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Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

— *of inventorship (Rule 4.17(iv))*

[Continued on next page]

(54) Title: ARRANGEMENT AND METHOD FOR DETERMINING POSITIONS OF THE TEATS OF A MILKING ANIMAL

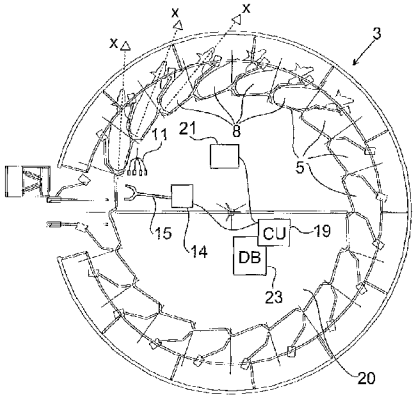

Fig. 1

(57) Abstract: An arrangement is provided for determining positions of the teats of an animal (8) in a milking system (3) comprising a milking stall (5) for housing the animal during milking, a movable robot arm (15) for automatically attaching teat cups (11) to the teats of the animal, and a control device (19) for controlling the movement of the robot arm based on determined positions of the teats of the milking animal. The arrangement comprises light emitting means (25) provided for emitting light pulses towards the udder of the milking animal; a shutter (27) arranged to allow at least one of the light pulses to pass through the shutter in its entirety after having been reflected by the udder of the milking animal and to allow a portion only of at least one of the light pulses to pass through the shutter after having been reflected by the udder of the milking animal; a two-dimensional camera array (26) for detecting the light pulses two-dimensionally after having passed through the shutter; and image processing means (28) for forming a three- dimensional image of the udder of the milking animal from the two-dimensional detections; and for detecting the teats of the milking animal and determining their positions in all three spatial dimensions based on the formed three-dimensional image.

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ARRANGEMENT AND METHOD FOR DETERMINING POSITIONS OF THE TEATS OF A MILKING ANIMAL

TECHNICAL FIELD OF THE INVENTION

The present invention generally relates to dairy farm robot milking and to automatic attachment of teat cups related thereto.

DESCRIPTION OF RELATED ART AND BACKGROUND OF THE INVENTION

WO 2009/093967 discloses an arrangement for determining positions of the teats of a milking animal in a milking system comprising a milking stall for housing the animal during milking, a movable robot arm for automatically attaching teat cups to the teats of the animal, and a control device for controlling the movement of the robot arm based on determined positions of the teats of the animal. The arrangement comprises a three-dimensional time-of-flight camera provided to repeatedly record three-dimensional images of the udder of the animal in real time and image processing means provided for repeatedly detecting the teats of the animal and determining their positions based on the repeatedly recorded three-dimensional images.

SUMMARY OF THE INVENTION

A drawback of the time-of-flight camera is that the calculations of the distance information is complex and requires high process capacity.

A further limitation of the time-of-flight camera is that it requires a dedicated camera chip which means that an ordinary CCD camera cannot be used. As a result the time-of-flight camera becomes costly.

Accordingly, it is an object of the present invention to provide an arrangement and a method for determining positions of the teats of a milking animal in a milking system comprising a

milking stall for housing the milking animal during milking, a movable robot arm for automatically attaching teat cups to the teats of the milking animal in the milking stall, and a control device for controlling the movement of the robot arm based on determined positions of the teats of the milking animal, which arrangement and method alleviates or mitigates at least some of the problems and drawbacks of the prior art as set forward above.

It is a particular object of the invention to provide such an arrangement and such a method, which can use an ordinary two-dimensional camera such as a CCD camera.

It is a further object of the invention to provide such an arrangement and such a method, which are robust, effective, fast, precise, accurate, reliable, safe, easy to use, and of low cost.

It is still a further object of the invention to provide such an arrangement and such a method, which are capable of obtaining a very high number of correct teat cup attachments.

These objects among others are, according to the present invention, attained by arrangements and methods as claimed in the appended patent claims.

According to one aspect of the invention an arrangement for determining positions of the teats of a milking animal is provided in a milking system comprising light emitting means, a shutter, a two-dimensional camera array, and image processing means. The light emitting means is provided for emitting light pulses towards the udder of the milking animal. The shutter is arranged to allow one or several light pulses to pass through the shutter in its/their entirety after having been reflected by the udder of the milking animal and to allow a portion only of one or each of several light pulses to pass through the shutter after having been reflected by the udder of the milking animal. The two-dimensional camera array such as e.g. an ordinary CCD array is arranged behind the shutter and is

provided for detecting the light pulses two-dimensionally after having passed through the shutter. The image processing means is provided for forming a three-dimensional image of the udder of the milking animal from the two-dimensional detections and for detecting the teats of the milking animal and determining their positions in all three spatial dimensions from the formed three-dimensional image.

By such arrangement the control device may control the robot arm very fast and accurately. The image recordings and the subsequent processing of the measurement data provide high quality information extremely fast and as a result the milking system is capable of operating at higher speed. The milking time will be shorter and the throughput of animals is increased. An ordinary CCD chip camera can be used.

The three-dimensional image of the udder of the milking animal is a two-dimensional image, e.g. a color image if the two-dimensional camera array provides color images, wherein for each of the pixels of the two-dimensional image the distance between the two-dimensional camera array and the imaged object point is provided. The two-dimensional image is obtained from two-dimensional detection(s) of the one or several light pulses which is/are passed through the shutter in its/their entirety. The distance between the two-dimensional camera array and the imaged object is, for each pixel, determined based on the ratio of the respective pixel intensity from the two-dimensional detection(s) of said portion(s) only of the one or several light pulses which is/are passed through the shutter and the respective pixel intensity from the two-dimensional detection(s) of the one or several light pulses which is/are passed through the shutter in its/their entirety.

Additionally, the distance between the two-dimensional camera array and the imaged object may be determined based on a time

delay between the emissions of the light pulses and the operation of the shutter.

In one embodiment the inventive arrangement is implemented in a rotary milking system, wherein the two-dimensional camera array and the shutter are preferably located at a fix position with respect to a floor, on which the rotary milking system is installed and with respect to which a rotary platform of the rotary milking system rotates during milking. By such provisions a single inventive arrangement can serve several or all of the milking stalls of the rotary milking system. The fast operation of the inventive arrangement is required since the milking stalls are moving (rotating) with respect to the inventive arrangement.

In another embodiment of the invention the two-dimensional camera array and the shutter are mounted on the movable robot arm and the image processing means determines the positions of the teats of the milking animal in all three spatial dimensions relative the movable robot arm. Additionally positions for other objects such as legs, udders, bodies, magazines, and teats can be determined by the inventive arrangement.

In still another embodiment of the invention the two-dimensional camera array and the shutter are mounted in a fixed position with respect to the milking stall and the image processing means determines the positions of the teats of the milking animal in all three spatial dimensions relative the milking stall.

Further embodiments of the inventive arrangement are set out in the dependent claims.

According to a second aspect of the invention a method for determining positions of the teats of a milking animal is provided. According to the method light pulses are emitted towards the udder of the milking animal. One or several light

pulses is/are allowed to pass through a shutter in its/their entirety after having been reflected by the udder of the milking animal and a portion only of one or each of several light pulses is allowed to pass through the shutter after having been reflected by the udder of the milking animal. The light pulses are detected two-dimensionally e.g. by a CCD camera after having passed through the shutter. A three-dimensional image of the udder of the milking animal is formed from the two-dimensional detections, and the teats of the milking animal are detected and their positions are determined in all three spatial dimensions based on the formed three-dimensional image.

Further characteristics of the invention, and advantages thereof, will be evident from the following detailed description of preferred embodiments of the present invention given hereinafter and the accompanying Figs. 1-3, which are given by way of illustration only, and are thus not limitative of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 displays in a top view a schematically outlined milking system including an arrangement for determining positions of the teats of a milking animal according to a respective embodiment of the present invention. Figs. 1 and 3 are top views while Fig. 2 is a perspective view.

Fig. 2 illustrates the inventive arrangement in greater detail.

Figs. 3a-b shows the light pulse before (Fig. 3a) and after (Fig. 3b) having been reflected against an object to be imaged three-dimensionally. Exposure time windows according to the invention are illustrated in Fig. 3b.

DETAILED DESCRIPTION OF EMBODIMENTS

In Fig. 1 is shown a milking system, in which an arrangement for determining positions of the teats of milking animals according to an embodiment of the invention is implemented. The rotary milking system 3 comprises a plurality of milking stalls 5, which milking animals 8 enter in a sequential order. Each of the milking stalls 5 comprises milking equipment including teat cups that are attached to the teats of the milking animal present in the milking stall prior to milking. For sake of simplicity teat cups 11 are illustrated only for one of the milking stalls 5. The rotary milking system 3 may be of parallel, tandem, or herringbone configuration. In the parallel configuration the longitudinal directions of the milking stalls and of the milking animals therein extend radially (the milking animals stand side by side), in the tandem configuration the longitudinal directions of the milking stalls and of the milking animals therein extend circumferentially (the milking animals stand one after the other), and in the herringbone configuration, which is illustrated in Fig. 1, the longitudinal directions x of the milking stalls and of the milking animals therein extends partly radially, partly circumferentially.

A robot 14 provided with a robot arm 15 is provided for automatically attaching teat cups 11 to the teats of the milking animals 8 present in the milking stalls 5 under the control of a control device 19, which is operatively connected to the milking robot 14. The milking robot 14 is preferably stationary with respect to a rotatable carousel or rotating platform 20 of the rotary milking system 3, which forms the support for the milking stalls 5. Alternatively, the milking robot 14 is movable back and forth in e.g. a circumferential direction.

The rotating platform 20 may, for each of the milking animals, be kept still while the milking robot 14 automatically attaches teat cups 11 to the teats of the milking animal 8, and is rotated there in between. Alternatively, the rotating platform

is rotated continuously during the attachment of the teat cups and the milking of the milking animals 8.

In order to determine positions of the teats of the milking animals 8 present in the milking stalls 5, and thus be capable of moving the teat cups 11 to the teats of the milking animal, an arrangement 21 is provided.

The arrangement 21 is illustrated in greater detail in Fig. 2 and comprises light emitting means 25, a two-dimensional camera array 26, a shutter 27 located in front of the two-dimensional camera array 26, control and process means 28 for controlling the light emitting means 25, the two-dimensional camera array 26, and the shutter 27, and for processing detected two-dimensional images, and suitable optics 29 e.g. including a mirror 29a, a beam splitter 29b, a lens arrangement 29c, and a filter 29d.

The light emitting means 25 is controlled to emit identical, preferably rectangular, light pulses towards the udder of the milking animal, one after the other. The light emitting means 25 may be a laser emitting laser pulses. The length l of and the distance d between the pulses as indicated in Fig. 3a are typically related to the range of the distances between the object imaged and the two-dimensional camera array 26 that is desired. Typical values for the pulse length l and the inter pulse distance d may be 2 meters.

The shutter 27 is controlled to allow one or preferably several light pulses to pass through the shutter 27 in its/their entirety after having been reflected by the udder of the milking animal. This may be achieved by operating the shutter 27 for each light pulse or by keeping the shutter open during the passage of the light pulses. The two-dimensional camera array 26, which is arranged behind the shutter 27, is in a first detection controlled to detect the light pulses two-dimensionally after having passed through the shutter 27.

Typically, thousands of light pulses are allowed to pass through the shutter 27 in their entirety after having been reflected by the udder of the milking animal and are subsequently detected by the two-dimensional camera array 26.

Next, the shutter 27 is controlled to allow a portion only of one or preferably each of several light pulses to pass through the shutter 27 after having been reflected by the udder of the milking animal. Typically the shutter 27 is synchronized to open such that only a latter part of each of the light pulses is allowed to pass through the shutter 27. In Fig. 3b the open shutter windows are illustrated with respect to several light pulses reflected at an object to be imaged. The distortion of the reflected light pulses is illustrated. The two-dimensional camera array 26 is in a second detection arranged to detect the portions of the light pulses two-dimensionally after having passed through the shutter 27. Typically, thousands of light pulses are cut by the shutter and are allowed to pass through the shutter 27 only in part after having been reflected by the udder of the milking animal and are subsequently detected by the two-dimensional camera array 26.

The control and process means 28 is arranged to form a three-dimensional image of the udder of the milking animal from the first and second two-dimensional detections, that is, to form a two-dimensional image, e.g. a color image if the two-dimensional camera array 26 provides color images, wherein for each of the pixels of the two-dimensional image the distance between the two-dimensional camera array 26 and the imaged object is provided.

The two-dimensional image is obtained from the first two-dimensional detection and the distance between the two-dimensional camera array 26 and the imaged object is, for each pixel, determined based on the ratio of the respective pixel intensity from the second two-dimensional detection and the

respective pixel intensity from the first two-dimensional detection and in addition optionally from the time delay between the emissions of the light pulses and the operation of the shutter 27. If the time delay between the emission of the light pulses and the operation of the shutter 27 is used absolute distance values are obtainable and if the time delay is not used relative distance values are obtainable.

The less light that is detected in a pixel in the second two-dimensional detection, the closer the imaged object point is to the two-dimensional camera array 26, and vice versa. If the above ratio for a pixel is zero this means that the distance between the imaged object point and the two-dimensional camera array 26 is equal to or less than a shortest detectable distance (for the light pulses used) and if the above ratio for a pixel is one this means that the distance between the imaged object point and the two-dimensional camera array 26 is equal to or larger than a longest detectable distance (for the light pulses used). The longer light pulses used, the larger distance range is detectable. The light pulses are preferably well defined in order to obtain high resolution in the distance determination.

Finally, the control and process means 28 is arranged to detect the teats of the milking animal and to determine their positions in all three spatial dimensions by a suitable image calculation method in the field of digital image processing based on the formed three-dimensional image.

Preferably, the three-dimensional image is previously filtered such that all pixels having the above ratio equal to zero or one are removed from the three-dimensional image. Alternatively, all pixels having the above ratio outside a suitable range are removed from the three-dimensional image. Such range may be e.g. 0.2-0.8 and may depend on the distance

between the two-dimensional camera array 26 and the imaged object.

The above detections, formation of a three-dimensional image, and teat detection and location are preferably repeated during the attachment of teat cups to the teat of a milking animal.

The control and process means 28 is preferably a stand alone device, but it may be implemented as a software module in the control device 19 or in any other device.

The two-dimensional camera array 26 and the shutter 27 can be mounted in fixed positions with respect to the different parts of the milking system 3 depending on the application in question. The two-dimensional camera array 26 and the shutter 27 can be located at a fix position with respect to a floor, on which the rotary milking system 3 is installed and with respect to which the rotary platform 20 of the rotary milking system 3 rotates during milking. In such instance, the two-dimensional camera array 26 and the shutter 27 may be mounted in a ceiling of a building in which the milking system is installed. Alternatively, the two-dimensional camera array 26 and the shutter 27 are mounted on the rotating platform 20 or on the robot arm 15. Still alternatively, the two-dimensional camera array 26 and the shutter 27 are movable along some path.

In one embodiment the two-dimensional camera array and the shutter are stationary arranged with respect to the milking stall, a visual teat sensing means is arranged on the movable robot arm, and the control device is provided for controlling the movement of the robot arm in order to attach the teat cups to the teats of the milking animal in a two-stage procedure.

During a first stage the robot arm is controlled to move to an approximate position for attachment of a teat cup to a teat of the milking animal based on a position of the teat as determined from three-dimensional images formed as disclosed

above. During a second stage the robot arm is controlled to fine adjust its position based on a position of the teat as determined from images recorded by the visual teat sensing means.

The above embodiment is further disclosed in our Swedish patent application No. 0801808-7, the contents of which being hereby incorporated by reference.

It shall be appreciated that the present invention may be implemented in other kind of milking systems such as voluntary milking systems or parallel stall milking systems.

It shall further be appreciated that the present invention may be used in the various embodiments disclosed in the above mentioned WO 2009/093967, the contents of which being hereby incorporated by reference.

CLAIMS

1. An arrangement provided for determining positions of the teats of a milking animal (8) in a milking system (3) comprising a milking stall (5) for housing the milking animal during milking, a movable robot arm (15) for automatically attaching teat cups (11) to the teats of the milking animal in the milking stall, and a control device (19) for controlling the movement of said robot arm based on determined positions of the teats of the milking animal, characterized in that said arrangement comprises:

- light emitting means (25) provided for emitting light pulses towards the udder of the milking animal;

- a shutter (27) arranged to allow at least one of the light pulses to pass through said shutter in its entirety after having been reflected by the udder of the milking animal and to allow a portion only of at least one of light pulses to pass through said shutter after having been reflected by the udder of the milking animal;

- a two-dimensional camera array (26) arranged behind the shutter and provided for detecting the at least one of the light pulses two-dimensionally after having passed through said shutter in its entirety and for detecting said portion of the at least one of the light pulses two-dimensionally after having passed through said shutter; and

- image processing means (28) provided for forming a three-dimensional image of the udder of the milking animal from the two-dimensional detections; and for detecting the teats of the milking animal and determining their positions in all three spatial dimensions based on said formed three-dimensional image.

2. The arrangement of claim 1 wherein said portion of the at least one of the light pulses is a latter portion.

3. The arrangement of claim 1 or 2 wherein

- said three-dimensional image of the udder of the milking animal is a two-dimensional image, wherein for each of the pixels of the two-dimensional image, the distance between the two-dimensional camera array and the imaged object point is provided; and

- the two-dimensional image is obtained from the two-dimensional detection of the at least one of the light pulses after having passed through said shutter in its entirety, and the distance between the two-dimensional camera array and the imaged object is, for each pixel, determined based on the ratio of the respective pixel intensity from the two-dimensional detection of said portion of the at least one of the light pulses and the respective pixel intensity from the two-dimensional detection of the at least one of the light pulses after having passed through said shutter in its entirety.

4. The arrangement of claim 3 wherein the distance between the two-dimensional camera array and the imaged object is, for each pixel, additionally determined based on a time delay between the emission of the light pulses and the operation of the shutter.

5. The arrangement of any of claims 1-4 wherein said arrangement is provided for determining positions of the teats of the milking animal in all three spatial dimensions in a rotary milking system.

6. The arrangement of claim 5 wherein said two-dimensional camera array and said shutter are, during the two-dimensional detections, located at a fix position with respect to a floor, on which said rotary milking system is installed and with respect

to which a rotary platform of said rotary milking system rotates during milking.

7. The arrangement of any of claims 1-5 wherein

- said two-dimensional camera array and said shutter are mounted on said movable robot arm; and

- said image processing means is provided for determining the positions of the teats of the milking animal in all three spatial dimensions relative said movable robot arm.

8. The arrangement of any of claims 1-5 wherein

- said two-dimensional camera array and said shutter are mounted in a fixed position with respect to said milking stall; and

- said image processing means is provided for determining the positions of the teats of the milking animal in all three spatial dimensions relative said milking stall.

9. The arrangement of claim 8 comprising a visual teat sensing means arranged on the robot arm.

10. A milking system (3) comprising a milking stall (5) for housing the milking animal during milking; a movable robot arm (15) for automatically attaching teat cups to the teats of a milking animal in the milking stall; a control device (19) for controlling the movement of said robot arm based on determined positions of the teats of the milking animal; and the arrangement of any of claims 1-9.

11. A method for determining positions of the teats of a milking animal (8) in a milking system (3) comprising a milking stall (5) for housing the milking animal during milking, a movable robot arm (15) for automatically attaching teat cups to the teats of the milking animal in the milking stall, and a

control device (19) for controlling the movement of said robot arm based on determined positions of the teats of the milking animal, said method being characterized by the steps of:

- by means of light emitting means (25) emitting light pulses towards the udder of the milking animal;

- allowing at least one of the light pulses to pass through a shutter (27) in its entirety after having been reflected by the udder of the milking animal and allowing a portion only of at least one of the light pulses to pass through said shutter after having been reflected by the udder of the milking animal;

- by means of a two-dimensional camera array (26) detecting the at least one of the light pulses two-dimensionally after having passed through said shutter in its entirety and detecting said portion of the at least one of the light pulses two-dimensionally after having passed through said shutter; and

- by means of image processing means (28) forming a three-dimensional image of the udder of the milking animal from the two-dimensional detections; and detecting the teats of the milking animal and determining their positions in all three spatial dimensions based on said formed three-dimensional image.

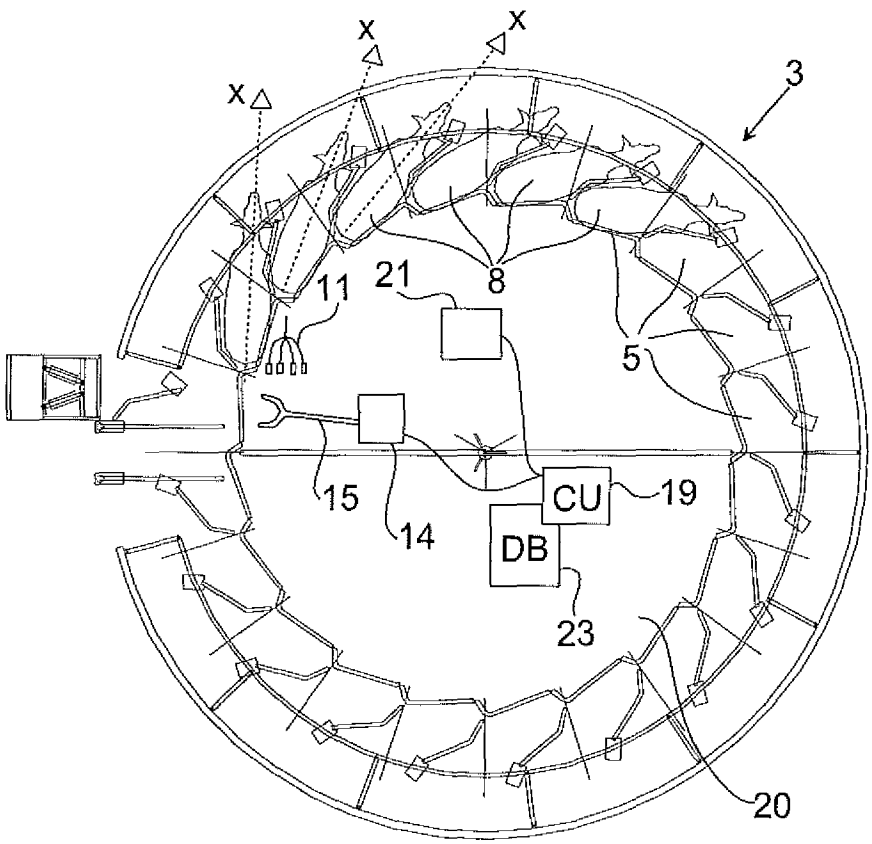
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Fig. 1

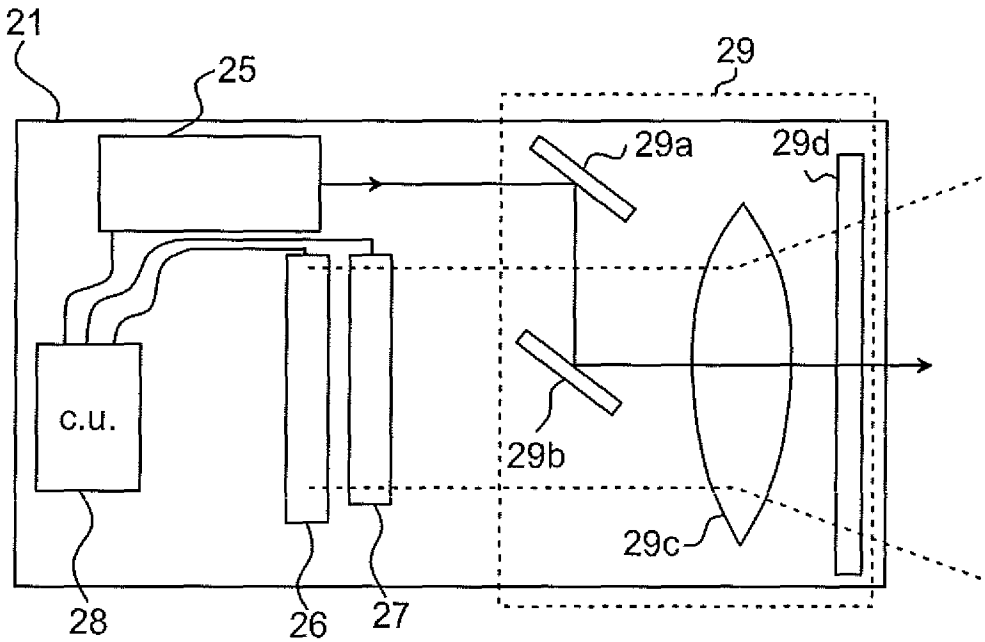
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Fig. 2

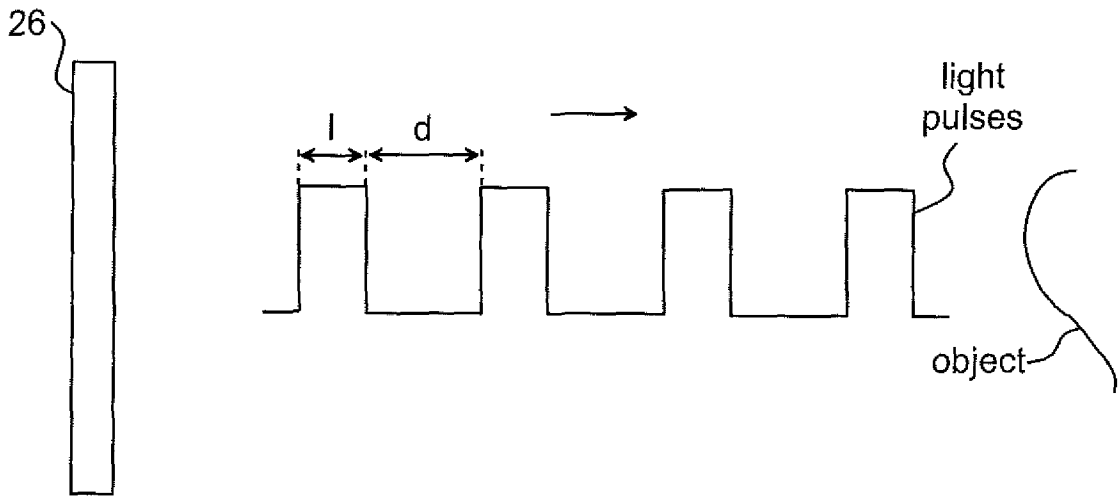
26
l
d
light
pulses
object

Fig. 3a

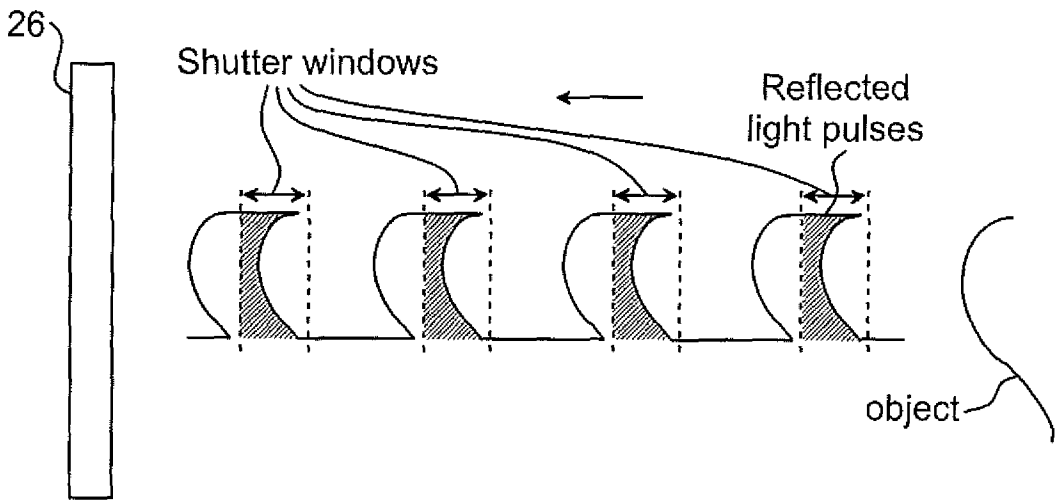
26
Shutter windows
Reflected
light pulses
object

Fig. 3b

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2010/050944

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet
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)

IPC: A01J, A01K, G06T, H04N

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ, INSPEC, NORDIC MATERIAL, INTERNET

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2009093965 A1 (DELAVAL HOLDING AB), 30 July 2009 (30.07.2009), page 2, line 17 - line 23; page 3, line 7 - line 10; page 9, line 29 - page 11, line 11, abstract --	1-11
A	US 7490576 B2 (L. METCALFE ET AL), 17 February 2009 (17.02.2009), whole document --	1-11
A	WO 2007050012 A1 (DELAVAL HOLDING AB), 3 May 2007 (03.05.2007), whole document --	1-11

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 December 2010	28 -12- 2010
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Per Nilsson / JA A Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2010/050944

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9715901 A1 (TETRA LAVAL HOLDINGS AND FINANCE S.A.), 1 May 1997 (01.05.1997), whole document ---	1-11
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International patent classification (IPC)

A01J 5/017 (2006.01)
A01K 1/12 (2006.01)
G06T 7/00 (2006.01)
H04N 13/00 (2006.01)

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