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(71) Applicant (for all designated States except US):
BRIDGESTONE CORPORATION [JP/JP]; 10-1, Kyobashi 1-Chome, Chuo-Ku, Tokyo 104-8340 (JP).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **ALLEVA, Lorenzo** [IT/IT]; Via Bisentina, 15, I-00137 Roma (IT).

(74) Agents: **JORIO, Paolo** et al.; Studio Torta S.r.l., Via Viotti, 9, I-10121 Torino (IT).

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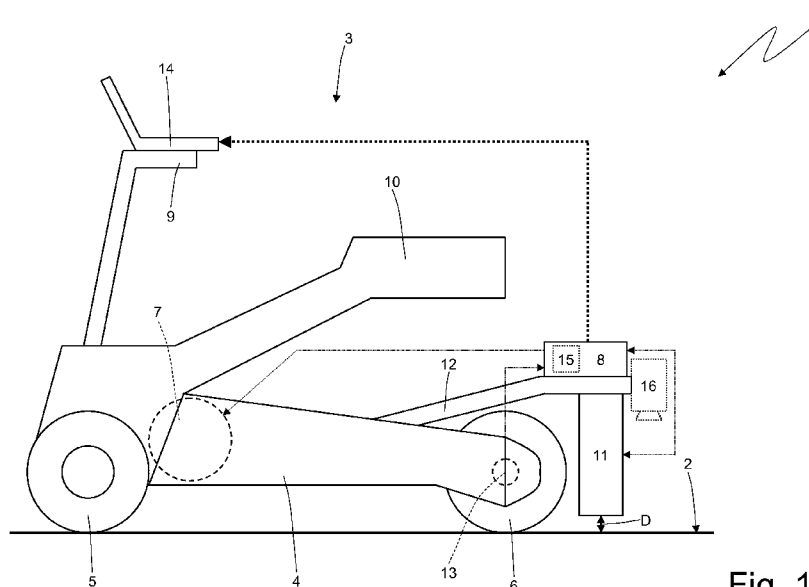


Fig. 1

(57) Abstract: A measuring system (1) and method for measuring the roughness of a road surface (2), the measuring system (1) having: a vehicle (3) which moves along a measuring path on the road surface (2); a first measuring device (11) mounted in a fixed vertical position on the vehicle (3) and aimed vertically towards the road surface (2) to measure the distance (D) with respect to the road surface (2); a second measuring device (13) for measuring travel of the vehicle (3) along the measuring path; and a control unit (8), which controls the first measuring device (11) as a function of the travel of the vehicle (3) along the measuring path, to measure the distance (D) with respect to the road surface (2) at predetermined, strictly constant measuring intervals.

ROAD SURFACE ROUGHNESS MEASURING SYSTEM AND METHOD

TECHNICAL FIELD

The present invention relates to a system and
5 method for measuring the roughness or texture of a road surface.

BACKGROUND ART

Vehicle tyre performance depends largely on the roughness of the rolling surface, so, to accurately
10 compare the results of tyre tests performed at different times and/or on different test tracks, any difference in road surface roughness must be determined accurately to factor in its effect on test results.

Also, in car racing, it helps to know the precise
15 roughness of the track surface to objectively select the right tyre rubber mix (especially in view of recent regulations drastically reducing the number of mixes that can be used in each race).

Particularly important is knowing the precise
20 macroroughness of the road surface, i.e. roughness with a 0.5 to 50 mm horizontal wavelength λ (road surface roughness with a wavelength λ below 0.5 mm and above 50 mm is known as microroughness and megaroughness respectively).

25 Road surface macroroughness is measured using various systems, the most accurate of which are stationary laser profilographs, which measure the macroroughness of a small road surface area. Continuous

macroroughness measurements, i.e. of an extensive road surface area, are made using a device known by the trade name ARAN (Automatic Road Analyzer) and manufactured by FUGRO ROADWARE. This comprises a four-wheel vehicle
5 (typically a small truck) equipped with one or more laser distance measuring devices mounted in a fixed position of the vehicle and aimed vertically downwards to 'survey' the road surface. In actual use, the vehicle is driven at relatively high speed (up to 100 km/h)
10 along the road surface, and each laser distance measuring device records the distance between itself and the road surface at a constant acquisition rate. The distance readings of each laser distance measuring device form a two-dimensional profile of the road
15 surface along the vehicle path, from which the roughness of the road surface, i.e. the point-to-point vertical changes in the road surface, can be determined.

As the vehicle moves forward, it does not remain in the same vertical position, but continually oscillates
20 vertically, thus also resulting in vertical oscillation of the laser distance measuring devices, which obviously affects the distance readings between the laser distance measuring devices and the road surface. To compensate for vertical oscillation of the moving vehicle, this is
25 equipped with a system of accelerometers for determining instantaneous vertical acceleration. From this, using a dual time integration process, it is possible to determine the instantaneous change in the vertical

position of the vehicle, and so compensate the laser distance measuring device readings.

The ARAN, however, has two major drawbacks: the two-dimensional road surface profile is not as accurate
5 as stationary laser profilographs, and can only be measured along straight or substantially straight trajectories, on account of noticeable roll-induced lateral tilting of the vehicle, and therefore of the laser distance measuring devices, when cornering, which
10 introduces errors that are hard to compensate and which seriously affect the laser distance measuring device readings. The ARAN is therefore suitable for use on motorways, but is totally unsuitable for car race tracks with numerous tight bends.

15 DESCRIPTION OF THE INVENTION

It is an object of the present invention to provide a road surface roughness measuring system and method designed to eliminate the above drawbacks, and which in particular are cheap and easy to implement.

20 According to the present invention, there are provided a road surface roughness measuring system and method as claimed in the attached Claims.

BRIEF DESCRIPTION OF THE DRAWINGS

A non-limiting embodiment of the present invention
25 will be described by way of example with reference to the accompanying drawings, in which:

Figure 1 shows a schematic of a road surface roughness measuring system in accordance with the

present invention;

Figure 2 shows a road surface roughness measurement graph;

Figures 3a and 3b show a rear wheel of the Figure 1
5 measuring system vehicle in an unloaded and loaded condition respectively.

PREFERRED EMBODIMENTS OF THE INVENTION

Number 1 in Figure 1 indicates as a whole a system for measuring the roughness or texture of a road surface
10 2. More specifically, measuring system 1 is designed to measure the so-called macroroughness of road surface 2, i.e. roughness with a 0.5 to 50 mm horizontal wavelength λ , may also be used to measure the so-called microroughness of road surface 2, i.e. roughness with a
15 lower than 0.5 mm horizontal wavelength λ , but is normally unsuitable (unless modified) for measuring the so-called megaroughness of road surface 2, i.e. roughness with a higher than 50 mm horizontal wavelength λ .

20 Measuring system 1 comprises a vehicle 3, which is moved along a measuring path on road surface 2, is a motor vehicle in the form of a tricycle, and has a frame 4 supporting two front wheels 5 (only one shown in Figure 1) and one rear drive wheel 6. The two front
25 wheels 5 are more effective in reducing roll than a single-front-wheel design; the rear drive wheel 6 is powered by a central electric motor 7 controlled by a control unit 8; the front wheels 5 are also direction

wheels turned by a handlebar 9; and a saddle 10 is fitted to and projects from frame 4, so the driver is seated at the rear, substantially over rear wheel 6, on which most of the driver's weight is exerted.

5 Vehicle 3 is equipped with at least one laser distance measuring device 11, which communicates with control unit 8, is fitted to vehicle 3 in a fixed vertical position, at a small distance D from road surface 2, and is aimed vertically downwards to 'survey'
10 road surface 2. More specifically, a supporting bracket 12 is fitted to and projects from frame 4, extends over rear wheel 6, and is fitted on the end with laser distance measuring device 11 located behind rear wheel 6. Vehicle 3 also comprises an angular position sensor
15 13 (more specifically, a high-resolution angular encoder) which communicates with control unit 8 and records the angular position of rear wheel 6 to determine travel of vehicle 3: from the angular position, and given the circumference, of rear wheel 6,
20 the position of vehicle 3 along the measuring path of vehicle 3 can be worked out fairly easily.

Measuring system 1 comprises a processing unit 14 (typically a small portable computer on vehicle 3) for processing the readings of laser distance measuring
25 device 11 and angular position sensor 13.

In actual use, as vehicle 3 is driven by the driver along the measuring path on road surface 2, laser distance measuring device 11 and angular position sensor

13 take a sequence of measurements, which are stored in a memory in processing unit 14, and, at the end of the measuring path, are processed by processing unit 14 using dedicated software.

5 As vehicle 3 is driven along the measuring path, control unit 8 controls laser distance measuring device 11 as a function of the travel of vehicle 3, so as to measure distance D with respect to road surface 2 at predetermined, strictly constant measuring intervals
10 compatible with the quantity being measured (micro- or macroroughness). In other words, the distance D measurements by laser distance measuring device 11 are strictly equally spaced, so the measuring interval between consecutive distance D measurements is always
15 the same, regardless of the travelling speed of vehicle 3 along the measuring path. Each distance D measurement by laser distance measuring device 11 is also assigned a corresponding position X along the measuring path, using the recordings made by angular position sensor 13.

20 To ensure the distance D measurements by laser distance measuring device 11 are strictly equally spaced, control unit 8 controls electric motor 7 of vehicle 3 so that the travelling speed v of vehicle 3 along the measuring path is always less than a maximum
25 speed equal to the measuring interval (i.e. the distance between consecutive distance D measurements) multiplied by the maximum measuring rate of laser distance measuring device 11. This ensures the actual measuring

rate of laser distance measuring device 11 is always less than its maximum measuring rate, and that laser distance measuring device 11 is therefore always capable of maintaining constant distance D measuring intervals.

5 At the end of the measuring path, the sequence of distance D measurements as a function of position X along the measuring path is processed by processing unit 14 applying a space-domain high-pass filter to the sequence to eliminate signals with a wavelength above a
10 predetermined filtration threshold. In other words, all the signals in the distance D measuring sequence with a wavelength above the filtration threshold in the space domain are eliminated, and all the signals with a wavelength below the filtration threshold in the space
15 domain are retained. The predetermined filtration threshold is chosen so that it is (adequately) higher than the maximum macroroughness wavelength (i.e. over 50 mm) and (adequately) lower than the wavelength λ of vertical oscillation of frame 4 of vehicle 3 with
20 respect to road surface 2.

 The need for signal filtration lies in frame 4 of vehicle 3. That is, resting on road surface 2 via an elastic system substantially comprising the tyres of wheels 5 and 6, frame 4 of vehicle 3 supporting laser
25 distance measuring device 11 is excited vertically, as it travels along the measuring path, by any unevenness in road surface 2, and so oscillates vertically with respect to road surface 2, thus resulting in errors in

the distance D measurements. This is shown clearly in the Figure 2 prefiltration graph of distance D as a function of position X along the measuring path: the targeted value, oscillating in space with a short wavelength, is overlaid with noise N produced by vertical oscillation of frame 4 with respect to road surface 2 and oscillating in space with a long wavelength. As shown clearly in the Figure 2 graph, noise N has an amplitude that may be as much as 50% that of the targeted value, and so completely distorts the measurements, if not eliminated.

It is important to note that space-domain low-pass filtration of the distance D measurement sequence as a function of position X along the measuring path is possible because of the predetermined, strictly constant distance D measuring intervals, whereas it would not be if the distance D measuring intervals were randomly variable. In conventional systems, the laser distance measuring device normally takes measurements at a fixed rate, regardless of vehicle speed; and an algorithm then converts the time between measurements into distance, to distribute the measurements in space. This, however, results in significant errors as compared with the solution proposed in the present invention.

Noise N, produced by vertical oscillation of frame 4 with respect to road surface 2, can be eliminated by space-domain high-pass filtration from the distance D measurement sequence as a function of position X along

the measuring path, by virtue of frame 4 oscillating vertically with respect to road surface 2 with a vertical oscillation wavelength λ well above the maximum macroroughness wavelength. This is an essential, far from random condition, which is expressly achieved by appropriately adjusting the natural frequency f of vertical oscillation of frame 4, and the travelling speed v of vehicle 3 along the measuring path. In other words, the natural frequency f of vertical oscillation of frame 4, and the travelling speed v of vehicle 3 along the measuring path are adjusted (optimized) by appropriately adjusting the system's suspended rigidities/masses, so that the wavelength λ of vertical oscillation of frame 4 is suitably higher than the maximum macroroughness wavelength.

As shown in Figure 3, the natural frequency f of vertical oscillation of frame 4 is determined as a function of downward displacement Δx of frame 4 caused by passage from the unloaded condition (i.e. unmanned vehicle 3, as shown in Figure 3a) to the loaded condition (i.e. manned vehicle 3, as shown in Figure 3b), and which is determined by laser distance measuring device 11 when vehicle 3 is stationary. In other words, when vehicle 3 is stationary, the driver mounting saddle produces a downward displacement Δx of frame 4 with respect to road surface 2, substantially due to elastic deformation of the rear wheel 6 tyre. Given the design of frame 4, the driver's weight weighs almost entirely

on rear wheel 6, and, because bracket 12 supporting laser distance measuring device 11 is connected to frame 4, close to rear wheel 6, downward displacement Δx of frame 4 may safely be assumed to be caused solely by elastic deformation of the rear wheel 6 tyre (which can be adjusted by adjusting the tyre inflation pressure of rear wheel 6).

Downward displacement Δx of frame 4 with respect to road surface 2 is produced by the gravitational force F_g (i.e. weight) of the driver, which is added to frame 4 and given by equation [1] below. When the system is balanced, the gravitational force F_g of the driver is counterbalanced by the elastic force F_e produced by deformation (equal to downward displacement Δx of frame 4) of the rear wheel 6 tyre and given by equation [2] below.

$$[1] \quad F_g = m \cdot g$$

$$[2] \quad F_e = k \cdot \Delta x$$

20

F_g driver gravitational force (N);

m total weight (kg);

g gravitational acceleration (m/sec²);

F_e elastic force produced by rear wheel 6 tyre (N);

25

k elastic constant of rear wheel 6 tyre (N/m);

Δx downward displacement of frame 4 caused by driver mounting the vehicle.

Assuming driver gravitational force F_g and elastic force F_e are equal in the balanced condition, this gives equation [3].

$$[3] \quad F_g = F_e \Rightarrow m \cdot g = k \cdot \Delta x \Rightarrow k = \frac{m \cdot g}{\Delta x}$$

The angular frequency ω and frequency f of vertical oscillation of frame 4 with respect to road surface 2 are given by equations [4] and [5] below.

$$[4] \quad \omega = \sqrt{\frac{k}{m}}$$

$$[5] \quad f = \frac{\omega}{2 \cdot \pi} = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{k}{m}}$$

- 15 ω angular frequency of vertical oscillation of frame 4 (rad/sec);
- k elastic constant of rear wheel 6 tyre (N/m);
- m total weight (kg);
- f frequency of vertical oscillation of frame 4
- 20 (Hz).

Substituting in equation [5] the elastic constant k expression in equation [3] gives equation [6] below.

$$[6] \quad f = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{k}{m}} = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{1}{m} \cdot \frac{m \cdot g}{\Delta x}} = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{g}{\Delta x}}$$

The manned-vehicle oscillation wavelength of frame 4 is given by equation [7] below. Substituting in equation [7] the vertical oscillation frequency f

expression in equation [6] gives equation [8].

$$[7] \quad \lambda = \frac{v}{f} = \frac{v}{\frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{g}{\Delta x}}}$$

$$5 \quad [8] \quad \lambda = \frac{v}{f} = \frac{v}{\frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{g}{\Delta x}}}$$

λ manned-vehicle vertical oscillation wavelength
of frame 4 (m);

v travelling speed of vehicle 3 along the
10 measuring path (m/sec).

Using equation [8], the vertical oscillation wavelength λ of frame 4 can be calculated accurately enough to ensure it is actually suitably higher than the
15 maximum macroroughness wavelength. The vertical oscillation wavelength λ of frame 4 is normally increased by increasing the travelling speed v of vehicle 3 along the measuring path, increasing driver weight (using heavyweight drivers), or reducing the
20 inflation pressure of the rear wheel 6 tyre, but in some cases may even be increased using a more elastic rear wheel 6 tyre (even one specially made for this application).

With a roughly 1 mm interval between consecutive
25 distance D measurements, measuring system 1 is capable of measuring macroroughness of road surface 2 with a horizontal wavelength λ of 0.5 to 50 mm (with a 1 mm

measuring interval and a maximum 3 kHz measuring frequency of laser distance measuring device 11, the maximum travelling speed v of vehicle 3 along the measuring path is 3 m/s). Using a higher-performance
5 laser distance measuring device 11 (essentially capable of operating at a higher maximum measuring rate), the measuring interval can be reduced considerably, even to as little as roughly 0.1-0.3 mm (provided the spot of laser distance measuring device 11 is less than 0.1 mm
10 in diameter), thus enabling measuring system 1 to also measure microroughness of road surface 2 with a horizontal wavelength λ of less than 0.5 mm.

In a preferred embodiment shown in Figure 1, control unit 8 is connected to a high-resolution (less
15 than 0.5 metres) satellite positioning device (or GPS) 15, which gives the instantaneous position of vehicle 3 in geographic coordinates. When measuring distances D , some of them (e.g. one every 500, i.e. one every 0.5 metres) are associated by control unit 8 not only with
20 the corresponding positions X along the measuring path, but also with the corresponding positions in geographic coordinates, so distances D can be overlaid on a geographic reference map to accurately determine the roughness of road surface 2 at major points (e.g. the
25 start of a particular bend on a car race track).

In the Figure 1 embodiment, control unit 8 is connected to a digital camera 16 with a lens aimed vertically downwards onto road surface 2. When measuring

distances D , digital camera 16 is activated cyclically to acquire digital photographic images of road surface 2 visually documenting the condition and conformation of road surface 2. Each digital photographic image acquired by digital camera 16 is associated by control unit 8 with the corresponding position X along the measuring path and/or the corresponding position in geographic coordinates, so as to accurately associate the digital photographic image with the measuring path. The digital photographic image acquisition rate can be varied to acquire more images of more critical points (e.g. the start of tight bends on a car race track), and fewer images of less critical points (e.g. the centre straight of a car race track). Digital photographic images are important, by possibly showing the presence on road surface 2 of extraneous material (i.e. 'fouling', such as soil, sand, gravel, or crash debris). In fact, an area in which anomalous roughness of road surface 2 is recorded may actually have asphalt defects (a permanent situation requiring long-term work) or simply be 'fouled' (a temporary situation that is soon remedied).

In the Figure 1 embodiment, vehicle 3 is equipped with one laser distance measuring device 11 for measuring distances D with respect to road surface 2 along one trajectory of the measuring path. In a different embodiment, vehicle 3 is equipped with two or more (even as many as four to six) laser distance measuring devices 11 for measuring distances D with

respect to road surface 2 along two or more parallel, side by side trajectories of the measuring path.

In the embodiment shown in the drawings, vehicle 3 is run along the measuring path by a driver. In a different embodiment (typically, when the measuring path extends along a known, controlled location, such as a car race track), vehicle 3 may be driven along the measuring path automatically (autonomously or remote controlled by radio), e.g. using the measuring path position X data supplied by angular position sensor 13 and/or the geographic position data supplied by satellite positioning device 15; in which case, vehicle 3 may be equipped with one or more television cameras to detect any obstacles in its path.

In another embodiment, vehicle 3 may be operated automatically (i.e. unmanned) to accurately determine the microroughness of a small area (e.g. no more than 0.5 m^2) of road surface 2; in which case, laser distance measuring device 11 is mounted on a slide, which runs along a straight, low-friction guide and is powered by a highly precise, low-noise motor with negative feedback from a high-resolution (submicron) optical rule, all fitted crosswise to the travelling direction of vehicle 3. After making one transverse scan with a measuring interval of less than 0.01 mm, laser distance measuring device 11 returns to its original position; vehicle 3 is moved forward automatically by a distance of less than a millimetre; and another crosswise scan is made, as part

of a synchronized process, controlled entirely by processing unit 14, to measure a targeted area of typically 200 x 200 mm. In a survey of this type, the distance D transverse measuring interval is very small
5 (e.g. roughly 0.01-0.1 mm) to accurately determine the microroughness of road surface 2.

It should be stressed that measuring system 1 described does not depend on the actual design of vehicle 3, which may differ entirely from the tricycle-
10 type vehicle 3 in the drawings. In other words, control unit 8, laser distance measuring device 11, angular position sensor 13, satellite positioning device 15, and digital camera 16 may easily be installed on any type of vehicle, once roll and radial resonance of the vehicle
15 are determined.

System 1 described for measuring the roughness of road surface 2 has numerous advantages.

In particular, it provides for measuring the roughness of road surface 2 quickly and accurately.

20 Vehicle 3 is designed to eliminate any significant rolling when cornering (especially at the low travelling speed of vehicle 3 along the measuring path), thus preventing any change in the vertical position of laser distance measuring device 11 when cornering, and so
25 ensuring a high degree of measuring precision, even around average and tight bends.

Measuring system 1 described is cheap and easy to produce: vehicle 3 is an ordinary commercial electric

tricycle, and the equipment installed (laser distance measuring device 11 and angular position sensor 13) is also readily available on the market and relatively cheap.

5 Measuring system 1 described is compact, lightweight, and easily transportable, even by air, which is an important feature in the case of car race tracks located all over the world.

CLAIMS

1) A measuring system (1) for measuring the roughness of a road surface (2); the measuring system (1) comprising:

5 a vehicle (3) which moves along a measuring path on the road surface (2); and

a first measuring device (11) mounted in a fixed vertical position on the vehicle (3) and aimed vertically towards the road surface (2) to measure the
10 distance (D) with respect to the road surface (2);

the measuring system (1) being **characterized by** comprising:

a second measuring device (13) for measuring travel of the vehicle (3) along the measuring path; and

15 a control unit (8), which controls the first measuring device (11) as a function of the travel of the vehicle (3) along the measuring path, to measure the distance (D) with respect to the road surface (2) at predetermined, strictly constant measuring intervals.

20 2) A measuring system (1) as claimed in Claim 1, and comprising a processing unit (14), which applies to the distance (D) measuring sequence a space-domain high-pass filter, which eliminates signals with a wavelength above a predetermined filtration threshold.

25 3) A measuring system (1) as claimed in Claim 2, wherein the predetermined filtration threshold is above the maximum macroroughness wavelength and below the wavelength (λ) of vertical oscillation of a frame (4) of

the vehicle (3) with respect to the road surface (2).

4) A measuring system (1) as claimed in Claim 2 or 3, wherein the frame (4) of the vehicle (3) oscillates vertically with respect to the road surface (2) with a
5 vertical-oscillation wavelength (λ) higher than the maximum macroroughness wavelength.

5) A measuring system (1) as claimed in Claim 4, wherein the natural frequency (f) of vertical oscillation of the frame (4) of the vehicle (3), and the
10 travelling speed (v) of the vehicle (3) are recorded so that the wavelength (λ) of vertical oscillation of the frame (4) of the vehicle (3) is adequately higher than the maximum macroroughness wavelength.

6) A measuring system (1) as claimed in one of
15 Claims 3 to 5, wherein the natural frequency (f) of vertical oscillation of the frame (4) of the vehicle (3) is determined as a function of downward displacement (Δx) of the frame (4) caused by passage from the unloaded to the loaded condition, and which is
20 determined by the first measuring device (11) when the vehicle (3) is stationary.

7) A measuring system (1) as claimed in one of Claims 1 to 6, wherein the second measuring device (13) is an angular position sensor (13) integral with a wheel
25 (6) of the vehicle (3).

8) A measuring system (1) as claimed in one of Claims 1 to 7, wherein the control unit (8) controls the motor (7) of the vehicle (3) so that the travelling

speed (v) of the vehicle (3) along the measuring path is always below a maximum speed equal to the product of the measuring interval and the maximum measuring rate of the first measuring device (11).

5 9) A measuring system (1) as claimed in one of Claims 1 to 8, wherein the vehicle (3) is a motor vehicle in the form of a tricycle, and comprises:

 a frame (4);
 two front direction wheels (5);
10 one rear drive wheel (6);
 a central electric motor (7); and
 a saddle (10) located at the rear, substantially over the rear wheel (6).

 10) A measuring system (1) as claimed in Claim 9,
15 wherein a supporting bracket (12) is connected to and projects from the frame (4), extends over the rear wheel (6), and is fitted on the end with the first measuring device (11) which is located behind the rear wheel (6).

 11) A measuring system (1) as claimed in one of
20 Claims 1 to 10, wherein the first measuring device (11) is located behind a rear wheel (6) of the vehicle (3).

 12) A measuring system (1) as claimed in one of Claims 1 to 11, wherein each distance (D) with respect to the road surface (2) is associated by the control
25 unit (8) with a corresponding position (X), determined by the second measuring device (13), along the measuring path.

 13) A measuring system (1) as claimed in one of

Claims 1 to 12, and comprising a satellite positioning device (15), which gives the instantaneous position of the vehicle (3) in geographic coordinates, to associate respective positions, expressed in geographic
5 coordinates and determined by the satellite positioning device (15), to at least some distances (D) with respect to the road surface (2).

14) A measuring system (1) as claimed in Claim 13, wherein each digital photographic image acquired by a
10 digital camera (16) is associated by the control unit (8) with the corresponding position (X) along the measuring path and/or the corresponding position in geographic coordinates.

15) A method of measuring the roughness of a road
15 surface (2); the method comprising the steps of:

moving a vehicle (3) along a measuring path on the road surface (2); and

measuring the distance (D) with respect to the road surface (2) by means of a first measuring device (11)
20 mounted in a fixed vertical position on the vehicle (3) and aimed vertically towards the road surface (2);

the method being **characterized by** comprising the further steps of:

measuring travel of the vehicle (3) along the
25 measuring path by means of a second measuring device (13); and

by means of a control unit (8), controlling the first measuring device (11) as a function of the travel

of the vehicle (3) along the measuring path, to measure the distance (D) with respect to the road surface (2) at predetermined, strictly constant measuring intervals.

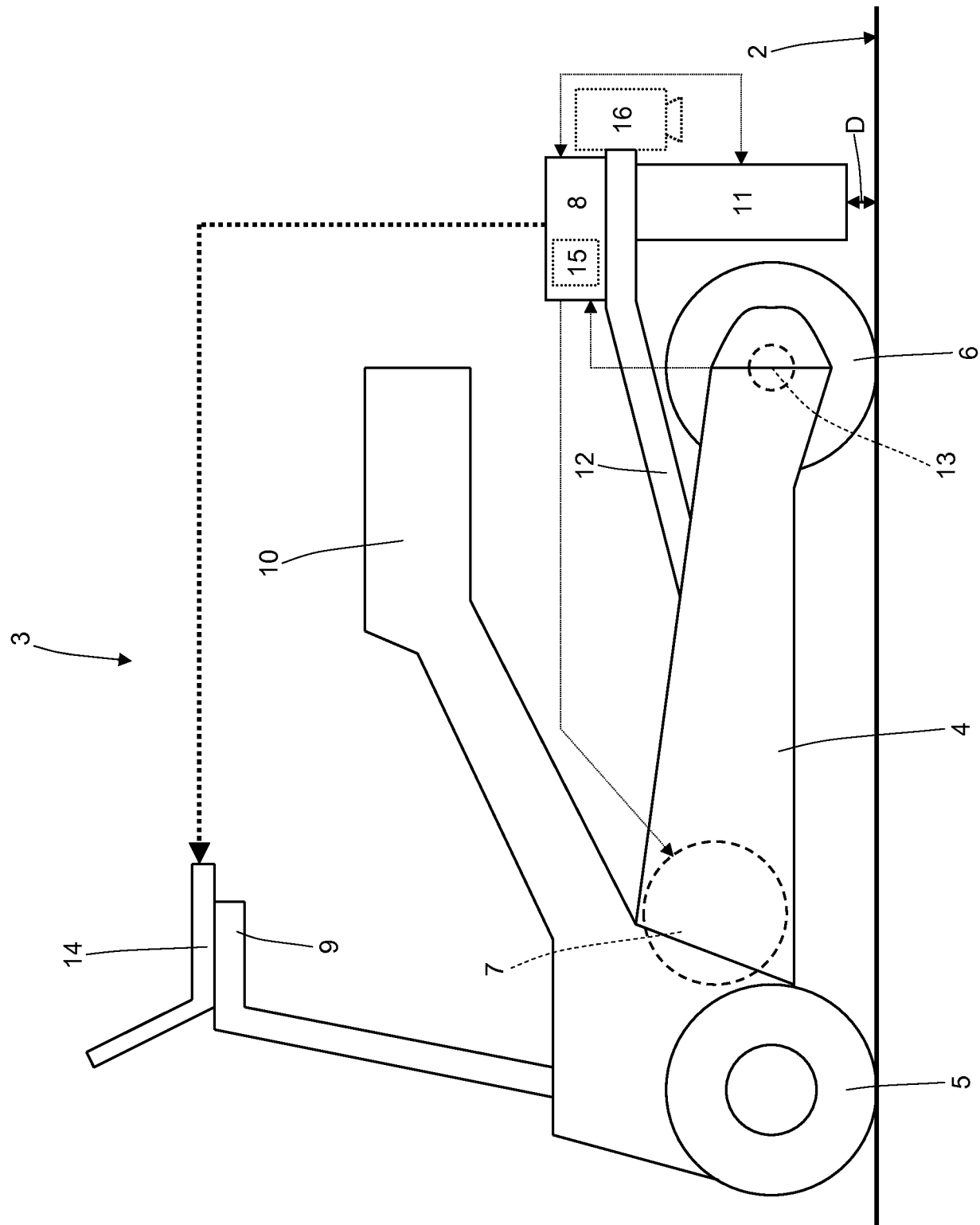


Fig. 1

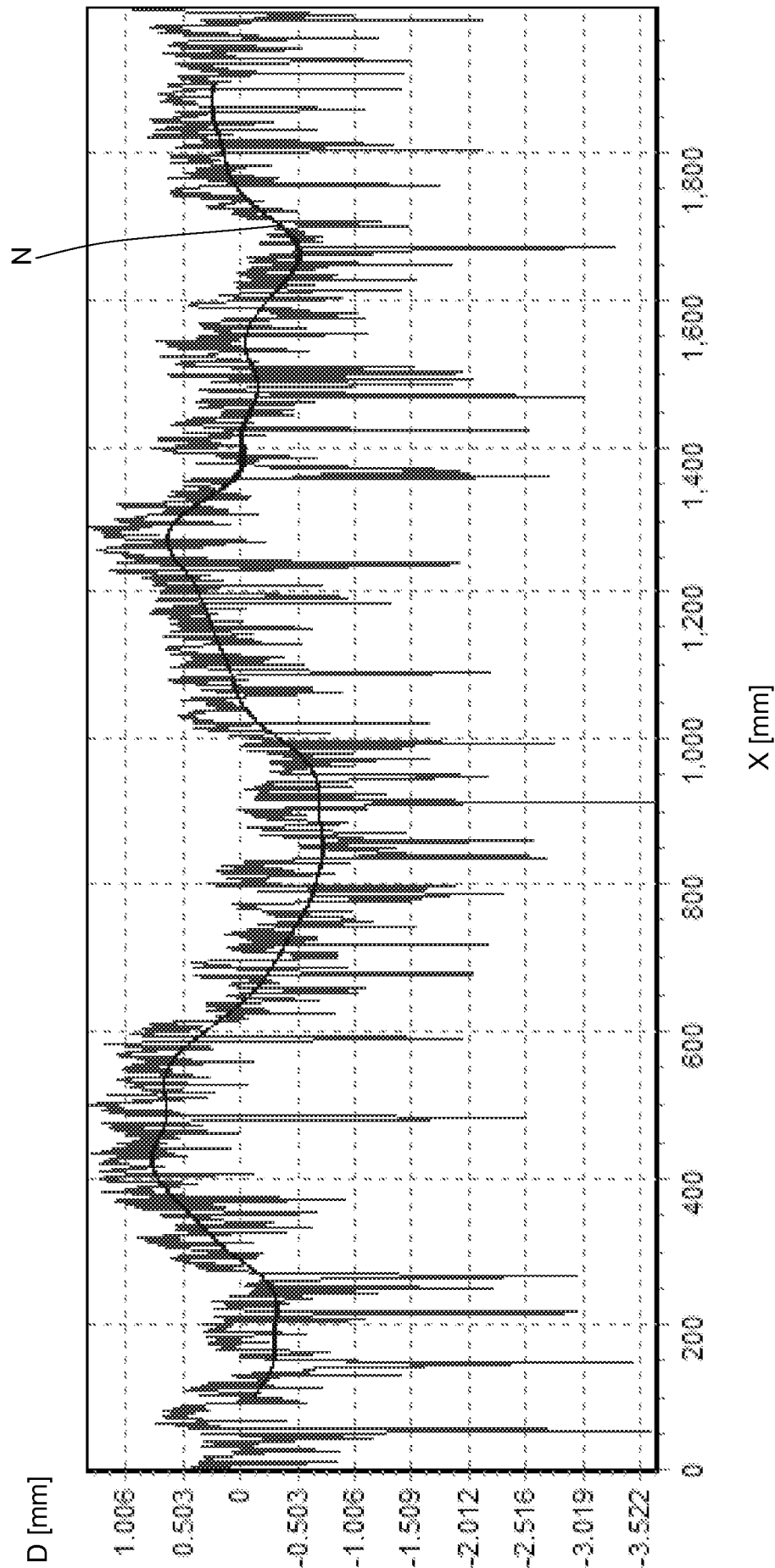


Fig. 2

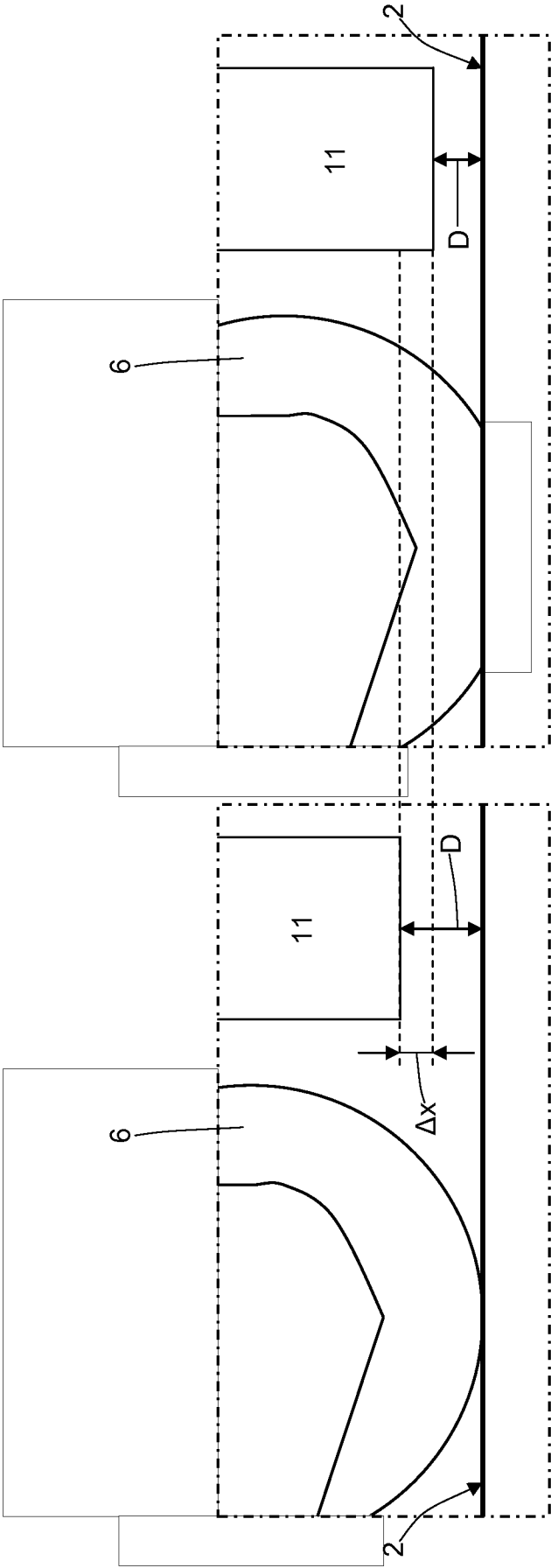


Fig. 3b

Fig. 3a

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/053797

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01B11/02 G01B11/30 E01C23/01 G01C7/04
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)

G01B E01C G01C B61K E01B

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 practical, 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 4 422 322 A (SPANGLER ELSON B [US]) 27 December 1983 (1983-12-27)	1,2,4-15
Y	column 3, line 15 - column 5, line 49; figures 1-3	3

X	DE 100 03 675 A1 (FRAUNHOFER GES FORSCHUNG [DE]) 9 August 2001 (2001-08-09)	1-15
	column 2, line 64 - column 4, line 55; figures 1-6	

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A	column 3, line 60 - column 5, line 18; figures 1-3D	1,2,4-15

A	US 6 682 261 B1 (KARAMIHAS STEVEN M [US] ET AL) 27 January 2004 (2004-01-27)	1-15
	column 3, line 19 - line 64; figures 2,4,5	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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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

Petelski, Torsten

INTERNATIONAL SEARCH REPORT

Information on patent family members

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