement vector image V , V' or the height profiles $W_{2.5}$, $W_{2.5}'$, W_2 , W_2' can be referenced and thus scaled. A shadow of the vehicle 2 on the road 1, for example an outermost point of this shadow, could also be detected in the images F_1 and F_2 and used for speed measurement in order to then scale the height profiles $W_{2.5}$, $W_{2.5}'$, W_2 , W_2' .

Alternatively, the moments in time t_2 , t_1 at which the two analysed images F_1 , F_2 are recorded may be selected beforehand such that they correspond to predetermined positions of the vehicle 2 on the road 1. For example, with the aid of wheel detectors D_1 , D_2 integrated into the carriageway, for example induction loops, photoelectric sensors, scanners, etc., but also by means of an evaluation of the continuous images (of the video stream) of the camera 4 itself, those two moments in time t_1 , t_2 at which the vehicle 2 adopts the two locations or posi-

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tions shown in Fig. 1a by solid and dashed lines can thus be detected so as to then record the images F_1 , F_2 . The height profiles $W_{2.5}$, $W_{2.5}'$, W_2 , W_2' are thus scaled automatically with the correct speed.

5 Of course, a height profile $W_{2.5}$, $W_{2.5}'$, W_2 , W_2' of a plurality of vehicles in the field of vision of the camera 4 can also be created with the method of the invention. The invention is therefore not limited to the presented embodiments, but includes all variants and modifications that fall within the
10 scope of the accompanying claims.

Claims

1. A method for measuring a height profile of a vehicle passing on a road, said method comprising the following steps:

5 directing a monocular camera from a point above the road onto the road with an angle of aperture that captures a section of the road from above,

recording at least a first image of the passing vehicle by means of the camera at a first moment in time,

10 recording at least a second image of the passing vehicle by means of the camera at a second moment in time,

generating a movement vector image of the vehicle from an analysis of the optical flow between the first and the second image, and

15 creating the height profile of the vehicle from the movement vector image.

2. The method according to Claim 1, characterised in that the camera is directed substantially vertically downwardly onto the road.

20 3. The method according to Claim 1 or 2, characterised in that the height profile is a 2.5D height profile.

4. The method according to Claim 1 or 2, characterised in that the height profile is a 2D height profile, which runs parallel to the longitudinal direction of the road.

25 5. The method according to any one of Claims 1 to 4, characterised in that the height profile is scaled on the basis of a speed of the lowest recorded point of the vehicle or on the basis of a shadow of the vehicle on the road.

30 6. The method according to any one of Claims 1 to 4, characterised in that the first moment in time is the moment in time at which the vehicle is detected in a first position on the road, and the second moment in time is the moment in time at which the vehicle is detected in a second position on the road.

7. The method according to Claim 6, characterised in that the vehicle is detected in the first and the second position with the aid of sensors arranged at the road or by means of an evaluation of the images of the camera itself.

5 8. The method according to any one of Claims 1 to 7, characterised by the further step of rectifying the movement vector image for compensation of the angle of aperture, before the height profile is created therefrom.

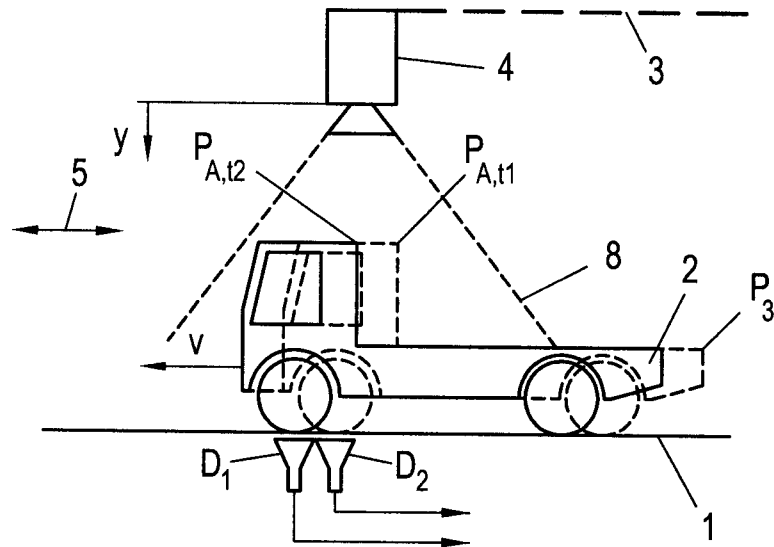
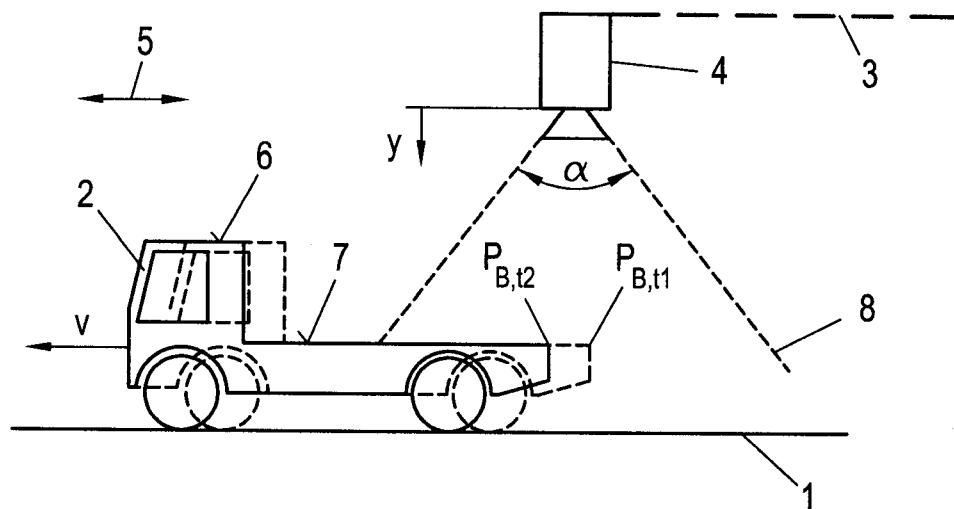
10 9. The method according to any one of Claims 1 to 7, characterised by the further step of rectifying the height profile for compensation of the angle of aperture.

10. The method according to any one of Claims 1 to 9, characterised in that a total variation optical flow method is used for the analysis of the optical flow.

15 11. The method according to any one of Claims 1 to 10, characterised by the further step of classifying the vehicle on the basis of a comparison of the created height profile with reference height profiles of known vehicle classes.

20 12. The method according to any one of Claims 1 to 11, characterised in that a traffic monitoring camera mounted above the road is used as the camera.

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*Fig. 1a**Fig. 1b*

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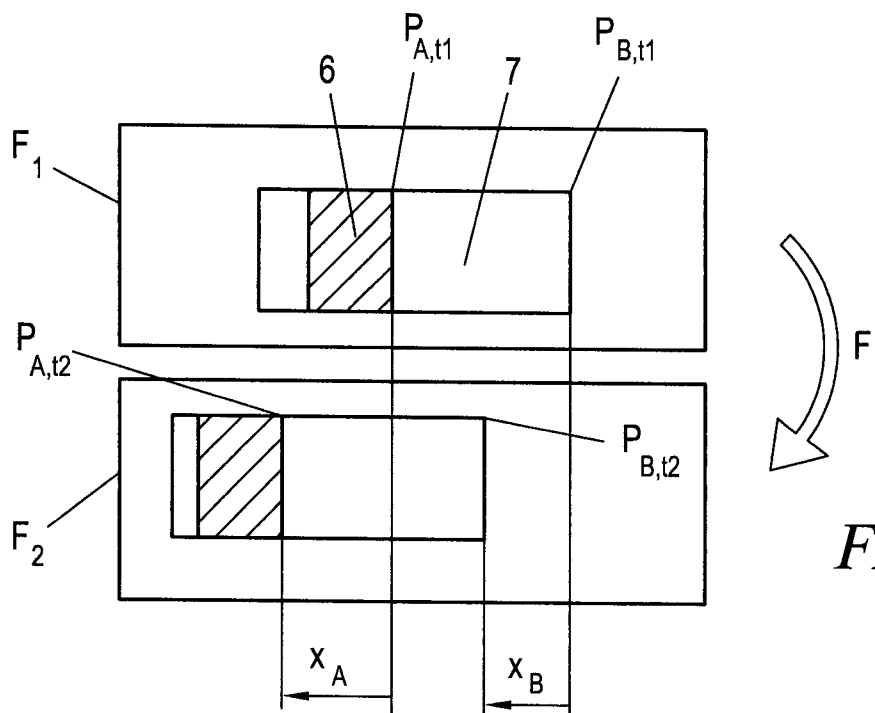


Fig. 2a

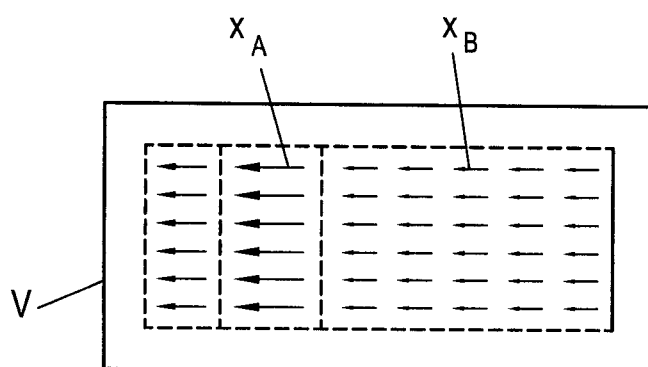


Fig. 2b

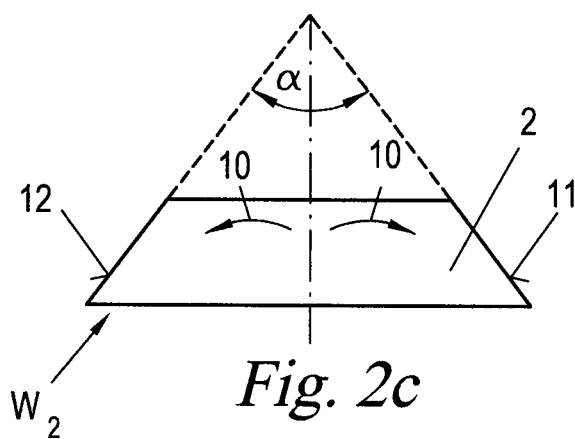


Fig. 2c

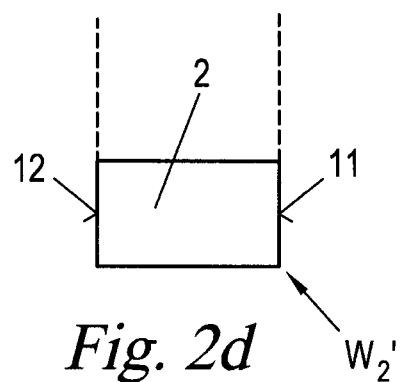


Fig. 2d

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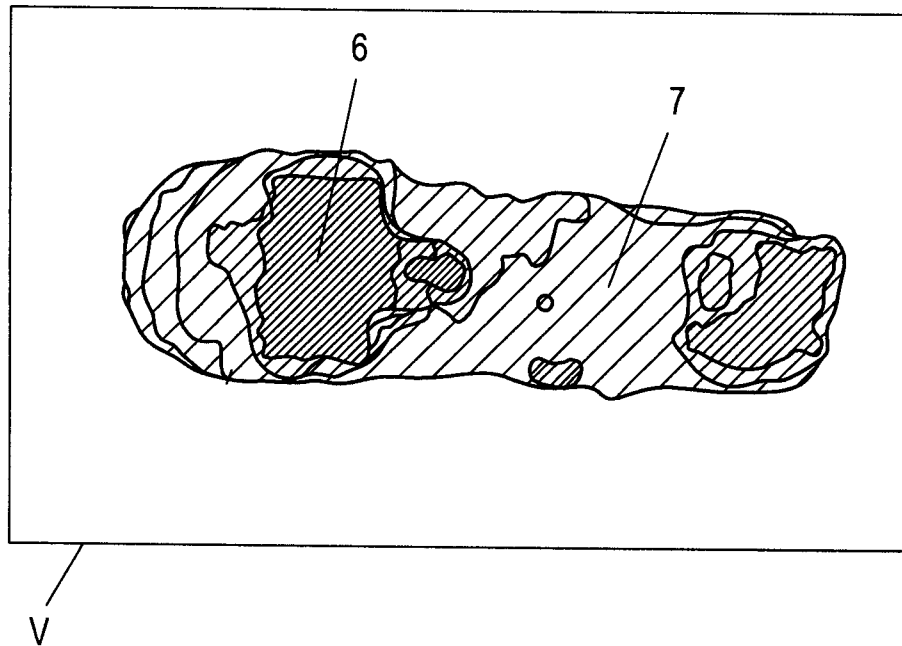


Fig. 3a

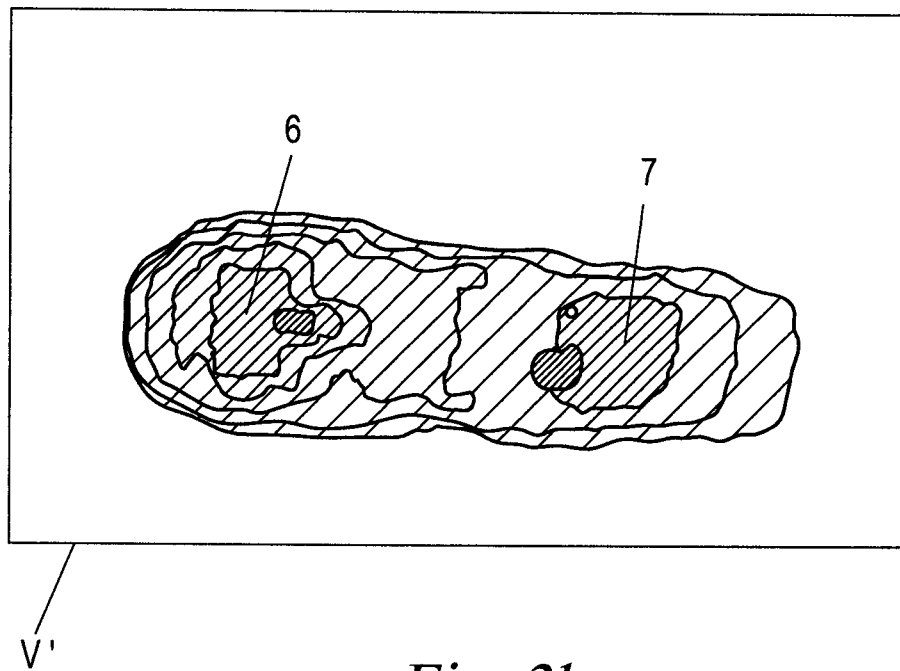


Fig. 3b

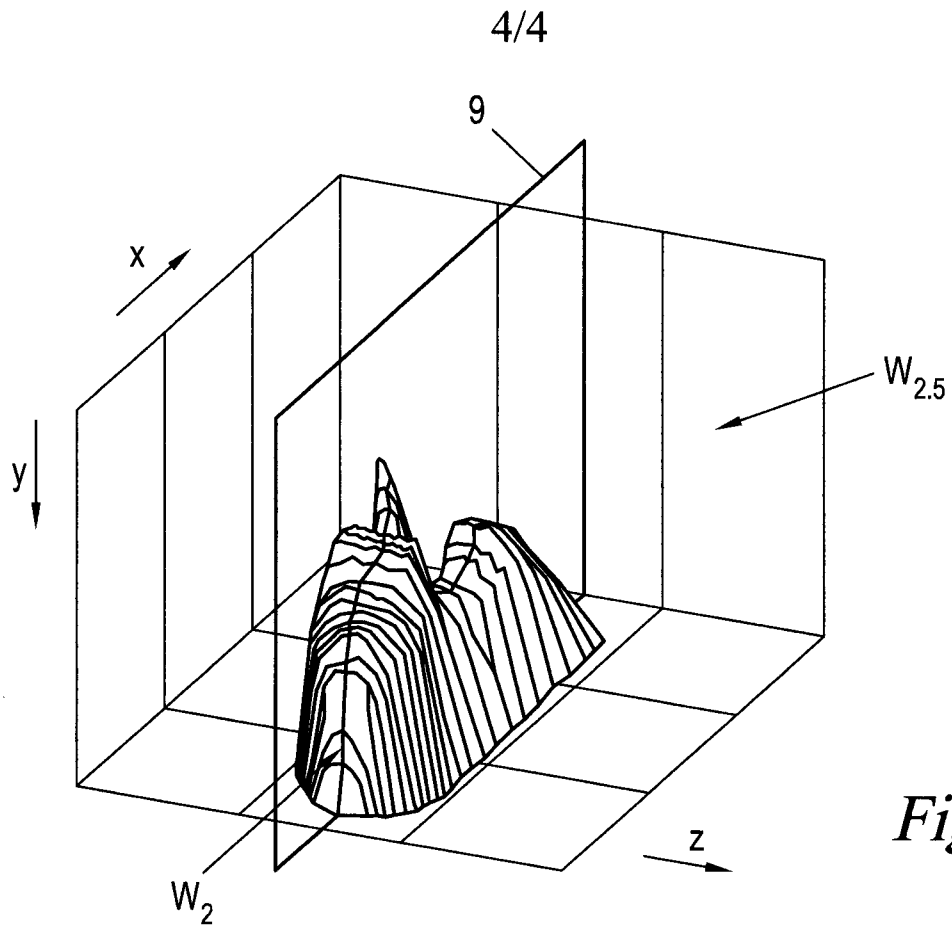


Fig. 4

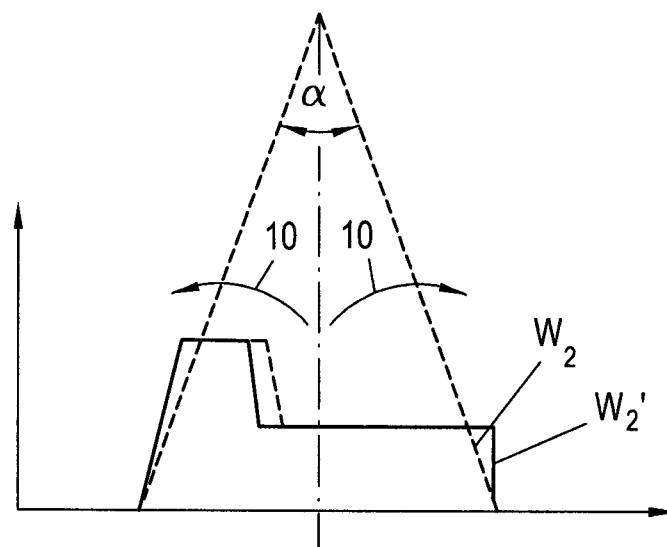


Fig. 5

