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(54) Benævnelse: **FREMGANGSMÅDE TIL KONSTRUKTION AF EN RESTAURERING**

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# Method for constructing a restoration

Description

Technical field

The invention relates to a method for constructing a restoration, wherein a dental camera is used to measure a dental situation and a 3D model of the dental situation is generated.

Prior art

Several methods for planning restorations are known from the prior art, wherein the user needs to manually determine the restoration type and needs to specify the tooth number of the restoration to be produced.

A disadvantage of this method is that the user can select an incorrect tooth type or an incorrect tooth number for the restoration to be produced, so that defective restorations can result.

US 2012/0239364 A1 discloses a method for the automated planning of a dental implant, wherein a 3D model of the numerical situation is analysed and zones in the jaw for the insertion of possible implants are determined. The dimensions, position and orientation of the implants are then determined. A tooth number can be determined based on a tooth width, for example.

WO 98/15234 A1 discloses a method for diagnosing a dental situation, wherein a dentist or a computer selects a suitable inlay, onlay or crown for a corresponding preparation.

WO 2018/022752 A1 discloses a method for recognising dental information of a tooth model, wherein a neural network is trained, wherein the trained neural network can automatically generate a model of a suitable restoration, such as a crown, on the basis of the tooth model.

The present invention therefore addresses the problem of providing a method which can automatically determine the tooth type and/or the tooth number of the restoration to be produced.

Description of the invention

The invention relates to a method, according to claim 1, for constructing a restoration, wherein a dental camera is used to measure a dental situation and a 3D model of the dental situation is generated. A computer-aided recognition algorithm is applied to the 3D model of the dental situation, wherein a restoration type is determined automatically.

The restoration can be any restoration that can be produced, for example, using a CAD/CAM process. The dental camera can be any three-dimensional dental camera that is based, for example, on a strip projection method or a confocal measurement method. The dental situation can comprise the immediate surroundings of the restoration to be inserted or also a larger region around the restoration to be inserted. The measurement by means of the dental camera can take place from different directions, such as an occlusal direction, a lingual direction, a buccal direction or a labial direction. The 3D model of the dental situation is generated after measurement by the dental camera. The recognition algorithm is then applied to the 3D model of the dental situation. The recognition algorithm can be based, for example, on an artificial neural network for machine learning or on a template-matching method. After the analysis of the 3D model from the recognition algorithm, the restoration type and/or the tooth number of the at least one tooth for the restoration to be inserted are automatically determined.

One advantage of this method is that the restoration type and tooth number are determined automatically without user interaction. This prevents possible operating errors by the user and shortens the duration of planning a restoration.

The restoration type can advantageously be an inlay, a crown, a bridge, an abutment, a pontic or a veneer.

The bridge can be attached to the jawbone using implants and abutments, for example, or attached to the stumps of neighbouring healthy teeth. The bridge can be fixed or removable. The bridge can also be a base bridge, which consists of a base made of a metal alloy and a structure made of ceramic or a plastic.

An abutment is a supporting pillar that is used as a connection part between a dental implant and a restoration, such as a dental crown. An abutment can be detachably or permanently attached to the implant. Implant abutments can be classified according to the type of manufacture. A distinction is made between ready-made, cast-on, or overpressable and CAD/CAM implant abutments. Prefabricated abutments are offered in various sizes, shapes and angles, as well as versions that can or cannot be ground. One-piece implants have integrated abutments. The abutments produced using a CAD/CAM process can be individually adapted to the given dental situation both in terms of the axial inclination and the shape. Tooth-coloured abutments are used in aesthetic restorations, in particular in the anterior region, so that the visual impression of a natural tooth is imitated as far as possible. Abutments are usually made of titanium or a ceramic.

A veneer is a cover shell made of a thin, translucent ceramic shell, in particular for the front teeth.

An inlay is an inlay filling that is used in a preparation of a tooth. In contrast to plastic filling material, which is inserted into the tooth in a soft consistency using shaping aids and then hardens, the inlay is a precisely fitting workpiece that is adhesively bonded into the preparation of the tooth.
A pontic is a bridge that is adhesively bonded to tooth stumps of healthy adjacent teeth or to implant abutments.
The 3D model of the dental situation is therefore analysed by means of the recognition algorithm to determine one of the restoration types mentioned.
The dental situation has at least one preparation or an implant-supported mesostructure, such as an abutment, for inserting the restoration to be produced.
A mesostructure, such as an abutment, serves as a connecting link between an implant and a restoration, such as a dental crown. A suitable restoration, such as an inlay, a crown, a pontic, or a veneer, can be constructed based on the shape of the preparation. The restoration to be produced is adhesively bonded to fit into the preparation. The 3D model of the dental situation can therefore comprise a preparation or an abutment.
The computer-aided recognition algorithm has an artificial neural network for machine learning (convolutional neural network; CNN), wherein the 3D model of the dental situation is used to analyse the shape of the preparation or of the implant-supported mesostructure and to select a suitable restoration type.
A convolutional neural network (CNN) is a computer algorithm that enables the automatic recognition of the restoration type. A method is explained below using a CNN.
A convolutional neural network (CNN) is a feed-forward artificial neural network. It is a biological process-inspired concept in the field of machine learning. Convolutional neural networks are used in a number of modern artificial intelligence technologies, primarily in the machine processing of image or audio data.
Basically, the structure of a conventional CNN consists of a convolutional layer, followed by a pooling layer. In principle, this unit can be repeated any number of times; if repeated enough, these are known as deep convolutional neural networks, which fall into the field of deep learning.
The CNNs learn from the fact that free parameters or classifiers of the convolution kernel per layer and the weighting thereof are learned when calculating the next layer.
In the first step, the 3D model of the dental situation is recorded using the dental camera. The recording can take place from an occlusal direction, a lingual direction, and/or a labial direction. In the second step, the position of the restoration to be inserted is determined. This can be done manually by the user, for example, in that the user selects the position

of the restoration to be inserted in a graphic representation of the 3D model of the dental situation. The position of the restoration to be inserted can also be determined automatically by determining the recording direction and the centre of the recording region. The position of the restoration to be inserted then corresponds to a position to which the dental camera points during the measurement.
In a further step, an analysis is carried out in a region of the restoration to be inserted, which can comprise a preparation, wherein the 3D model of the dental situation is divided into a plurality of layers, which are termed height fields, from different directions such as an occlusal direction, a mesial direction, a lingual direction, buccal direction and/or a labial direction.
As an alternative to forming a plurality of layers of the 3D model, the height fields of the 3D model can also be formed in that the brightness of each pixel of a height field corresponds to the distance between a surface point of the 3D model relative to a defined position of a virtual camera. Such a height field from an occlusal direction would then contain, for example, dark regions which correspond to surface regions of the 3D model which are arranged further away from the camera, and light regions which correspond to surface regions of the 3D model which are arranged closer to the camera.
The height fields of the 3D model are thus used as an input to the machine learning system, which has been trained using a collection of a plurality of 3D models of different dental situations.
In a further step, the 3D model of the dental situation is analysed using the machine learning system and a suitable restoration type and/or a tooth number of the restoration to be inserted is submitted as output.
Further in the method, a 3D model of the restoration to be inserted can be calculated on the basis of the known 3D model of the dental situation including the shape of the preparation on the basis of the determined restoration type and on the basis of the determined tooth number of the restorations to be inserted. A preparation margin can be determined automatically and structures such as neighbouring teeth, opposing teeth and the shape of the preparation can be taken into account. The restoration can be designed fully automatically.
In the next step, the restoration can be produced fully automatically from a blank by means of a CAM milling machine with the use of the constructed 3D model of the restoration. The method explained has the advantage that the restoration can be produced fully automatically without user interaction.
The machine learning system can consist of one or a plurality of CNN networks.

Colour information of the dental situation can also be used as input for the CNN network. The colour information is then assigned to the surface points of the 3D model of the dental situation.

A method for training or parametrising the machine learning system consisting of one or more CNN networks is explained below. In the first step, a large number of known 3D models of dental situations with a known restoration type and a known tooth number are analysed. Possible input data or entry data are generated. The input data are generated in such a way that all possible degrees of freedom are available in the input data. This is achieved using data augmentation. For this purpose, the 3D models of the dental situations are rotated by the defined degrees of freedom and/or scaled along the degrees of freedom. The individual CNN networks are then applied to the individual 3D data of the individual 3D models of the dental situations to train the CNN networks.

With this method, the CNN networks automatically learn a plurality of 3D models of dental situations with a known restoration type and tooth number using a training set.

As an alternative to using CNN networks, it is also possible to use an alternative method, not according to the invention, from the machine learning/deep learning field on the basis of deep belief networks, in which height fields are also used as input data.

In an alternative not according to the invention, a hybrid method could also be used to analyse the 3D model of the dental situation, wherein manually defined classifiers are defined by a user, wherein the parameters of the defined classifiers are trained using the training set of a large number of known 3D models of several dental situations.

The advantage of a CNN network is that the parameter values of the internal convolution filter and the further processing of the filter outputs are learned along with the analysis of the training set and therefore no further user specification is necessary.

The classifiers or characteristics are therefore automatically defined and refined during the analysis of the training set. The automatically determined classifiers of a 3D model of a dental situation could, for example, be a total area of a preparation or the profile of the preparation margin.

The CNN network can consist of a plurality of layers, for example, wherein simple classifiers such as edges, flat surfaces or regions of equal brightness are automatically identified in a first layer. The classifiers are automatically refined in a second layer. The classifiers in the second layer can be, for example, the relative arrangement of the edges to one another, the relative direction of the edges, or the profile of the edges. In the other layers, the classifiers are increasingly refined and thus become increasingly complex. In this way, the CNN network learns to automatically determine the appropriate restoration type and/or the tooth number as output parameters using the 3D model as input parameters.

Advantageously, the tooth number and/or a position of the tooth for the restoration to be inserted and/or the neighbouring teeth relative to the respective tooth can additionally be determined on the basis of a surface of at least one residual tooth of the respective tooth. The tooth number or the position of the tooth is therefore automatically determined on the basis of the surface of the residual tooth and/or the neighbouring teeth. This is because the recognition algorithm automatically recognises which tooth number of the restoration to be produced involves the shape, dimensions and alignment of the neighbouring teeth.

Advantageously, the computer-aided recognition algorithm can have a template-matching method with defined geometric shapes, such as a cusp tip, an incisal edge or a labial surface, wherein a surface of at least one residual tooth of the tooth for the restoration to be inserted and/or the neighbouring teeth relative to the tooth are used to determine the tooth number and/or a position of the tooth.

This embodiment represents an alternative to the fully automatic machine learning system from at least one CNN network. The geometric shapes or features of the 3D model of the dental situation are thus manually defined and parametrised by a user. In the template-matching method, the 3D model of the dental situation to be analysed is searched with respect to these defined geometric shapes. A search algorithm for a cusp tip could be based on a gradient method, for example. The search algorithm can recognise and segment distinctive geometric shapes such as cusp tips, the incisal edge or the labial surface. In this way, the tooth number is determined. Thus, canines can be recognised, for example, by the distinctive cusp tips.

The determined restoration type and/or tooth number can advantageously be displayed to a user by means of a display device.

The recorded 3D model of the dental situation can therefore be displayed by means of a display device such as a monitor, wherein the information determined, such as the restoration type and/or the tooth number, can be shown. The restoration can also be constructed and displayed graphically within the measured 3D model of the dental situation.

The determined restoration type and/or tooth number can advantageously be used to construct the restoration.

As a result, the restoration is constructed fully automatically using the measured 3D model of the dental situation, the determined restoration type, and the tooth number, wherein, for example, distinctive structures such as the preparation edge, the shape of the preparation, the shape of the neighbouring teeth, and the shape of the opposing teeth are taken into account.

This enables fully automatic construction of the restoration without user interaction.

Advantageously, colour information of the residual tooth of the relevant tooth for the restoration to be inserted and/or of the neighbouring teeth is used to define a colour for the restoration to be inserted.

As a result, the colour of the restoration to be inserted can be defined automatically by means of the computer without any user interaction. This shortens the construction time of a restoration. This also prevents operating errors which could lead to a faulty restoration if the colour were selected manually.

The determined restoration type and/or tooth number can advantageously be used to define a material for the restoration to be produced.

As a result, the material for the restoration to be produced is automatically defined by means of a computer. If the restoration is manufactured using a CAD/CAM manufacturing process, a suitable blank can be automatically selected from a suitable material. This shortens the time it takes to manufacture a restoration.

Brief description of the drawings

The invention is explained with reference to the drawings, as follows:

Figure 1 shows a drawing to clarify the method for constructing a restoration;

Figure 2 shows a drawing to explain the height fields in the occlusal direction;

Figure 3 shows a drawing to explain the height fields in the labial and mesial directions.

Exemplary embodiments

Figure 1 shows a drawing to clarify the method for constructing a restoration 1 such as a bridge, wherein a dental situation 3 is measured by means of a dental camera 2 and a 3D model 4 of the dental situation 3 is generated. The measurement of the dental situation 3, indicated by a rectangle, by means of the dental camera 2 is indicated by the dashed lines 5. The 3D model 4 of the dental situation 3 is displayed by means of a display device 6, such as a monitor, which is connected to a computer 7. The image data from the three-dimensional camera 2 are forwarded to the computer 7. Input means, such as a mouse 8 and a keyboard 9, are connected to the computer 7 so that a user can navigate within the graphic representation of the 3D model 4 by means of a cursor 10. The dental situation 3 has a missing incisor 11 of the upper jaw 12 with a tooth number 11 according to dental notation. In addition, a first preparation 13 of the neighbouring tooth is arranged with tooth number 12 according to dental notation. A second preparation 14 in the form of a tooth stump of the adjacent tooth with tooth number 21 is arranged on the right-hand side. The restoration 1 to be constructed and produced is shaped in such a way that a first recess 15 is made to match the first preparation 13 and a second recess 16 is made to match the second preparation 14. The restoration 1 is therefore placed on the two preparations 13 and 14 and adhesively bonded. Using a computer-aided recognition algorithm, the 3D model 4 of the dental situation 3 is analysed and a restoration type 17 and a tooth number 18 are automatically determined, wherein the restoration type 17 and the tooth number 18 are displayed in a menu 19 using the display device 6. Using the measured 3D model 4 of the dental situation 3, the determined restoration type 17 and determined tooth number or position of the restoration 18 to be inserted, a 3D model 20 of the restoration 1 to be produced is automatically generated, wherein essential structures such as the shape of the preparation 15 and of the preparation 16 and the shape of a first neighbouring tooth 21 and of a second neighbouring tooth 22 are taken into account. The first neighbouring tooth 21 is a canine tooth with tooth number 13 and the second neighbouring tooth 22 is a tooth with tooth number 22 according to dental notation. Using the constructed 3D model 20, the restoration 1 can be machined fully automatically from a blank by means of a CAM processing machine. The advantage of the explained method is that the restoration 1 can be produced fully automatically after the measurement by means of the dental camera 2, without user interaction being required.

Figure 2 shows a drawing to explain the height fields 30 which serve as input data for a CNN network, wherein the CNN network is a computer algorithm which runs on the computer 7 from figure 1. The 3D model 4 is cut at equal intervals perpendicular to an occlusal direction 31 so that sectional images or height fields 30 are generated. When training a CNN network, a large number of different 3D models of different dental situations are analysed.

In figure 3, the 3D model 4 is cut perpendicular to a labial direction 40 so as to produce height fields 41 or sectional images perpendicular to the labial direction 40. The 3D model 4 is also cut perpendicular to a mesial direction 42 so that height images 43 perpendicular to the mesial direction 42 are generated. The sectional images or height images 30, 41 and 43 serve as input data for the CNN network, wherein the restoration type 17 and the tooth number 18 of the restoration 1 to be inserted from figure 1, for example, are determined as output data from the CNN network.

Reference signs

| | |
|---|---|
| 1 | Restoration |
| 2 | Camera |
| 3 | Dental situation |
| 4 | 3D model |
| 5 | Lines of the recording region |
| 6 | Display device |
| 7 | Computer |
| 8 | Mouse |
| 9 | Keyboard |
| 10 | Cursor |
| 11 | Incisor |
| 12 | Upper jaw |
| 13 | Preparation |
| 14 | Second preparation |
| 15 | Recess |
| 16 | Second recess |
| 17 | Restoration type |
| 18 | Tooth number of the restoration to be inserted |
| 19 | Menu |
| 20 | 3D model |
| 21 | Neighbouring tooth |
| 22 | Second neighbouring tooth |
| 30 | Height fields |
| 31 | Occlusal direction |
| 40 | Labial direction |
| 41 | Height fields |
| 42 | Mesial direction |
| 43 | Height images |

# FREMGANGSMÅDE TIL KONSTRUKTION AF EN RESTAURERING

## Patentkrav

1. Fremgangsmåde til konstruktion af en restaurering (1), hvor der opmåles en tandsituation (3) ved hjælp af et dentalt kamera (2) og fremstilles en 3D-model (4) af tandsituationen (3), **kendetegnet ved, at** en computerunderstøttet registreringsalgoritme anvendes til 3D-modellen (4) af tandsituationen (3), hvor en restaureringstype (17) for restaureringen (1), der skal indsættes, beregnes automatisk, hvor tandsituationen (3) indeholder mindst én præparation (13, 14) eller en implantatunderstøttet mesostruktur til indsættelse af restaureringen (1), der skal fremstilles, hvor den computerunderstøttede registreringsalgoritme indbefatter et kunstigt neuralt netværk til maskinel indlæring, hvor formen af præparationen (13, 14) eller den implantatunderstøttede mesostruktur analyseres ved hjælp af 3D-modellen (4) af tandsituationen (3) ved hjælp af et maskinindlæringssystem, og der vælges en passende restaureringstype (17), hvor maskinindlæringssystemet består af et eller flere CNN-netværk.

2. Fremgangsmåde ifølge krav 1, kendetegnet ved, at restaureringstypen (17) er et inlay, en krone, en bro, et abutment, en pontic eller en veneer.

3. Fremgangsmåde ifølge et af kravene 1 eller 2, kendetegnet ved, at den beregnede restaureringstype (17) vises for en bruger ved hjælp af en displayanordning (6).

4. Fremgangsmåde ifølge et af kravene 1-3, kendetegnet ved, at den beregnede restaureringstype (17) anvendes til at konstruere restaureringen (1).

5. Fremgangsmåde ifølge et af kravene 1-4, kendetegnet ved, at der anvendes farveinformation for resttanden af den respektive tand til restaureringen (1), der skal indsættes, og/eller nabotænderne (21, 22) til at definere en farve til restaureringen, der skal indsættes.

6. Fremgangsmåde ifølge et af kravene 1-5, kendetegnet ved, at den beregnede restaureringstype (17) anvendes til at definere et materiale til restaureringen, der skal fremstilles.

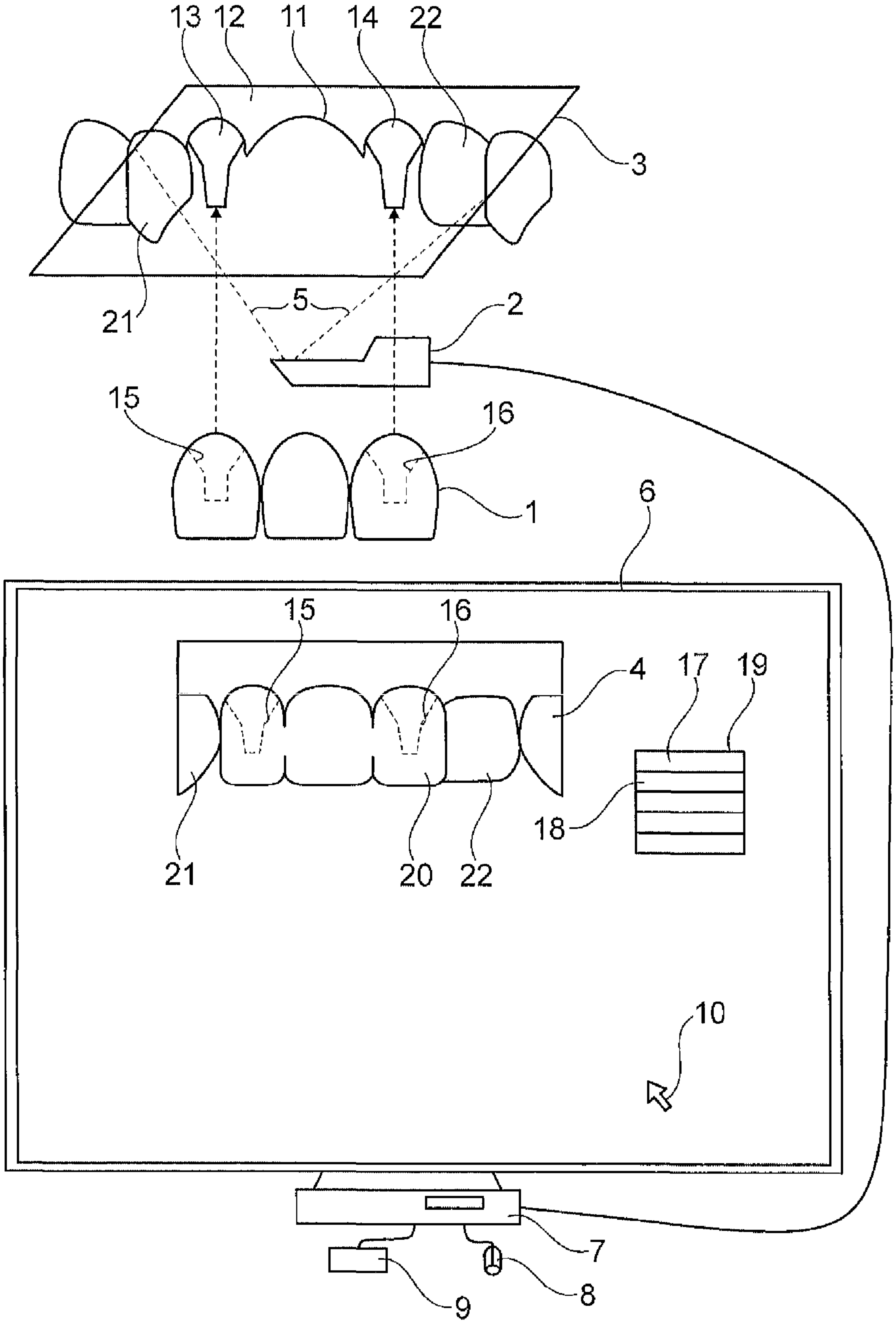


Fig. 1

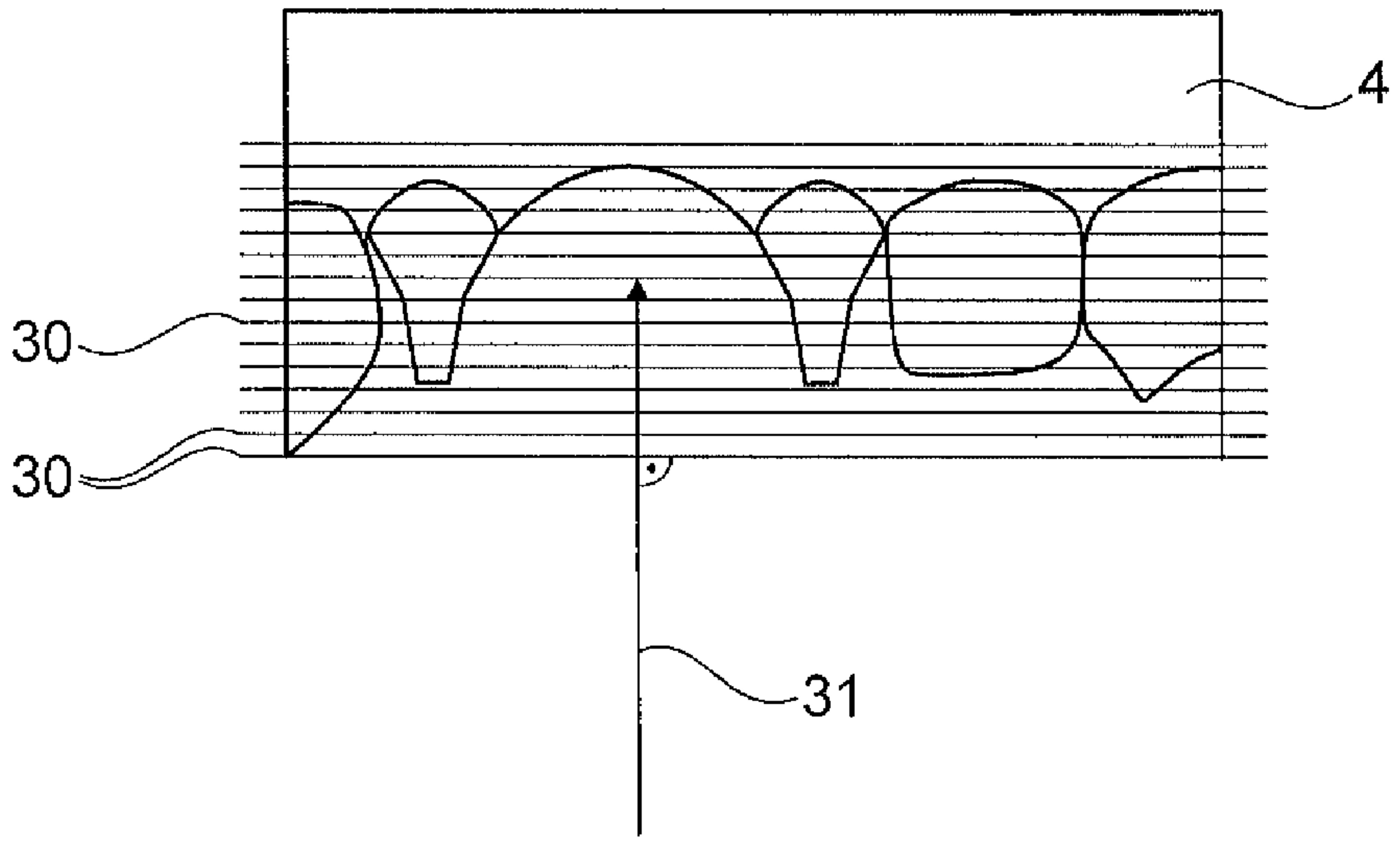


Fig. 2

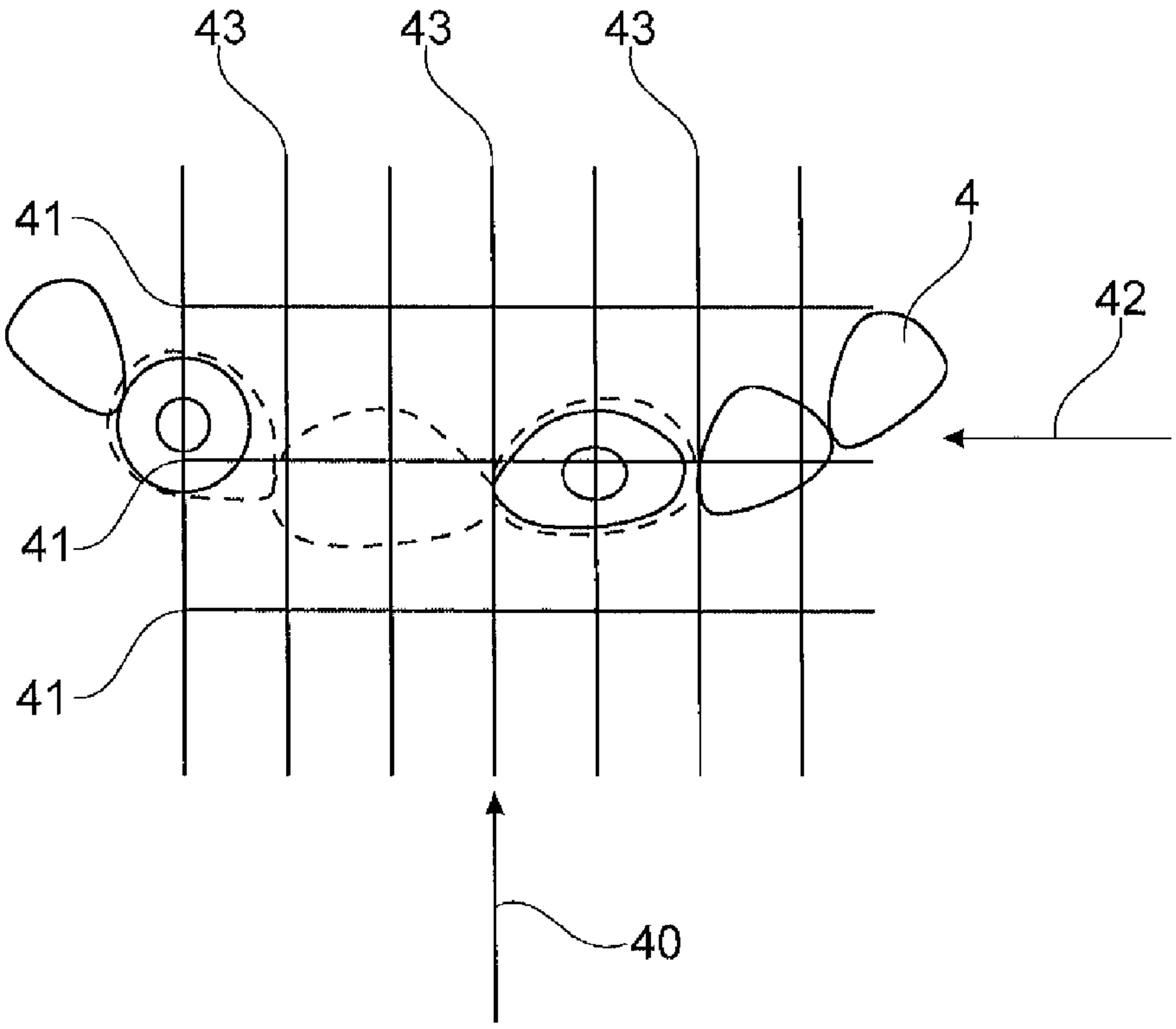


Fig. 3