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WO 2019/227865 A1 **CN 011612849 A**
US 20170098304 A1

(58) Field of Search:
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Other: **WPI, EPODOC**

(54) Title of the Invention: **Measuring vehicle speeds with an uncalibrated camera**
Abstract Title: **Measuring speed of a vehicle in a road environment using a traffic camera**

(57) Measuring speed of a vehicle in a road environment using a calibrated traffic camera. During calibration, multiple images are captured of a calibration vehicle traveling at a known ground speed. A calibration image feature is located in the image of the calibration vehicle and an optical flow of the calibration image feature is computed to determine a model between an image speed of the calibration image feature and the known ground speed of the calibration vehicle. During speed measurement, multiple images are captured of a target vehicle traveling along a road surface at unknown ground speed and a target image feature located in an image of the target vehicle is identified. An image speed is computed of the target image feature and the model is applied to determine the ground speed of the target vehicle from the image speed of the target image feature.

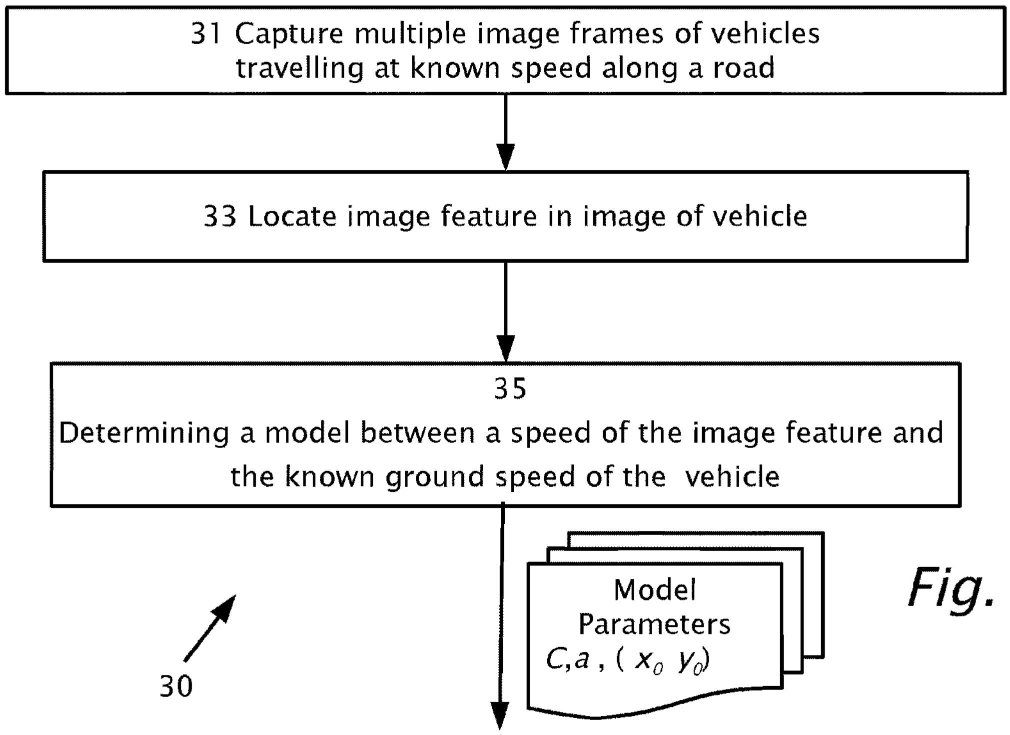

Fig. 3

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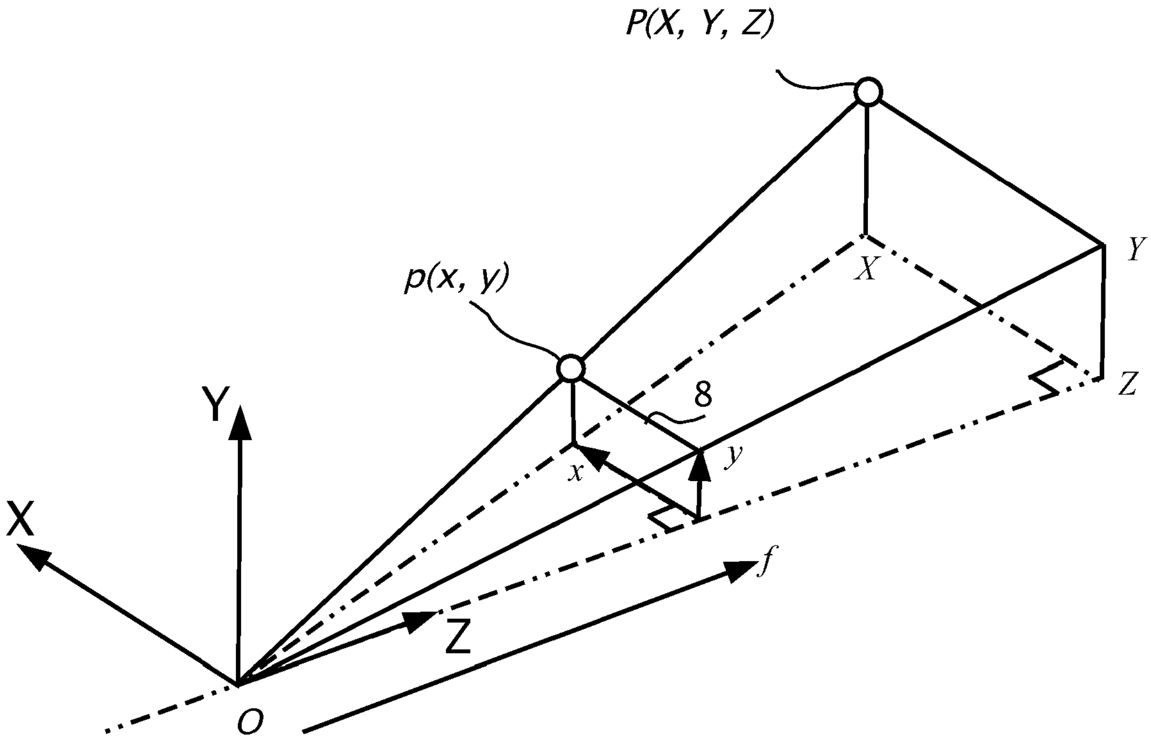

Fig. 1

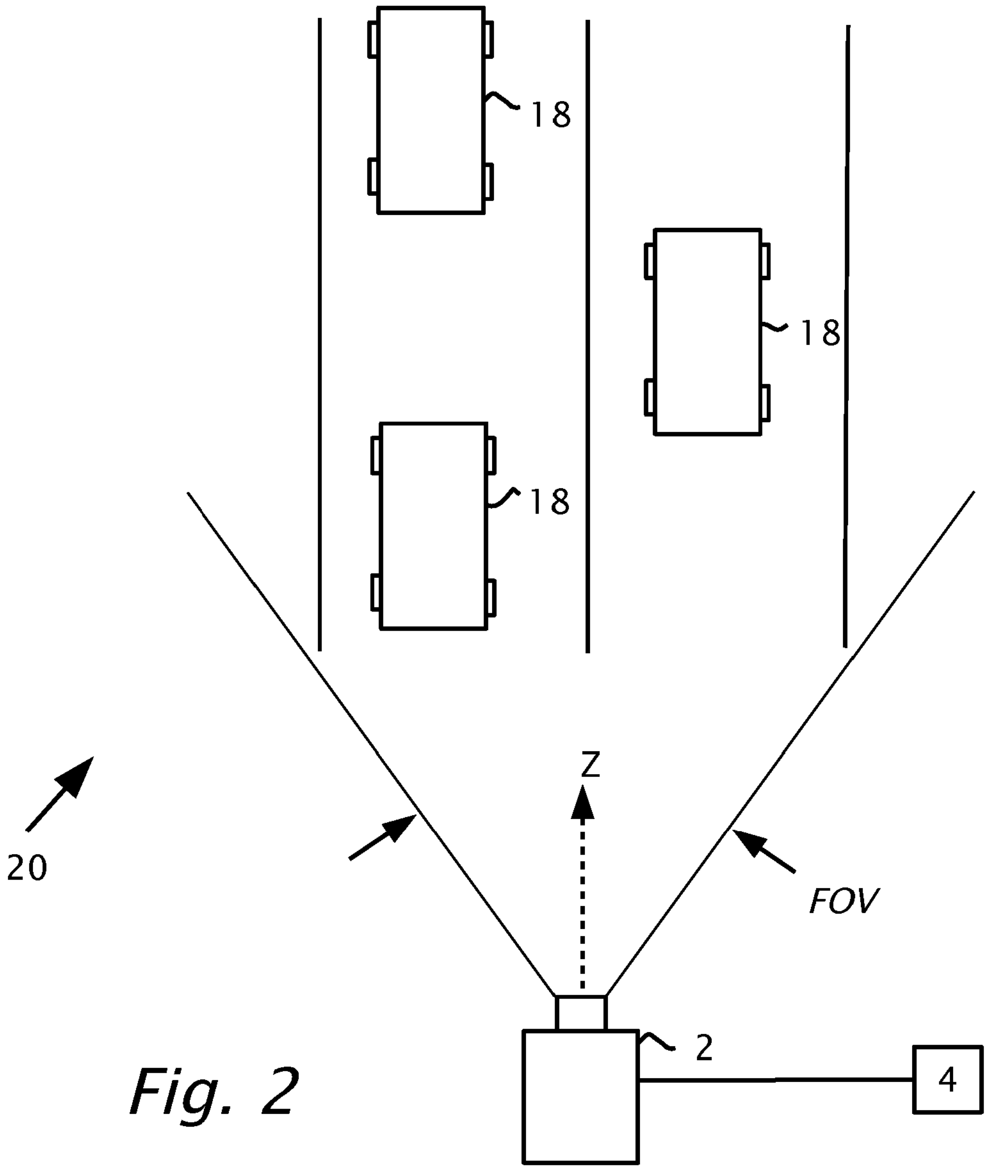

Fig. 2

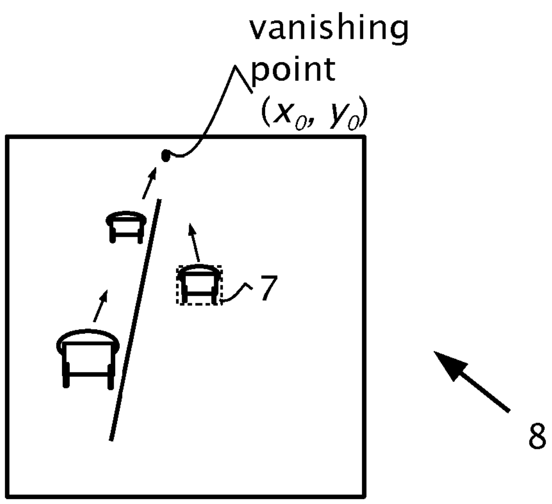

Fig. 2A

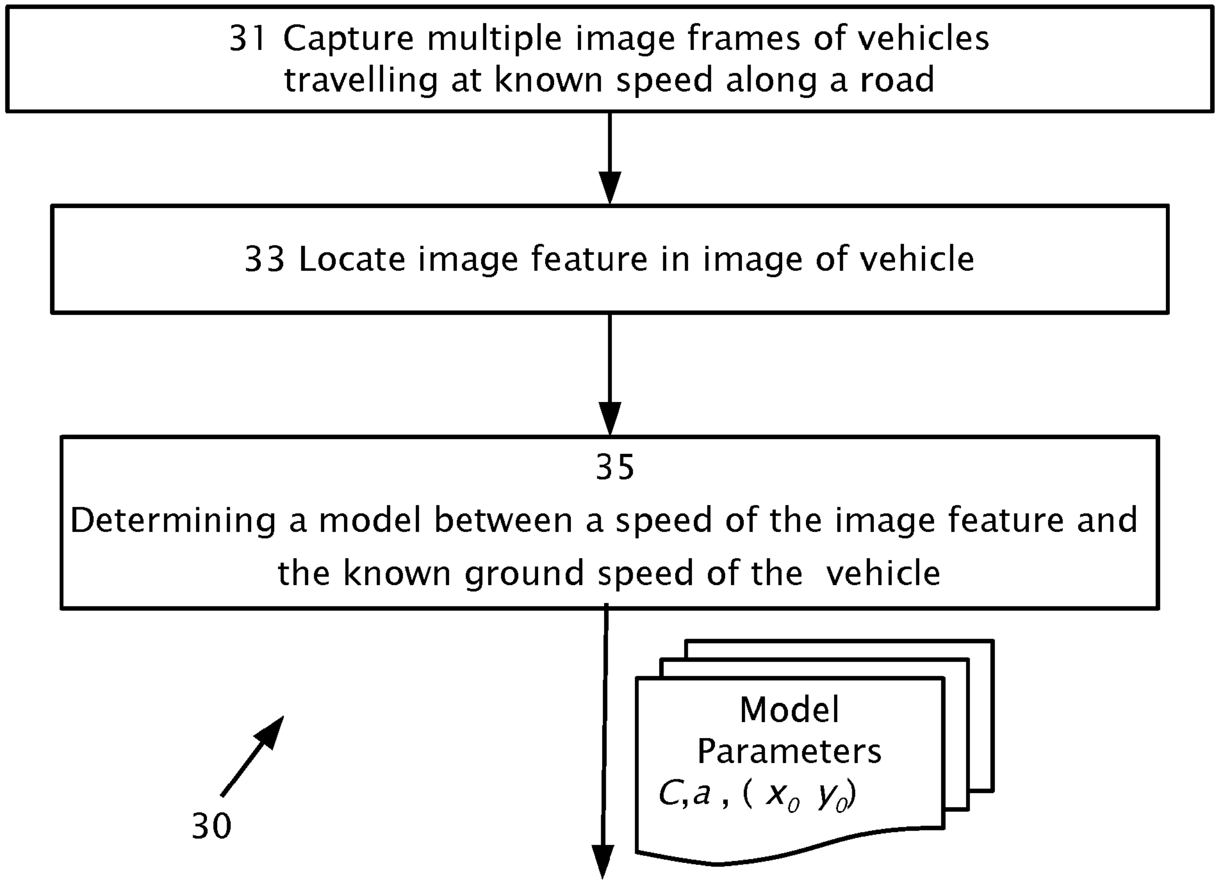
31 Capture multiple image frames of vehicles travelling at known speed along a road
33 Locate image feature in image of vehicle
35
Determining a model between a speed of the image feature and the known ground speed of the vehicle
Model Parameters
C,a , (x0 y0)
30

Fig. 3

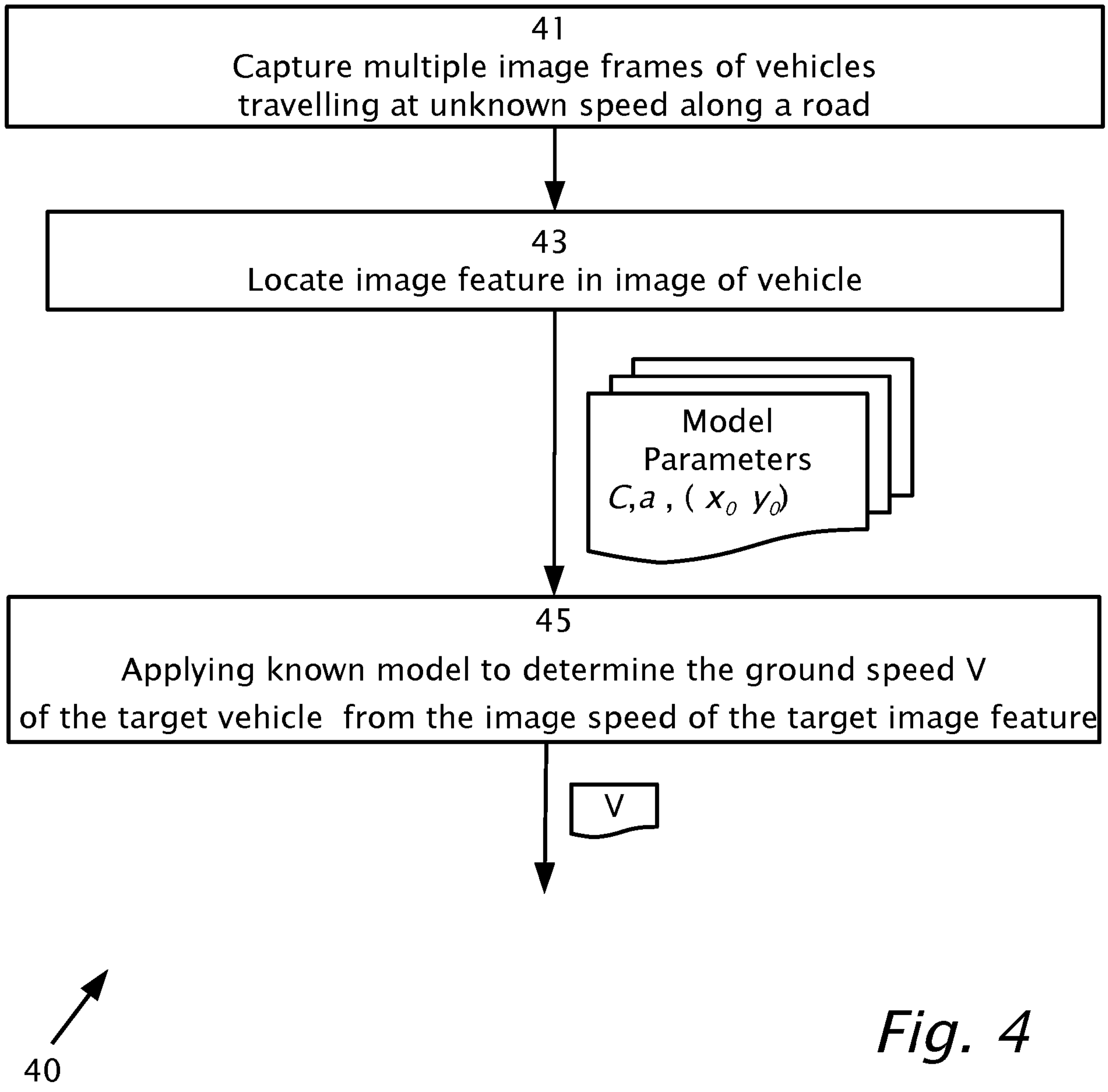
41
Capture multiple image frames of vehicles
travelling at unknown speed along a road
43
Locate image feature in image of vehicle
Model
Parameters
C,a , (x0 y0)
45
Applying known model to determine the ground speed V
of the target vehicle from the image speed of the target image feature
V
40

Fig. 4

MEASURING VEHICLE SPEEDS WITH AN UNCALIBRATED CAMERA

BACKGROUND

1. Technical Field

The present invention relates to usage of traffic cameras for measurement of vehicle speed.

2. Description of Related Art

Modern speed enforcement involves use of a speed measuring device for measuring vehicle speeds and triggering a camera to capture an image to identify the speeding vehicle and driver to whom a citation may be issued. An accurate vehicle speed measurement is necessary for law enforcement of speeding. A number of methods exist for measuring vehicle speeds . RADAR, “radio detection and ranging”, is a technology that uses electromagnetic radio waves to detect moving vehicles and measure their speeds. LiDAR uses pulsed laser light instead of radio waves to measure vehicle speeds. Digital image processing has been suggested for measuring speed of moving vehicles in a road environment.

BRIEF SUMMARY

Various methods and systems are disclosed herein for measuring speed of a vehicle in a road environment. During calibration, multiple images are captured of a calibration vehicle traveling at a known ground speed. A calibration image feature is located in the image of the calibration vehicle. An optical flow of the calibration image feature is computed to determine a model between an image speed of the calibration image feature and the known ground speed of the calibration vehicle. During speed measurement, multiple images are captured of a target vehicle traveling along a road surface at unknown ground speed. A target image feature may be located in an image of the target vehicle. An image speed may be computed of the target image feature. The model may be applied to determine the ground speed of the target vehicle from the image speed of the target image feature. Image speed relative to ground speed may be proportional to a distance from a vanishing point of an image feature and proportional to a vertical image coordinate measured from a vanishing point. Image speed relative to ground speed of the vehicle may be proportional to a horizon slope factor related to camera roll about the horizon and a horizontal image coordinate measured from the vanishing point. The model may be a parameterized model including multiple parameters. The model may be determined by determining the parameters of the model. The parameters of the model may include: a proportionality constant C relating ground speed V to image speed v, image coordinates x_0 and y_0 of a vanishing point in an image plane, and the horizon slope factor related to camera roll about the horizon.

Various non-transitory computer-readable storage media store instructions that, when executed by a processor, cause the processor to perform a method as disclosed herein

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

Figure 1 illustrates a camera or pinhole coordinate system which relates world-space coordinates (X,Y,Z) to image coordinates (x,y);

Figure 2 illustrates schematically a top view of a system including a camera viewing a road environment, according to embodiments of the present invention;

Figure 2A illustrates an image viewed by the camera in Figure 2;

Figure 3 is a simplified flow diagram of a calibration stage of a method, according to embodiments of the present invention; and

Figure 4 is a simplified flow diagram of speed measurement method of target vehicles, according to embodiments of the present invention

The foregoing and/or other aspects will become apparent from the following detailed description when considered in conjunction with the accompanying drawing figures.

DETAILED DESCRIPTION

Reference will now be made in detail to features of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout. The features are described below to explain the present invention by referring to the figures.

By way of introduction, aspects of the present invention are directed to a system and method for accurately measuring the speeds of vehicles along a stretch of road. A planar road model may be assumed. The present method as disclosed herein may be used to retrofit, with only a software upgrade, an existing camera already in use for license plate recognition, by way of example. Speed measurements, according to embodiments of the present invention may be used to monitor local traffic and/or trigger an issuance of a citation for a speeding violation.

Once setup, the system may be used to measure respective speeds of multiple vehicles within the camera's field of view (*FOV*), simultaneously including vehicles travelling in opposite directions, to and from the camera. The system and method as disclosed herein includes two stages of operation.

(1) An initial calibration stage, during which images are captured, ie. video, of a sample of vehicles travelling at known speeds.

(2) a measurement stage where the system may operate continuously, measuring and logging vehicle speeds in real-time.

Referring now to the drawings, reference is now made to Figure 1 which illustrates camera or pinhole projection which relates a point *P(X,Y,Z)* in world space Cartesian coordinates to a point *p(x,y)* image coordinates on image plane **8** where X is the horizontal Cartesian coordinate in world space, Y is the vertical Cartesian coordinate in world space and Z is the direction along the optical axis of the camera. The origin O of camera projection is at the pinhole, image plane **8** is in reality behind the origin at focal length f with the image inverted. Image plane **8** is shown in the projection of Figure 1 in a symmetric position with a non-inverted image in front of origin O at a distance focal length f so the centre of the image plane **8** is at world space coordinates $(0,0,f)$. The following equations approximate the relation between image coordinates x,y and world space coordinates X,Y,Z assuming camera or pinhole projection.

$$x(t)=f\frac{X(t)}{Z(t)} \quad y(t)=f\frac{Y(t)}{Z(t)}$$

Reference is now also made to Figure 2, which illustrates schematically a system **20**, according to embodiments of the present invention, a view from above of a road environment. System **20** illustrates fixed in a road environment, a camera **2** with field of view (*FOV*) with the optical axis Z of camera **2** parallel to the direction of motion of vehicles **18**. Using the camera coordinate system as shown in Figure 1, the motion of a vehicle **18** is modelled as starting from $(X_0, Y_0, 0)$, a point in a plane perpendicular to the camera optical axis, and moving along a straight trajectory in three dimensions, toward a point $(X(t), Y(t), Z(t))$. The vehicle position is imaged on image plane **8** as being at $(x(t), y(t))$. A processor **4** is shown connected to camera **2** configured to capture image frames from the road environment.

Reference is now also made to Figure 2A which schematically illustrates image plane **8** imaging the road environment as shown in Figure 2. Vanishing point (x_0, y_0) is shown, the point on image plane **8** to which the trajectories of vehicle **18** converge as $Z(t)$ approaches infinity. Arrows emanating from images of vehicles **18** moving along the road in the positive Z direction indicate respective image velocity vectors in the direction of the vanishing point. Length of the arrows represents speed v in image space.

Defining image coordinates relative to the vanishing point: $\Delta x = x - x_0$ and $\Delta y = y - y_0$, a model relating speed v measured in image space on image plane **8** and ground speed V of the vehicle is a ratio:

$$\frac{v}{V} = C(a\Delta x - \Delta y)\sqrt{((\Delta x)^2 + (\Delta y)^2)} \qquad (1)$$

where C is a proportionality constant and a is a horizon slope factor related to roll angle of the camera about the optical axis. If the camera horizontal x axis is exactly parallel with the horizon, then a=0. Using equation (1), parameters: C, a , x_0 and y_0 may be determined during the calibration phase when vehicle speed is known. Subsequently, during the measurement stage, equation (1) may be used to determine respective ground speeds V from speed v measurements in image plane **8** of image features of vehicles.

Still referring to Figure 2A, a bounding box **7** is shown with a broken line tightly fitting an image of a vehicle **18.** When using bounding box 7, x' may be defined as the mid-point of bounding box 7 along the horizontal image axis x; and measured relative to vanishing point horizontal coordinate x_0\ is:

$\Delta x' = x' - x_0$

Similarly y' may be defined along the vertical image axis y as the bottom of bounding box **7**; and relative to the vertical coordinate y_0 of the vanishing point is:

$$\Delta y' = y' - y_0$$

When using bounding box **7**, we can improve upon equation (1) by assuming that the bottom of bounding box **7** is on the road to yield:

$$\frac{v}{V} = C(a\Delta x' - \Delta y')\sqrt{((\Delta x)^2 + (\Delta y)^2)} \quad (2)$$

Calibration Stage:

Calibration stage is for initial setup which, in some embodiments of the present invention, may include operator supervision. As long as camera **2** remains fixed, the initial setup may be performed only once. There are two purposes to calibration mode: (i) to map regions of the road that are straight and planar without dips or turns, and (ii) to find the model parameters, C, a, x_0 and y_0.

Reference is now made to Figure 3, a flow diagram of a calibration stage **30** according to embodiments of the present invention. Multiple image frames are captured (step **31**) of vehicles travelling along a road with known respective speeds. Image features in images of the travelling vehicles are located, (step **33**). Image features are tracked between image frames. ORB may be used to match features and track between image frames. (Ethan Rublee, Vincent Rabaud, Kurt Konolige, Gary R. Bradski: ORB: An efficient alternative to SIFT or SURF. ICCV 2011: 2564-2571)

Optical flow of the image features may be computed between two or more image frames to produce a set of motion vectors. Vehicle images may be stabilised by considering optical flow outside the vehicle images, i.e. the part of the image that is not expected to be moving.Any other known methods for stabilization may be used. Spurious optical flow vectors may be filtered out. Spurious optical flow vectors include: vectors that do not emanate or end in a bounding box. Vectors that are too short and represent noise. Motion vectors with directions very different from most of the optical flow vectors or are too long and may represent an optical flow feature mismatch are outliers and preferably filtered out.

Filtered optical flow vectors are input into a model based on equation (1) to optimally determine (step **35)** parameters C, a , x_0 and y_0. Some regions in image plane **8** may consistently have improved fits to the model, other regions may have worse fits to the model.

Image plane **8** may be mapped so that better fitting images are used for parameter determination. (step **35)**

Speed Measurement Stage

Reference is now made to Figure 4 which is a simplified flow diagram of speed measurement of target vehicles **18**, according to embodiments of the present invention. Multiple image frames are captured (step **41**) of vehicles travelling along a road with unknown respective speeds. Image features in images of the travelling vehicles are located, (step **43**).

As in the calibration stage, similar processing steps may be performed.. Target image features are tracked between image frames. Optical flow of the image features may be computed between two or more image frames to produce a set of motion vectors. Vehicle images may be stabilised and spurious optical flow vectors may be filtered out. Filtered optical flow vectors are input into the model based on equation (1) including model parameters C, a , x_0 and y_0 to optimally determine determine (step **45**) the ground speed V of the target vehicle from the image speeds of the target image features.

The term "image feature" as used herein is one or more portion of an image such as a corner or “blob” and may be detected by any method in the art of digital image processing.

The term “optic flow” or “optical flow” as used herein refers to pattern of apparent motion of image features in image space caused by motion of an object relative to the camera.

The term “image speed” as used herein is the magnitude of an optical flow vector in an image plane divided by time.

The term “calibration” as used herein is not “camera calibration” which generally refers to determining internal camera parameters: *e.g.* focal length, distortion, and external camera parameters: position coordinates and/or angular coordinates of the camera relative to the road. These camera coordinates are not generally required to be known *a priori* in the present method. The term “calibration” as used herein refers to the initial stage of the method disclosed herein which uses images of a vehicle travelling at known speed to determine parameters of a model relating ground speed to image speed.

The term "vanishing point" as used herein is a point (x_0,y_0) in image space to which an image of an object emanates as the object approaches infinite distance from the camera along the positive optical axis.

The transitional term “comprising” as used herein is synonymous with “including”, and is inclusive or open-ended and does not exclude additional, unrecited elements or method steps. The articles "a", "an" is used herein, such as "a vehicle”, "an image feature” have the meaning of "one or more" that is "one or more vehicles", "one or more image features".

The various aspects, embodiments, implementations or features of the described embodiments can be used separately or in any combination. Various aspects of the described embodiments can be implemented by software, hardware or a combination of hardware and software. The described embodiments can also be embodied as computer readable code on a non-transitory computer readable medium. The non-transitory computer readable medium is any data storage device that can store data which can thereafter be read by a computer system. Examples of the non-transitory computer readable medium include read-only memory, random-access memory, CD-ROMs, HDDs, DVDs, magnetic tape, and optical data storage devices. The non-transitory computer readable medium can also be distributed over network-coupled computer systems so that the computer readable code is stored and executed in a distributed fashion.

All optional and preferred features and modifications of the described embodiments and dependent claims are usable in all aspects of the invention taught herein. Furthermore, the individual features of the dependent claims, as well as all optional and preferred features and modifications of the described embodiments are combinable and interchangeable with one another.

Although selected features of the present invention have been shown and described, it is to be understood the present invention is not limited to the described features.

CLAIMS

THE CLAIMED INVENTION IS:

1. A method comprising:

during calibration, capturing a plurality of images of a calibration vehicle traveling at a known ground speed;

locating a calibration image feature in an image of the calibration vehicle;

computing an optical flow of the calibration image feature thereby determining a model between an image speed of the calibration image feature and the known ground speed of the calibration vehicle;

during speed measurement, capturing a plurality of images of a target vehicle traveling along a road surface at unknown ground speed;

locating a target image feature in an image of the target vehicle;

computing an image speed of the target image feature; and

applying the model to determine the ground speed of the target vehicle from the image speed of the target image feature.

2. The method of claim 1, wherein image speed relative to ground speed is proportional to a distance from a vanishing point of an image feature and proportional to a vertical image coordinate measured from a vanishing point.

3. The method of claim 1, wherein image speed relative to ground speed of the vehicle is proportional to a horizon slope factor related to camera roll about the horizon and a horizontal image coordinate measured from the vanishing point.

4. The method of claim 1, wherein the model is a parameterized model including a plurality of parameters, wherein said determining the model includes determining the parameters of the model.

5. The method of claim 4, wherein the parameters of the model include: a proportionality constant C relating ground speed V to image speed v, image coordinates x_0 and y_0 of a vanishing point in an image plane and a horizon slope factor related to camera roll about the horizon.

6. A system including a processor and a camera, the system configured to:

during calibration, capture a plurality of images of a calibration vehicle traveling at a known ground speed;

locate a calibration image feature in an image of the calibration vehicle;

compute an optical flow of the calibration image feature thereby determine a model between an image speed of the calibration image feature and the known ground speed of the calibration vehicle;

during speed measurement, capture a plurality of images of a target vehicle traveling along a road surface at unknown ground speed;

locate a target image feature in an image of the target vehicle;

compute an image speed of the target image feature; and

apply the model to determine the ground speed of the target vehicle from the image speed of the target image feature.

7. The system of claim 6, wherein image speed relative to ground speed is proportional to a distance from a vanishing point of an image feature and proportional to a vertical image coordinate measured from a vanishing point.

8. The system of claim 6, wherein image speed relative to ground speed of the vehicle is proportional to a horizon slope factor related to camera roll about the horizon and a horizontal image coordinate measured from the vanishing point.

9. The system of claim 6, wherein the model is a parameterized model including a plurality of parameters, wherein said determining the model includes determining the parameters of the model.

10. The system of claim 6, wherein the parameters of the model include: a proportionality constant C relating ground speed V to image speed v, image coordinates x_0 and y_0 of a vanishing point in an image plane and a horizon slope factor related to camera roll about the horizon.

11. A non-transitory computer-readable storage medium storing instructions that, when executed by a processor, cause the processor to perform a method comprising:

during calibration, capture a plurality of images of a calibration vehicle traveling at a known ground speed;

locate a calibration image feature in an image of the calibration vehicle;

compute an optical flow of the calibration image feature thereby determine a model between an image speed of the calibration image feature and the known ground speed of the calibration vehicle;

during speed measurement, capture a plurality of images of a target vehicle traveling along a road surface at unknown ground speed;

locate a target image feature in an image of the target vehicle;

compute an image speed of the target image feature; and

apply the model to determine the ground speed of the target vehicle from the image speed of the target image feature.

12. The non-transitory computer-readable storage medium of claim 11, wherein image speed relative to ground speed is proportional to a distance from a vanishing point of an image feature and proportional to a vertical image coordinate measured from a vanishing point.

13. The non-transitory computer-readable storage medium of claim 11, wherein image speed relative to ground speed of the vehicle is proportional to a horizon slope factor related to camera roll about the horizon and a horizontal image coordinate measured from the vanishing point.

14. The non-transitory computer-readable storage medium of claim 11, wherein the model is a parameterized model including a plurality of parameters, wherein said determining the model includes determining the parameters of the model.

15. The method of claim 14, wherein the parameters of the model include: a proportionality constant C relating ground speed V to image speed v, image coordinates x_0 and y_0 of a vanishing point in an image plane and a horizon slope factor related to camera roll about the horizon .

Intellectual Property Office

Application No:	GB2015434.0	**Examiner:**	Mr Joe McCann
Claims searched:	1-15	**Date of search:**	24 March 2021

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 6, 11	WO 2019/227865 A1 (UNIV CHINA MINING) - see abstract and paragraphs 41-44
X	1, 6, 11	CN 11612849 A (SHENZHEN HIT TRAFFIC ELECTRONIC TECH CO LTD) - see whole document
X	1, 6, 11	US 2017/098304 A1 (BLAIS-MORIN) - see abstract, paragraphs 3 and 75 and figure 3

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

G06T

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
G06T	0007/246	01/01/2017
G06T	0007/80	01/01/2017