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(54) Benævnelse: **SYSTEM TIL FREMSTILLING AF ET ORTODONTISK APPARAT**

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SYSTEM FOR PRODUCING AN ORTHODONTIC APPARATUS

Description

Technical field

The present invention relates to a system for producing an orthodontic appliance to replace an orthodontic appliance worn by a patient.

State of the art

It is desirable for everyone to have their teeth checked regularly, in particular to ensure that the position and/or shape and/or appearance of their teeth are not changing unfavorably.

In the case of orthodontic treatment, this unfavorable trend may lead to a change in treatment. After orthodontic treatment, this unfavorable trend, referred to as “recurrence”, may lead to the need for renewed treatment. Finally, in a more general way and independently of any treatment, everyone may wish to monitor any displacement and/or changes in the shape and/or appearance of their teeth.

Traditionally, the checks are carried out by an orthodontist or dentist, who are the only ones with the right equipment. These checks are therefore costly. Furthermore, the visits are burdensome.

US 2009/0291417 describes a method for creating and modifying three-dimensional models, in particular for the manufacture of orthodontic appliances.

WO 2008/149221 A1 discloses a system for manufacturing an orthodontic appliance, but does not disclose a two-dimensional image acquisition device or a computer with means for deforming a dentition model to match a two-dimensional image.

One objective of the present invention is to address the aforementioned problems, at least partially.

Summary of the invention

The invention provides a system for producing an orthodontic appliance to replace an orthodontic appliance worn by a patient according to claim 1. This system makes it possible to carry out the method of checking the positioning and/or shape of a patient's teeth, said method comprising the following steps:

a) producing a digital three-dimensional reference model of at least one part of an arch, preferably of at least one arch of the patient, or “initial reference model” and, preferably, for each tooth, defining, from the initial reference model, a digital three-dimensional reference model of said tooth, or “tooth model”;

b) acquiring at least one two-dimensional image of the patient's arches, referred to as an “updated image”, under real acquisition conditions;

c) analyzing each updated image and producing, for each updated image, an updated map relating to discriminative information;

d) optionally, determining, for each updated image, rough virtual acquisition conditions approximating said real acquisition conditions;

e) searching, for each updated image, for an updated reference model corresponding to the positioning and/or the shape of the teeth at the time of acquiring the updated image, the search preferably being carried out by means of a metaheuristic method, which is preferably evolutionary, preferably by simulated annealing, and

f) for each tooth model, comparing the positions of said tooth model in the initial reference model and in the reference model obtained from the previous steps, referred to as the “updated reference model”, in order to determine the displacement of teeth between steps a) and b), and/or comparing the shapes of the initial reference model and the reference model obtained from the previous steps, referred to as the “updated reference model”, in order to determine the deformation and/or displacement of teeth between steps a) and b).

As will be seen in greater detail later in the disclosure, a system for manufacturing a replacement orthodontic appliance for an appliance worn by a patient according to the invention makes it possible, based on a simple image of the teeth, taken without precise pre-positioning of the teeth relative to the image acquisition device, for example a photograph taken by the patient, to accurately assess the displacement and/or deformation of the teeth since the initial reference model was produced. This evaluation can further be carried out by a simple computer, server or cell phone.

Preferably, step e) comprises:

- a first optimization operation to search for virtual acquisition conditions corresponding as closely as possible to the real acquisition conditions in a reference model to be tested, determined from the initial reference model, and

- a second optimization operation to find, by testing a plurality of said reference models to be tested, the reference model that best corresponds to the positioning and/or shape of the patient's teeth when the image updated in step b) is acquired.

Preferably, a first optimization operation is performed for each test of a reference model to be tested in the second optimization operation.

Preferably, the first optimization operation and/or the second optimization operation, preferably the first optimization operation and the second optimization operation, implement a metaheuristic method, preferably evolutionary, preferably simulated annealing.

Preferably, step e) comprises the following steps:

e1) defining a reference model to be tested as the initial reference model, then,

e2) in line with the following steps, testing virtual acquisition conditions with the reference model to be tested in order to precisely approximate said real acquisition conditions;

e21) determining virtual acquisition conditions to be tested;

e22) producing a two-dimensional reference image of the reference model to be tested under said virtual acquisition conditions to be tested;

e23) processing the reference image to produce at least one reference map representing, at least partially, said discriminative information;

e24) comparing the updated map and reference map so as to determine a value for a first evaluation function, said value for the first evaluation function depending on the differences between said updated map and reference map and corresponding to a decision to continue or stop the search for virtual acquisition conditions approximating said real acquisition conditions more accurately than said virtual acquisition conditions to be tested which are determined at the last occurrence of step e21);

e25) if said value for the first evaluation function corresponds to a decision to continue said search, modifying the virtual acquisition conditions to be tested, then returning to step e22);

e3) determining a value for a second evaluation function, said value for the second evaluation function depending on the differences between the updated map and reference map under the virtual acquisition conditions best approximating said real acquisition conditions and resulting from the last occurrence of step e2), said value for the second evaluation function corresponding to a decision to continue or stop the search for a reference model approximating the positioning of the teeth at the time of acquiring the updated image more accurately than said reference model to be tested which is used in the last occurrence of step e2), and if said value for the second evaluation function corresponds to a decision to continue said search, modifying the reference model to be tested by deforming the reference model to be tested and/or by moving and/or deforming one or more tooth models, then returning to step e2).

The method for checking the positioning and/or shape of teeth may further comprise one or more of the following optional features:

- in step a), an occlusal plane is determined by the following operations:

I. determining the points of the initial reference model which belong to one arch and which are at a distance from the other arch which is less than a predetermined distance, preferably less than 3 mm from the other arch, referred to as “contact points”;

II. optionally, filtering of some of the contact points, preferably so that the number of contact points belonging to the upper arch is identical to the number of contact points belonging to the lower arch, preferably by eliminating the points of one arch furthest away from the other arch;

III. linear regression, preferably by the least-squares method, on all remaining contact points to determine the occlusal plane;

- in step a), the following operations are performed:

i. projecting, in an occlusal plane, the contact points between the teeth of the patient's upper and lower arches, the contact points and/or the occlusal plane preferably being determined according to steps I to III;

ii. determining the barycenter of the projections of said contact points and creating a reference frame, in the occlusal plane, centered on said barycenter;

iii. determining, in said reference frame, the parabolic function with the highest correlation coefficient with all the projections of the contact points;

iv. rotating the set of contact point projections around the barycenter, and repeating the previous operation *iii* until the set of contact point projections has covered a given sector, preferably greater than 90°, greater than 180°, or even about 360°;

v. identifying the highest correlation coefficient for the set of angular positions of the set of projections of the contact points around the barycenter, and the axis of the corresponding parabolic function;

vi. determining a median longitudinal plane of the initial reference model, said plane passing through said axis and being perpendicular to the occlusal plane;

- in step a), a tooth model is at least partially delimited by the following operations:

i'. determining, at least in part, the inner and outer gingival edges of the arch of the tooth concerned, preferably by analysis of variations in the orientation of the surface of the initial reference model;

ii'. projecting, in the occlusal plane, the inner and outer gingival edges;

iii'. identifying the deformations of the projections of the inner and outer gingival edges corresponding to the interdental regions, the vertices of these deformations being referred to as “convergence points” (in an interdental region, the two projections each have a point, the two points pointing substantially toward each other, the end of a point being a convergence point);

iv'. determining the shortest path, on the surface of the initial reference model, between two convergence points of inner and outer gingival edges, respectively, of an interdental region, preferably by a metaheuristic method, preferably evolutionary, preferably by simulated annealing, said shortest path at least partially delimiting a tooth model;

- an updated image is acquired less than 7 days after step a), then steps c) to f) are carried out based on this updated image;

- the time interval between steps a) and b) or between steps A and B may be greater than 1 week, 2 weeks, 1 month, 2 months or 6 months;

- in step b), a hand-held acquisition device is used (in particular one which is not immobilized, e.g. by means of a support resting on the floor) and/or the patient's head is not immobilized;

- an individual device selected from the group formed by a connected camera, a smartwatch, a digital tablet, a portable 3D scanner and a computer coupled to an image acquisition system, such as a webcam or a digital camera, is used to implement step b) and, preferably, at least one of the steps, preferably all steps c) to f);

- in step b), a spreader having one, preferably more than two, preferably non-aligned register marks is used and, preferably, the representation of the register marks on the updated image is used to

- in step c), resize the image and/or,

- in step d), roughly evaluate the real acquisition conditions;

- in step c), the discriminative information is selected from the group consisting of contour information, color information, density information, distance information, brightness information, saturation information, reflection information and combinations thereof;

- in step c), the discriminative information is an optimal discriminative information obtained by means of an optimization method, described below;

- in step d), data supplied by the acquisition device is used, preferably concerning its orientation;

- in step e2), the virtual acquisition conditions sought comprise calibration parameters for the acquisition device used in step b);

- optimization by a metaheuristic method, preferably evolutionary, preferably simulated annealing, is implemented:

- in step a), to at least partially determine a gingival margin delimiting a tooth model, and/or

- in step e2), to search for virtual acquisition conditions corresponding to real acquisition conditions, and/or

- in step e), to search for a reference model corresponding to the updated image;

- said metaheuristic method is selected from the group formed by

- evolutionary algorithms, preferably selected from among evolution strategies, genetic algorithms, differential evolution algorithms, estimation of distribution algorithms, artificial immune systems, Shuffled Complex Evolution path relinking, simulated annealing, ant colony algorithms, particle swarm optimization algorithms, Tabu search, and the GRASP method;

- the kangaroo algorithm,

- the Fletcher-Powell method,
- the noise injection method,
- stochastic tunneling,
- random-restart hill climbing,
- the cross-entropy method, and
- hybrid methods between the above-mentioned metaheuristic methods;
- from the comparison in step f), a map is produced showing changes in the shape of the initial reference model and/or the displacement of one or more tooth models;
- the discriminative information used for the updated map and/or for the reference map is, prior to this use, optimized by means of an optimization method discriminative information below, comprising steps C1. to C3., the acquired image being the updated image or the reference image, respectively, and the reference model being the initial reference model or the reference model to be tested, respectively.

The method for checking tooth positioning can be used to

- detect a recurrence, and/or
- determine the rate of change of tooth positioning, and/or
- optimize the appointment date with an orthodontist or dentist, and/or
- evaluate the effectiveness of an orthodontic treatment, and/or
- evaluate the evolution of tooth positioning toward a theoretical model corresponding to a given tooth positioning, in particular an improved tooth positioning, and/or
- in a dental office.

The method can in particular be implemented during orthodontic treatment, in particular to check the progress thereof, with step a) being implemented less than 3 months, less than 2 months, less than 1 month, less than one week, less than 2 days after the start of treatment, that is, after the fitting of an appliance designed to correct the positioning of the patient's teeth, referred to as an “active retainer”.

The method can also be used after orthodontic treatment, to check that the positioning of the teeth does not change unfavorably (“recurrence”). Step a) is then preferably carried out less than 3 months, less than 2 months, less than 1 month, less than one week, less than 2 days after the end of treatment, that is, after fitting a passive retainer to hold the teeth in position.

A method for checking tooth positioning is described, for checking tooth displacement only, wherein the tooth models are assumed to be dimensionally stable in step e). In particular, in step e3), the reference model to be tested can only be modified by moving one or more tooth models.

Conventionally, at the start of orthodontic treatment, the orthodontist determines the position of the teeth he or she wishes to achieve at the end of the treatment, referred to as the “final set-up”. The final set-up can be defined by means of an impression or a three-dimensional scan of the patient's teeth. The orthodontist then fabricates the appropriate orthodontic appliance for the treatment.

At regular intervals, the patient visits the orthodontist for a visual check. Depending on the diagnosis, the orthodontist may modify the orthodontic appliance.

For example, if the orthodontic appliance is one with a metal archwire attached to the teeth, he can modify the tension exerted by the archwire. If necessary, he can also have a new, better-fitting orthodontic appliance made.

Orthodontic appliances can be aligners. An aligner typically takes the form of a one-piece removable appliance, typically made of a transparent polymer material, which features a channel shaped so that several teeth of an arch, usually all the teeth of an arch, can be accommodated within it. The shape of the channel is designed to hold the aligner in position on the teeth, while at the same time correcting the position of certain teeth.

Treatment with aligners is advantageously less restrictive for the patient. In particular, the number of orthodontic appointments is limited. Additionally, there is less pain than with a metal archwire attached to the teeth.

The market for orthodontic aligners is therefore growing.

If the orthodontic appliance is an aligner, the shapes to be taken by the different aligners at different points in the treatment are usually determined at the start of the treatment, and the corresponding set of aligners is then manufactured. At predetermined times, the patient changes his aligner. Checks can be carried out at regular intervals. If the orthodontist diagnoses that the treatment is unsuitable, he takes a new impression of the teeth, or, equivalently, a new three-dimensional scan of the teeth, then orders a new set of aligners. On average, the number of aligners ultimately manufactured is around 45, instead of the 20 aligners typically planned at the start of treatment.

WO2008/149221 describes a method for detecting drift in the treatment. This drift can be measured by comparing digital models of the patient's teeth. In the event of drift, the treatment can be recalculated. WI 2008/149221 does not, however, suggest any solution for accurate drift measurement without an appointment with an orthodontist.

The need to travel to the orthodontist is a burden for the patient. The patient's trust in his orthodontist can also be undermined. Last but not least, the result is an additional cost.

The number of visits to the orthodontist should therefore be limited.

One aim of the present invention is to at least partially meet this need.

A method of fitting an orthodontic appliance worn by a patient is described, the method comprising the following steps:

a') Creating an initial reference model of at least part of an arch, preferably of at least one arch, preferably of both of the patient's arches, in accordance with step a);

b') Independently of steps a') and c'), but prior to step d'), creating a digital three-dimensional reference model, referred to as an “objective reference model”, corresponding to a desired positioning of the teeth of said at least one part of said patient's arch at a time during treatment, in particular at the end of treatment with said orthodontic appliance;

c') Acquiring at least one updated image, under real acquisition conditions, and searching, by deformation of the initial reference model, for an updated reference model corresponding to the positioning of the teeth at the time of acquisition of the updated image, the search preferably being carried out by means of a metaheuristic method, preferably evolutionary, preferably by simulated annealing, preferably in accordance with steps b) to e);

d') Determining, based on the initial reference model and/or the objective reference model, a comparison model wherein the teeth of the initial reference model are in an anticipated position, preferably substantially as anticipated at the time of the acquisition carried out in step c');

e') Comparing the updated reference model with the comparison model;

f) If, in step e'), said comparison results in an unsatisfactory outcome, manufacturing a replacement orthodontic appliance, by modifying the worn orthodontic appliance or by manufacturing a new orthodontic appliance, the replacement orthodontic appliance being configured based on said result.

The replacement orthodontic appliance is designed based on the results of a comparison between real tooth positioning, assessed using the updated reference model, and anticipated positioning, corresponding to the comparison model. The replacement orthodontic appliance is configured at the time of the check-up cycle (steps c') to f')) and can therefore be well adapted to the actual treatment.

Advantageously, the check-up cycle can be carried out remotely, using simple photographs taken by a cell phone, without the patient having to visit the orthodontist in particular. As will be seen in greater detail later in the description, the production of the updated reference model in step c') is in fact possible without any particular precautions, notably because the real positioning of the teeth is measured with an updated reference model which results from a deformation of the initial reference model so that it corresponds to the observations provided by the updated images, that is, so that the updated images are views of the deformed initial reference model.

The patient and/or orthodontist can therefore easily evaluate the treatment, and in particular the effectiveness of the orthodontic appliance worn by the patient, without having to visit an orthodontist. Step c') can therefore be repeated as often as required.

Additionally, it becomes possible in practice to schedule an appointment with the orthodontist only when the comparison in step e') leads to an unsatisfactory result and a replacement orthodontic appliance has to be made.

Moreover, the accuracy of the initial reference model means that an updated reference model can be obtained that is also highly accurate, without the need for a new scan of the teeth. Tests have shown that the updated images, and in particular the photographs taken in step c'), are sufficient to accurately determine the deformation to be applied to the initial reference model. The position of the teeth represented on the updated images, determined by deforming the initial reference model and analyzing the updated images, corresponds with a very high degree of accuracy to the measured reality.

To further improve accuracy, several updated images are preferably used.

The updated reference model is advantageously determined exclusively based on patient information, irrespective of any statistical considerations regarding third-party orthodontic treatment. The updated reference model is thus patient-specific.

The invention therefore relies on the ability to combine two sources of information of different kinds, namely an initial reference model that is accurate but provides no information on tooth displacement, and one or more updated images that contain little information on the precise positioning of the teeth, but whose analysis enables the initial reference model to be used to accurately determine the displacement of the teeth represented since the time at which the initial reference model was created. Preferably, model deformation is carried out by means of a metaheuristic method whereby the updated image is compared with a succession of reference models obtained by deformation of the initial reference model, the model closest to the updated image, that is, allowing observation of said model corresponding to the updated image, being retained to constitute the updated reference model.

In the case of orthodontic treatment using aligners, the method also reduces the number of aligners produced. In particular, the aligners can be manufactured throughout the treatment process, enabling them to be perfectly adapted to the actual situation at the time they are to be used.

Last but not least, the cost and duration of treatment are reduced.

The fitting method may also include one or more of the following optional features:

- the comparison model can be, in particular, the objective reference model or, preferably, a three-dimensional digital model providing an estimate of the positioning, planned for an intermediate time, of the teeth of the initial reference model, referred to as the “intermediate reference model”;

- preferably, the comparison model corresponds to an anticipated positioning of the teeth substantially at the time of said acquisition. Preferably, it provides an estimate of the positioning, predicted for an intermediate instant, of the teeth of the initial reference model, the time between said intermediate instant and the instant of acquisition performed in step c') being less than 1 month, preferably less than 1 week, most preferably less than 24 hours;

- the method comprises more than 2, more than 5, more than 10 or even more than 20 check-up cycles, each check-up cycle consisting of an execution of steps c') to f');

- in step d'), the comparison model is determined based on updated reference models determined in one or more steps c') of check-up cycles preceding the test cycle comprising said step d'), in particular based on the updated reference model or models determined in steps c') of check-up cycles immediately preceding the check-up cycle including said step d');

- in step c'), said updated image is acquired by means of a patient's telephone, the search for the updated reference model is preferably carried out by means of said telephone, and the updated reference model is transmitted, by said telephone, to an orthodontist;

- before each date scheduled for a step c'), preferably less than 3 weeks, preferably less than 2 weeks, preferably less than one week before said date, a reminder message is sent to the patient, preferably on his telephone, so that he carries out said step c');

- steps c') to e') of each check-up cycle are performed “remotely”, that is, without the patient visiting the orthodontist;

- in step d'), the comparison model is determined based on parameter values of the orthodontic appliance worn;

- in step e'), a report is drawn up from said comparison, providing diagnostic information and/or recommendations for modifying the patient's treatment;

- in step e'),

- an “updated” score, representative of treatment efficacy, is established based on said comparison, and

- preferably, said updated score is compared with a reference score representative of the efficacy of an equivalent standard treatment and the result of the comparison between the updated and reference scores is presented to the patient;

- in step f'), an orthodontic arch of the worn orthodontic appliance is tensioned and/or an orthodontic arch of the worn orthodontic appliance is changed and/or an orthodontic aligner is made to replace the worn orthodontic appliance;

- in step f'), several potential treatments are determined to achieve a positioning of the teeth corresponding to the objective reference model, said potential treatments are presented to the patient and/or to an orthodontist so that he chooses one of said potential treatments, and then said replacement orthodontic appliance corresponding to the chosen treatment is manufactured;

- in step f'), the patient determines whether the result is unsatisfactory;

- the orthodontic appliance worn is a first aligner, and the replacement orthodontic appliance is a second aligner and, preferably, said second aligner is sent to the patient.

A method is described for evaluating the behavior of an orthodontic appliance, including

- repeated implementation of a fitting method according to the invention, with said orthodontic appliance and/or orthodontic appliances of the same type,

- for each occurrence of the fitting method, a collection of data, said data including at least the initial reference model and/or the objective reference model, on the one hand, and one or more updated reference models, on the other hand, as well as parameter values of the orthodontic appliance worn by the patient during said occurrence,

- statistical analysis of said data to establish a correlation between a parameter of the orthodontic appliance(s) worn during said occurrences and the behavior of said orthodontic appliance(s) worn.

By facilitating checks, the fitting method according to the invention enables a large amount of data to be collected on the action of orthodontic appliances. Advantageously, it enables these data to be used statistically.

The method for evaluating the behavior of an orthodontic appliance may further comprise, in particular, one or more of the following optional features:

- said fitting method is carried out more than 10, preferably more than 100, preferably more than 1,000, preferably more than 10,000, preferably more than 100,000 times, that is, for a large number of patients;

- after said statistical analysis, the results of said statistical analysis are used to optimize:

- orthodontic appliance design, and/or
- the choice of braces for a particular treatment, and/or
- diagnosis, and/or
- the manufacture of a replacement orthodontic appliance, and/or
- the determination of a predictive model to build a comparison model.

Also described is a method for monitoring the effectiveness of an orthodontic appliance worn by a patient, the method comprising the following steps:

a") Creating an initial reference model of at least part of an arch, preferably of at least one arch, preferably of both of the patient's arches, in accordance with step a);

b") Acquiring at least one updated image, under real acquisition conditions, and searching, by deformation of the initial reference model, for an updated reference model corresponding to the positioning of the teeth at the time of acquisition of the updated image, the search preferably being carried out by means of a metaheuristic method, preferably evolutionary, preferably by simulated annealing, preferably in accordance with steps b) to e);

c") determining, for at least one point of a tooth, the value of at least one positioning parameter in the updated reference model;

d") repeating the cycle of steps b") and c") and, for each cycle, graphically depicting said value of said positioning parameter so as to visualize the evolution of said value over time.

A positioning parameter is a useful parameter for determining the position or orientation of a tooth. For example, *x*, *y* and *z* are positioning parameters in a Cartesian Oxyz reference frame. The radial coordinate, often noted *r* or ρ, and referred to as radius, the angular coordinate, also referred to as polar angle or azimuth, and often noted *t* or *θ*, and the height, often noted *h* or *z*, are positioning parameters in a cylindrical reference frame. The values of these positioning parameters are used to define a point's position in space.

A method for monitoring the effectiveness of an orthodontic appliance makes it possible to visualize the displacement dynamics of at least one point on a tooth. Preferably, this point is a remarkable point, chosen to be representative of the intensity of the orthodontic appliance's action.

The point of the tooth is preferably the barycenter of the tooth. It can also be, for example, the center of the vestibular face of the crown.

The positioning parameter is preferably chosen according to the desired action of the orthodontic appliance.

The pictorial, preferably a curve, the time scale preferably being linear, immediately reveals the dynamics of the action of the orthodontic appliance. In particular, the fact that the curve increases or decreases less rapidly as time goes by can be interpreted as meaning that the orthodontic appliance is losing its effectiveness.

Such a curve is particularly easy to understand, making it possible for patients to use it themselves.

In a preferred embodiment, the pictorial includes indications of the satisfactory or unsatisfactory nature of said evolution. For example, the curve may change color if the slope is considered abnormal. Preferably, the curve can be displayed on an acquisition device, preferably a cell phone, used for said acquisition. In particular, it can be viewed by the patient. Advantageously, the patient can thus decide for himself, at the most opportune moment, to take steps to modify or change his orthodontic appliance, for example by making an appointment with an orthodontist.

A document, whether electronic or paper, can feature said pictorial.

The number of positioning parameters whose evolution is depicted graphically may be less than 10, preferably less than 5, more preferably less than 4, more preferably less than 3, most preferably less than 2. The number of tooth points for which the evolution of one or more positioning parameters is graphically depicted can be less than 10, preferably less than 5, more preferably less than 4, more preferably less than 3, most preferably less than 2. This facilitates decision-making.

Reducing the number of graphically displayed positioning parameters and the number of tooth points, however, requires an appropriate choice of these parameters and tooth points.

The use of the method for checking tooth shape can make it possible to:

- visualize and/or measure and/or detect dental plaque, and/or a cavity, and/or microfissures, and/or wear, for example resulting from bruxism or the use of active or passive orthodontic appliances, particularly in the event of breakage or detachment of an orthodontic arch;

- visualize and/or measure and/or detect a change in volume, in particular during tooth growth or following an intervention by a dental professional, e.g. a deposit of glue on the surface of the teeth;

- assess the need for interceptive treatment, prior to any orthodontic treatment, in particular to evaluate the benefits of orthodontic treatment.

In one embodiment of the checking method, to check for tooth deformation exclusively, step e) assumes that the tooth models are fixed, that is, that they have not moved between steps a) and b). In particular, in step e3), the reference model to be tested can only be modified by deformation of one or more tooth models.

The comparison of the shapes of the initial reference model and the updated reference model for determining tooth deformation between steps a) and b) can in particular result from a comparison of the shape of one or more tooth models in the initial reference model and in the updated reference model.

Also described is a method for checking a property of the appearance of a patient's teeth, said method comprising the following successive steps:

A. acquiring, by means of a first acquisition device, at least a first two-dimensional image of said teeth and of a first reference gauge, referred to as the “initial image”;

B. acquiring, by means of a second acquisition device, at least one second two-dimensional image of said teeth and of a second reference gauge having the same appearance as the first reference gauge, referred to as the “updated image”;

C. normalizing the initial and updated images so that the representations of the first and second reference gauges on the normalized initial and updated images have the same appearance;

D. before or after step C., locating the same region of the teeth on the initial and updated images;

E. comparing the appearance of said region on the initial and updated normalized images.

The method of checking a tooth appearance property preferably includes one or more of the following optional features:

- the time interval between steps A. and B. is greater than 1 week;

- the first acquisition device and/or the second acquisition device are cameras and/or cell phones;

- the acquisitions in steps A. and/or B. are performed under flash illumination;

- the reference gauges used for each of steps A. and B. have the same appearance;

- the reference gauges used for each of steps A. and B. are attached to a dental spreader;

- the acquisitions in steps A. and/or B. are carried out using an acquisition kit, described below;

- the reference gauges used for each of steps A. and B. are register marks;

- the first acquisition device and/or the second acquisition device includes a computer program comprising program code instructions for locating, in real time, the register mark(s) on the spreader, analyzing its/their position(s) and/or dimensions, in particular the relative positions of several register marks and, as a result, providing information, preferably luminous or audible, so as to inform the user of said acquisition device;

- in step D., location comprises a comparison of discriminative information common to both the initial and updated images, followed by identification of the position of said region with respect to said common discriminative information;

- in step D., locating the region on the initial and/or updated images comprises a search for virtual acquisition conditions under which the first and/or second acquisition device, respectively, would have acquired said initial and/or updated image, respectively, by observing a digital three-dimensional reference model of the patient's arches.

- in step D., locating the region on the initial and/or updated images involves carrying out a method for evaluating the real acquisition conditions, as described below.

An acquisition kit can be used, in particular for carrying out step b), A. or B., said acquisition kit comprising:

- a dental spreader designed to be placed in a patient's mouth and featuring a register mark;

- an image acquisition device comprising;

- a display screen,

- a computer memory containing information on target acquisition conditions,

- a computer program comprising program code instructions for simultaneously displaying, on said screen, an acquirable image and a reference, said reference being in a position such that, when the register mark corresponds to the reference on the screen, the acquisition device complies with the target acquisition conditions.

In particular, the acquisition kit can be used in step b) of a method for checking the positioning and/or shape of teeth, or in steps A. and/or B. of a method for checking a tooth appearance property, and more generally for any method involving evaluating image acquisition conditions.

As will be seen in greater detail later in the description, the acquisition kit in particular makes it possible to position the acquisition device in a position that substantially corresponds to a predetermined position, for example considered optimal for the desired check. The acquisition kit therefore considerably improves the speed of information processing for the implementation of the checking methods.

The acquisition kit preferably has one or more of the following optional features:

- the image acquisition device is a cell phone;
- the reference is chosen from the group consisting of
- a point,
- a geometric shape, preferably a circle, square, rectangle or line,
- an area colored the same color as said register mark,
- a shape identical to the shape of said register mark,
- a shape complementary to the shape of said register mark, in particular to form a shape with meaning, such as a geometric shape, a letter or text, a drawing, or a pattern, and
- combinations thereof;
- the spreader has several non-aligned, preferably coplanar, register marks;
- the register mark is positioned so that, when it corresponds to said reference on the screen, it is less than 1 cm from an edge of the screen.

A method is described for acquiring a two-dimensional image of part of a dental arch, or of one dental arch or of both dental arches of a patient, by means of an acquisition kit, in particular for carrying out a step b), A. and/or B. This method is remarkable in that it comprises the following successive steps:

(a) determining target acquisition conditions, for example based on a treatment to be applied, in particular orthodontic treatment, and determining matching conditions adapted so that matching a register mark of the spreader with a reference displayed on the screen of the acquisition device results in the application of the target acquisition conditions;

(b) programming the acquisition device to display the reference in a position such that said mapping results in the application of the target acquisition conditions;

(c) placing the spreader in the patient's mouth;

(d) positioning the acquisition device so as to match the register mark to the reference and thus apply the target acquisition conditions;

(e) acquiring the acquirable image in the position of the acquisition device adopted in the previous step.

The target acquisition conditions are those that enable suitable positioning of the acquisition device, preferably optimal positioning of the acquisition device for image acquisition. Preferably, the target acquisition conditions are therefore determined according to the teeth to be observed.

Preferably, the acquisition method is used for those steps of the checking methods requiring the acquisition of a two-dimensional image of a part of an arch or of one or both dental arches of a patient, in particular for steps b).

Preferably, the cycle of steps (a) to (e) is repeated several times, preferably more than twice or even more than three times, with different target acquisition conditions.

For example, to measure the displacement of a tooth, the first target acquisition conditions might correspond to a positioning 40 cm from the spreader, in front of and at the height of the spreader. Second and third target acquisition conditions may correspond to positioning 40 cm from the spreader, at spreader height, 45° to the right and left of the sagittal plane, respectively.

Preferably, steps (c), (d) and (e) are carried out by a person with no university training in orthodontics and/or outside a medical, dental or orthodontic practice, and/or without the use of a mechanical stabilization device for the acquisition device and/or without the use of devices other than a cell phone and/or without the use of a calibration gauge.

A method is described for optimizing discriminative information extracted from a two-dimensional image of a patient's dental arches, referred to as the “acquired image”, by means of a digital three-dimensional reference model of at least part of one or both of the patient's arches, said method comprising the following steps:

C1. assessing the quality of the discriminative information and of a quality threshold, filtering so as to retain only discriminative information with a quality higher than the quality threshold, and defining the “discriminative information to be tested” as the discriminative information retained;

C2. testing for agreement between the discriminative information to be tested and said reference model;

C3. evaluating the test result, and based on this evaluation:

- adding non-retained discriminative information to the discriminative information to be tested and/or deleting discriminative information from the discriminative information to be tested, then resuming at step C2., or

- defining optimal discriminative information as the discriminative information to be tested.

Preferably, the optimization method further comprises one or more of the following optional features:

- the discriminative information is selected from the group consisting of contour information, color information, density information, distance information, brightness information, saturation information, reflection information and combinations of this information;

- step C2. includes the following steps:

- searching for virtual acquisition conditions approximating, preferably optimally, real acquisition conditions under which said acquired image was acquired and observing the reference model under said virtual acquisition conditions so as to obtain a reference image;

- processing the acquired image and the reference image to produce at least one acquired map and one reference map, respectively, said acquired and reference maps representing said discriminative information;

- comparing the acquired and reference maps in order to determine a degree of concordance, the test result of step C2. being dependent on, preferably equal to, said degree of concordance;

- searching for virtual acquisition conditions approximating real acquisition conditions comprises the following steps:

01) optionally, determining rough virtual acquisition conditions approximating said real acquisition conditions, preferably by analyzing the representation, on the acquired image, of a spreader used during acquisition of the acquired image;

02) determining virtual acquisition conditions to be tested;

03) producing a two-dimensional reference image of the reference model observed under the virtual acquisition conditions to be tested;

04) processing the reference image to produce at least one reference map representing said discriminative information;

05) comparing the acquired map and reference map so as to determine a value for an evaluation function, said value for the evaluation function depending on the differences between said acquired map and reference map and corresponding to a decision to continue or stop the search for virtual acquisition conditions approximating the real acquisition conditions more accurately than said virtual acquisition conditions to be tested;

if said value for the evaluation function corresponds to a decision to continue said search, modifying said virtual acquisition conditions to be tested, then returning to step 03);

otherwise, evaluating real acquisition conditions by said virtual acquisition conditions to be tested;

- the determination of the discriminative information to be added and/or to be added to step C3. results from the implementation of a metaheuristic method, preferably evolutionary.

A method is described for evaluating the real acquisition conditions of a two-dimensional image of a patient's teeth, referred to as the “acquired image”, said method comprising the following steps:

001) creating a digital three-dimensional reference model of at least part of an arch, preferably an arch, preferably both of the arches, of the patient;

002) analyzing the acquired image and producing a map relating to discriminative information, referred to as the “acquired map”;

003) searching for virtual acquisition conditions approximating said real acquisition conditions, preferably according to steps 01) to 05).

One or more of the optional features of step a) are applicable to step 001). In particular, the reference model can be prepared, by scanning, from measurements taken on the patient's teeth or on a physical model of the patient's teeth, such as a plaster model.

One or more of the optional features of step c) are applicable to step 002).

Described is:

- a computer program, and in particular a specialized mobile telephone application, comprising program code instructions for executing one or more, preferably all, of steps b) to f) or A. to E. or C1 to C3, when said program is executed by a computer,

- a data medium on which such a program is recorded, for example a memory or a CD-ROM, and

- a personal device, in particular a cell phone or tablet, wherein such a program is loaded.

The invention also relates to a system comprising:

- a three-dimensional scanner suitable for carrying out step a) of a method for checking the positioning and/or shape of teeth according to the invention, or step 001).

- a personal device, preferably a cell phone, loaded with a program described above.

Definitions

The term “patient” refers to any person for whom a method is implemented in order to check their teeth, whether or not that person is ill, or whether or not that person is undergoing treatment.

A “dental professional” is defined as a dentist, orthodontist or orthodontic laboratory.

A “dentist” refers to a dentist or dental assistant working under the supervision of a dentist.

“Dentition” refers to the patient's two dental arches.

An image of an arch is, of course, a partial representation of that arch.

A “cell phone” is a device weighing less than 500 g, equipped with a sensor enabling it to capture images, capable of exchanging data with another device more than 500 km away from the cell phone, and capable of displaying said data, and in particular said images.

For a method of checking tooth positioning, the “acquisition conditions” specify the position and orientation in space of an image acquisition device relative to the patient's teeth or a model of the patient's teeth, and preferably the calibration of this image acquisition device.

The “calibration” of an acquisition device is made up of all the calibration parameter values. A calibration parameter is a parameter intrinsic to the acquisition device (unlike its position and orientation) whose value influences the acquired image. For example, the aperture value is a calibration parameter that modifies the depth of field. Exposure time is a calibration parameter that modifies the brightness (or “exposure”) of the image. Focal length is a calibration parameter that modifies the angle of view, that is, the degree of “zoom”. “Sensitivity” is a calibration parameter that modifies the reaction of a digital acquisition device's sensor to incident light.

Preferably, calibration parameters are chosen from the group formed by aperture, exposure time, focal length and sensitivity.

The “occlusal plane” is the plane that provides the best linear correlation with the set of contact points between the teeth of the upper arch on the one hand and the teeth of the lower arch on the other.

The “median longitudinal plane” is the substantially vertical plane, when the patient holds the head upright, which separates the right and left parts of each arch in a substantially symmetrical manner.

A “tablet” is a portable computer with a touch screen.

A 3D scanner is a device for obtaining a three-dimensional representation of an object.

An “image” refers to a two-dimensional image, such as a photograph. An image is made up of pixels.

An “acquirable” image (“preview”) is the image that the acquisition device can record at a given moment. For a camera or phone, this is the image that appears on the screen when the photo or video capture application is running.

“Discriminative information” is characteristic information that can be extracted from an image (*“image feature”*), conventionally by computer processing of this image.

Discriminative information can have a variable number of values. For example, contour information can be equal to 1 or 0 depending on whether or not a pixel belongs to a contour. Brightness information can take on a large number of values. Image processing is used to extract and quantify discriminative information.

Acquisition conditions are said to be “virtual” when they correspond to a simulation wherein the acquisition device would be in said acquisition conditions (theoretical positioning and preferably calibration of the acquisition device).

“Comprising a” or “including a” or “having a” means “comprising at least one”, unless otherwise specified.

In the various methods described, the step references are identical if these steps are similar or identical.

<u>Brief description of the figures</u>

Further features and advantages of the invention will become apparent from the following detailed description and from an examination of the appended drawing, wherein:

- Figure 1 shows a flow chart depicting the implementation of a method for checking tooth positioning and/or shape,
- Figure 2 shows an example of an initial reference model,
- Figure 3 shows the treatment performed to determine the occlusal plane,
- Figure 4 (4a-4d) shows the step required to determine the tooth models in a reference model,
- Figure 5 (5a-5d) shows the acquisition of updated images, as well as the cutting operation,
- Figure 6 (6a-6b) shows the processing of an updated image to determine tooth contours,

- Figure 7 schematically shows the relative position of register marks 12 on updated images 14_1 and 14_2 of a spreader 10, depending on the viewing direction (dashed line),

- Figure 8 shows a map resulting from the implementation of a method for checking the shape of a patient's teeth,

- Figure 9 shows a flow chart depicting the implementation of a method for checking tooth appearance,

- Figure 10 shows a flow chart depicting the implementation of a method for optimizing discriminative information, and

- Figure 11 shows a reference map for reflection information on an acquired image,

- Figures 12a and 12b show two views of a three-dimensional model with two different focal distances,

- Figure 13 shows an example of real and theoretical changes in the value of a momentum parameter as a function of time. The x-axis shows the time in weeks. The y-axis shows the parameter value, as a percentage of the desired value at the end of treatment,

- Figure 14 shows a flow chart depicting the implementation of an orthodontic appliance fitting method

<u>Detailed description of a method for checking tooth positioning</u>

A method for checking tooth positioning comprises the above-mentioned steps.

In step a), an initial reference model of the patient's arches, or part of the patient's arches, is created (see Figure 2).

The initial reference model is a three-dimensional digital model of the patient's arches, e.g. .stl or.Obj,.DXF 3D, IGES, STEP, VDA, or point cloud. Advantageously, such a “3D” model can be viewed from any angle.

For follow-up orthodontic treatment, the initial reference model is preferably prepared at the start of treatment. The initial reference model may correspond to a pre-treatment positioning of the patient's teeth, or to a positioning of the patient's teeth that the treatment is intended to achieve. In this case, the initial reference model is typically calculated from a first three-dimensional model corresponding to the positioning of the patient's teeth prior to treatment.

To check for recurrence, the initial reference model is preferably prepared less than six months, preferably less than three months, preferably still less than one month after the end of orthodontic treatment, usually immediately after the end of treatment. It thus corresponds to a substantially optimal positioning of the teeth.

The initial reference model can also be prepared independently of any treatment, for example because the patient wishes to monitor tooth movements.

The initial reference model can be prepared from measurements taken on the patient's teeth or on a physical model of the patient's teeth, e.g. a plaster model.

The initial reference model is preferably created using a professional device, such as a 3D scanner, preferably implemented by a healthcare professional, such as an orthodontist or orthodontic laboratory. In an orthodontic practice, the patient or the physical model of his teeth can be placed in a precise position, and the professional appliance can be perfected. The result is a highly accurate initial reference model. The initial reference model preferably provides tooth positioning information with an error of less than 5/10 mm, preferably less than 3/10 mm, most preferably less than 1/10 mm.

<u>Orientation of the initial reference model:</u>

Preferably, the orientation of the initial reference model in space is determined, and in particular, preferably, the occlusal plane and the median longitudinal plane.

The occlusal plane and median longitudinal plane can be determined manually, as an approximation. The inventors have, however, discovered procedures for determining these plans by computer processing.

Preferably, the reference model is a model of the arches with the mouth closed, that is, in a position wherein teeth of the upper arch are in contact with teeth of the lower arch.

Conventionally, the initial reference model provided by a three-dimensional CT scanner is used to distinguish the upper arch from the lower arch. Generally, the model is provided in the form of two files corresponding respectively to these arches, and including data enabling the models of these arches to be positioned relative to each other in the occlusal position.

Preferably, to estimate the points of contact between the teeth of the upper and lower arches, the set of points in the model of the upper and lower arches that are at a distance less than a predetermined limit is determined, this limit preferably being less than 3 mm, more preferably around 2 mm. All other points in these models are then ignored, resulting in the representation shown in Figure 3b. Linear regression is then used to determine the occlusal plane ("plane 1" in Figure 3c).

The initial reference model can then be oriented in the occlusal plane (Figure 3d).

If the initial reference model does not include data enabling the upper and lower arches to be positioned in relation to each other, an occlusal bite is preferably used, showing the contact points between the upper and lower teeth, and the upper and lower arch models are then repositioned in relation to this occlusal bite.

The median longitudinal plane is perpendicular to the occlusal plane, but its orientation is unknown.

Preferably, the orientation of the median longitudinal plane is determined as follows:

Consider axes [Ox) and [Oy) in the occlusal plane, with point O being the barycenter of the normal projections of the contact points onto the occlusal plane.

- In this reference frame (xOy), we look for the curve, preferably parabolic, with the highest correlation coefficient with all said projections.

- The set of contact point projections is then moved in the occlusal plane, by rotation around point O, and the previous step is repeated from this new angular position of the contact point projections.

The cycle of previous operations is continued, preferably until the set of contact points has been rotated through 360° around the barycenter O. The correlation coefficients corresponding to the different orientations of the set of contact points are then compared. The axis of the curve that leads to the highest correlation coefficient is then considered to be included in the median longitudinal plane, allowing the orientation of the latter to be defined exactly.

In this way, the orientation in space of the initial reference model is quickly and accurately determined.

Creating tooth models

In the initial reference model, a part that corresponds to a tooth, or "tooth model", is delimited by a gingival margin that can be broken down into an inner gingival margin (on the inside of the mouth with respect to the tooth), an outer gingival margin (facing the outside of the mouth with respect to the tooth) and two lateral gingival margins. Gingival margins correspond to regions wherein the surface orientation defined by the initial reference model undergoes strong amplitude changes. These variations in orientation can be identified using known techniques, for example by identifying changes in the direction of the normal to the modeled surface. Figure 4a shows a view of the initial reference model, processed to show these changes in direction. Figure 4b shows the inner gingival margin that can be extracted by analyzing the image in Figure 4a.

Several views of the initial reference model are thus analyzed, enabling the inner and outer gingival margins to be determined in three dimensions, as shown in Figure 4c.

In addition, when projected in the occlusal plane, the inner and outer gingival contours of an arch approach each other on both sides of a tooth. To determine a tooth's lateral gingival margin, we look for the shortest path, on the surface of the initial reference model, between the two points of the inner and outer gingival margins thus brought together and which are substantially opposite each other. Finding the shortest path between two points on a three-dimensional model calls on well-known optimization techniques. Preferably, this search results from a metaheuristic method, preferably evolutionary, preferably simulated annealing.

Two adjacent lateral gingival margins and the parts of the inner and outer gingival margins that connect these lateral gingival margins thus delimit a tooth at gingival level. Taking into account that a tooth extends from the gingival contour toward the occlusal plane, it is thus possible to determine which parts of the initial reference model correspond to which teeth ("tooth models"). Figure 4d shows all the tooth models in an arch.

The initial reference model can be stored in a centralized database, grouping together the initial reference models of a plurality of patients. This database can be physically installed in a specialized facility. It can also be installed in a laboratory or orthodontic practice, limiting the transfer of confidential information.

In one embodiment, the initial reference model is given to the patient. Preferably, a computer file corresponding to the initial reference model is saved on a removable medium, for example on a USB stick or on an electronic card, preferably on a cell phone, tablet or laptop of the patient, and in particular on the personal device that will preferably be used in steps b) and following. Preferably, the patient or a dental professional loads the initial reference model into said individual device or makes it available for loading into said individual device. Preferably, the patient loads the initial reference model from the Internet.

In a preferred embodiment, the reference model is not given to the patient. Preferably, the reference model is only made available to a specialized facility to implement steps c) to f). It can remain stored in the establishment where it was produced in step a) and where, preferably, steps c) to f) are carried out.

In step b), an updated image of a part of an arch, an arch or the arches is taken using an image acquisition device. Step b) is preferably carried out by the patient or someone close to the patient, but can also be carried out by a dentist.

<u>Time of acquisition</u>

Preferably, the updated image is taken after a time interval Δt after step a). The time interval Δt can be predetermined. It can be constant, regardless of the occurrence of the method, that is, whether this interval concerns the first execution of the method or a subsequent one. It can be variable, depending for example on the results obtained following a previous execution of the method. In particular, to check for recurrence, the time interval Δt can be all the shorter when this execution has detected a significant drift.

In a preferred embodiment, the time interval Δt is determined by the orthodontist, based on a schedule of checks. Depending on changes in tooth position, the orthodontist can modify this schedule and alter the time interval Δt accordingly. In one embodiment, the method for checking tooth positioning according to the invention is carried out several times, the time intervals between each execution being identical or different. The time intervals between two successive executions can all be determined before the first execution to correspond to a checking schedule drawn up by the orthodontist.

The time interval Δt can also be indeterminate, depending for example on patient decisions. For example, an updated image can be created at the time of a dental appointment, or at any time the patient wishes, or even independently of any orthodontic treatment.

The time interval Δt is preferably determined to correspond to a potentially significant change in tooth positioning.

For example, to check for recurrence, the time interval Δt is preferably less than three months in the first year after treatment. After this first year, the time interval Δt is preferably greater than one month, or even greater than six months or greater than twelve months. Particularly for detecting tooth drift, a time interval of between six and eighteen months is suitable.

Preferably, at least one reminder informing the patient of the need to create an updated image is sent to the patient. This reminder can be in paper form or, preferably, in electronic form, for example in the form of an e-mail, an automatic alert from the specialized mobile app or an SMS. Such a reminder can be sent by the orthodontic practice or laboratory, or by the dentist, or by the patient's specialized mobile app, for example.

In a preferred embodiment, an updated image is acquired before the teeth have been able to move significantly, substantially at the same time as the initial reference model was created, preferably less than 7 days, less than 3 days, less than 1 day after step a), that is, before the teeth have been able to move significantly. Implementing the method with this updated image advantageously enables verification that the method does not lead to the detection of any difference between the initial and updated reference models, and therefore functions correctly.

In one embodiment, the updated image can be acquired prior to the creation of the initial reference model. For example, steps a) and b) can be carried out at the end and beginning of an orthodontic treatment, respectively. This makes it possible, for example, to assess treatment efficacy in the absence of a 3D model at the start of treatment. In particular, the time interval Δt' between steps a) and b) in this embodiment can take on the values described above for Δt.

Image acquisition device

Preferably, the image acquisition device is a commercially available personal device, such as a cell phone, a connected camera, a smartwatch, or a tablet or personal computer, fixed or portable, with an image acquisition system, such as a webcam or a camera, preferably a digital camera. Even if the updated image can be created by a dentist, it is preferably created by the patient himself or someone close to him.

In particular, the updated image can be created by a person who has no particular knowledge of orthodontics, and in particular has no degree in orthodontics or dentistry.

Preferably, the same acquisition device is used to take all the updated images.

The image acquisition device preferably weighs less than 3 kg, less than 2 kg, less than 1 kg, less than 500 g, preferably less than 300 g.

Step b) can therefore advantageously be carried out at a distance from step a), that is, in a different location from that wherein step a) is carried out, in particular more than 50 m, more than 100 m, more than 1 km from the location where step a) is carried out, in particular outside the orthodontic practice. In one embodiment, step b) is not carried out in a dental practice, orthodontic practice or orthodontic laboratory, except possibly during a patient training session.

Preferably, the updated image is a photograph, in particular a panoramic photograph. In one embodiment, the updated image is extracted from a film.

In a preferred embodiment, the method uses several updated images to provide at least one representation of each tooth, preferably at least three updated images corresponding to a front, right and left view of the patient's teeth.

Preferably, in step b), at least one image updated in the closed-mouth position and at least one image updated in the open-mouth position are taken. The closed-mouth image can be used to identify relative displacements between the two arches. The updated open-mouth image makes it possible to clearly identify the contours of the teeth, without the upper-arch teeth obscuring the lower-arch teeth or vice versa.

Updated images can be taken for either the upper or lower arch, or preferably for both arches, in whole or in part.

Several similar images (representing substantially the same teeth) can also be useful in searching for the best score. In particular, depending on the acquisition conditions, discriminative information may lead to different scores depending on the updated image used.

Preferably, a dental retractor is used in step b), as shown in Figures 5a and 5c. The first function of the spreader is to spread the lips to improve the visibility of the teeth. Preferably, a retractor is given to the patient, for example at an appointment with the orthodontist or dentist.

The image acquisition device preferably provides color and/or infrared images of the patient's mouth, or even the patient's face. Color images preferably represent the patient's mouth in its true colors. Infrared images are ideal for showing the teeth with excellent contrast.

Preferably, the image acquisition device includes a dedicated application to implement step b), but also, preferably, the following steps, preferably all of the following steps. Preferably, this application manages reminders and informs the patient of the need to create an updated image.

Preferably, the specialized application is loaded into the image acquisition device from a physical medium such as a USB key or CD-ROM, or is downloaded from the Internet or over the air. In one embodiment, the specialized application is provided to the patient by the orthodontic practice and/or laboratory. In particular, it can take the form of an application of the type commonly downloaded on Apple® brand iPhones or devices of any brand running Android® or any other operating system.

The image acquisition device preferably comprises a still camera or a video or infrared camera, which the user, e.g. the patient or a person close to him, positions by means of a viewfinder or screen, before operating it.

Coding means and acquisition kit

A method for checking the positioning of teeth according to the invention does not require precise positioning of the image acquisition device relative to the teeth.

In one embodiment, no positioning constraints are imposed to ensure that the image acquisition device is positioned within 30 cm, 20 cm, 10 cm or 5 cm of a given location.

Preferably, however, the image acquisition device includes coding means to facilitate its approximate positioning relative to the patient prior to acquisition of the updated image.

The user can be guided through the acquisition process by written and/or voice prompts. For example, the personal device may announce “take a photo from the front”, emit a signal to inform the user that the photo is acceptable or that, on the contrary, that he must take another photo, announce “take a photo from the right”, preferably displaying an arrow to orient the user, etc. The end of the acquisition process may also be announced by the device. The device can also assist positioning, for example by visual messages (e.g. by displaying arrows), and/or audible messages (such as a succession of beeps whose frequency increases as the device's positioning improves), and/or written and/or vocal messages (“higher”, “lower”, etc.).

In particular, the coding means can include references that appear on the viewfinder or screen. The references may, for example, comprise a line intended to be aligned with the general direction of the joint between the upper and lower teeth when the teeth are clenched by the patient, and/or a vertical line intended to be aligned with the joint between the two upper incisors. References can also be made to other parts of the patient. For example, they may consist of marks corresponding to the position of the eyes, or take the form of a contour wherein the patient's mouth or face is to be positioned.

The reference(s) are preferably “immobile” on the screen, that is, they do not move on the screen when the acquisition device is in motion.

In a preferred embodiment, the reference(s) each correspond(s) to a register mark carried by a patient-reported reference frame, that is, not present on the patient prior to implementation of the method, preferably carried by a dental spreader. A reference frame can also be a part bitten by the patient.

The register mark can have a surface area greater than 0.5 mm^2, preferably greater than 1 mm^2, more preferably greater than 2 mm^2, more preferably greater than 5 mm^2, more preferably greater than 10 mm^2, even greater than 20 mm^2, even greater than 30 mm^2, and/or less than 50 mm^2.

The larger the size of a register mark or the more register marks there are, the more precise the positioning of the acquisition device will advantageously be.

The register marks can be identical or different.

In particular, the register marks can differ according to their position, for example whether they are at the top or bottom of the reference frame, and in particular of the spreader, or to the right or left of the reference frame, and in particular of the spreader.

The register mark may be identical to or different from the corresponding reference. It is preferably geometric in shape, e.g. a point, one or more lines, e.g. parallel, a star, a circle, an oval, a regular polygon, in particular a square, a rectangle or a rhombus.

The register mark can also be an image, a letter, a number or a sequence of letters and/or numbers.

The register mark is preferably of a different color from the surrounding spreader surface, preferably so as to provide a high contrast.

A register mark can be visible or invisible to the naked eye, as long as it appears on the screen of the acquisition device.

To improve accuracy, the register marks are preferably spaced apart so that, when they correspond to their respective references on the screen, at least the first and second register marks are less than 3 cm, preferably less than 2 cm, more preferably less than 1 cm, more preferably less than 0.5 cm, from first and second edges, respectively, of the screen. The first and second edges are preferably opposite edges of the screen.

The register mark may have one or more dimensions and/or a shape and/or color identical to or different from that of the corresponding reference.

The “correspondence” between a reference and a register mark is a predefined arrangement of one in relation to the other. It indicates a particular positioning of the acquisition device in relation to the register mark. The correspondence depends on the nature of the reference and the register mark. The predefined situation, which corresponds to target acquisition conditions, can in particular be a total or partial superposition, juxtaposition or alignment of the reference and register mark.

The exact superposition of the reference and register mark not only determines the direction in which the lens of the acquisition device should point and/or the distance between the acquisition device and the spreader, but also, if the reference and/or register mark are asymmetrical, the orientation of the acquisition device around this direction.

The dimensions and/or surfaces of a register mark and the corresponding reference and/or the distance between several register marks and between corresponding references can be used to set the distance between the acquisition device and the arches.

The reference can be, for example

- a fixed line, on which the user must align register marks, for example,

- a shape, preferably asymmetrical, corresponding to the shape of a register mark to be superimposed, for example a point which the user must superimpose on the register mark, or a circle wherein the user must place the register mark,

- a colored shape corresponding to the color of a register mark to be superimposed,

- a shape complementary to the shape of a register mark, preferably in such a way that matching the register mark and the reference leads to a shape with meaning, such as a geometric shape, a letter or text, a drawing, or a pattern, for example.

In one embodiment, the references are defined, at least in part, based on information provided by the initial reference model. For example, following the principles of “augmented reality”, the reference can be a view of the initial reference model, for example a front view or a right view or a left view of the initial reference model, made visible, in transparency, on the screen of the image acquisition device during acquisition. This makes it very easy for the patient to superimpose such a view approximately on the teeth to be photographed.

In a preferred embodiment, acquisition is carried out by means of an acquisition kit as described comprising:

- a dental spreader, preferably made of a biocompatible material, with a register mark;

- an image acquisition device, preferably of the type described above, comprising a screen for viewing an acquirable image, and a computer program comprising program code instructions for displaying at least one reference on said screen, said reference preferably being stationary on the screen, and arranged in a so-called “correspondence position” wherein, when the register mark corresponds to the reference on the screen, the acquirable image represents the spreader at a predetermined viewing angle and/or distance.

A kit enables images to be acquired without the need for a specialist, such as an orthodontist. In particular, acquisition can be carried out by the patient himself or by a person close to him, using a simple mobile phone, anywhere, and in particular outside a medical, dental or orthodontic practice.

Additionally, the image acquisition device does not need to be mechanically stabilized, for example by means of a tripod or by integration into a ground-mounted device.

Of course, an acquisition kit does not allow very precise positioning of the acquisition device in relation to the teeth.

In particular, the positioning accuracy of the spreader in relation to the teeth is limited. The person creating the images also positions the image acquisition device in an approximate manner, despite matching the register mark to the reference on the screen. As will be seen in greater detail later in the description, however, image processing does not require great precision in the positioning of the acquisition device at the time the images are acquired.

In contrast to previous technology, for example as described in WO2006/065955, it is not necessary, in particular, to use register marks at the time of image acquisition, the positioning of which is perfectly defined in relation to the teeth, in particular because they have been attached to the teeth themselves or because they result from a local modification, at a precise location, of a tooth, for example by laser. The ability to acquire images with limited precision is a considerable advantage, as it makes it possible for images to be acquired anywhere, by anyone. The patient is therefore no longer obliged to visit the orthodontist.

Preferably, no measurements are taken on the teeth to bring the acquisition device into the matching position.

Preferably, no register mark corresponding to a reference appearing on the screen is attached directly to the patient's teeth, gums or dental arches.

In particular, the acquisition device can be a cell phone, and the program can be a specialized cell phone application.

The spreader can have the same characteristics as the spreaders used to date. Conventionally, it comprises a support with a rim extending around an opening and arranged so that the patient's lips can rest on it, leaving the patient's teeth visible through said opening (Figure 5a and Figure 5c).

The support, for example made of plastic, is preferably substantially flat and weighs less than 500 g, preferably less than 300 g. The opening is preferably arranged substantially in the center of the support. The surface area of the opening is preferably greater than 15 cm^2, greater than 30 cm^2, greater than 40 cm^2, greater than 50 cm^2, and/or less than 100 cm^2, less than 80 cm^2, less than 60 cm^2.

Preferably, as shown in Figure 5a, the spreader has a number of register marks, preferably non-aligned, preferably coplanar.

Preferably, the spreader has at least three register marks, and the computer program can be used to display one or more corresponding references on the screen of the acquisition device.

In one embodiment, the positioning of the image acquisition device results from the sole matching of references appearing on the screen of said acquisition device with corresponding register marks, preferably with register marks of a dental spreader.

In one embodiment, the reference(s) displayed on the screen are determined according to the patient and/or therapeutic treatment. In other words, the computer program is parameterized according to the patient, so that the images acquired correspond specifically to the patient's needs. Advantageously, at the time of image acquisition, the acquisition device is therefore positioned in a substantially optimal position with regard to the particularities of the patient and/or the therapeutic treatment applied.

As will be seen in greater detail later in the description, the register marks of the spreader preferably have several functions. Firstly, they are used to guide the positioning of the image acquisition device at the time of image acquisition, by means of corresponding references appearing on the screen of the acquisition device. In step c), they also enable the updated images to be resized. Finally, in step d), the register marks of the spreader that appear on the images enable virtual acquisition conditions that approximate real acquisition conditions to be roughly determined, thus speeding up computer processing.

Steps c) and following are preferably carried out either on the patient's own device, preferably the device used in step b), or with a dental professional's application, or with a dedicated third-party server.

In step c), each updated image is analyzed to produce, for each updated image, an updated map relating to at least one piece of discriminative information.

Resizing

Image analysis may involve resizing the updated image to isolate the relevant part, in particular to remove, at least partially, from the updated image those elements which were not the subject of the initial reference model, such as the patient's nose or eyes, or the spreader. This resizing, or “cropping”, is facilitated by the representation of register marks on the updated image.

In particular, as shown in Figures 5a and 5c, the spreader 10 carries at least three non-aligned register marks 12. If the spreader is in several parts, for example conventionally in two parts, each part preferably carries at least three non-aligned register marks.

The shape of a register mark, for example an asymmetrical shape, can also be used to mark the position of the spreader on the updated image.

Preferably, the register marks have shapes and/or colors that make them easy to identify on an updated image. For example, they may be black, while the rest of the spreader is white.

In one embodiment, the register marks are individually identifiable by shape and/or color. For example, they can each be a different color.

By identifying the register marks on the updated image, it is possible to identify the area of the updated image containing the elements that were the subject of the initial reference model, that is, the teeth and gums. The updated image can then be cropped accordingly. Comparing Figures 5a and 5b, or 5c and 5d, shows the effect of resizing on an updated image.

Updated map

An updated map depicts discriminative information in the updated image reference frame. For example, Figure 6b is an updated tooth contour map obtained from the updated image of Figure 6a.

The discriminative information is preferably selected from the group consisting of contour information, color information, density information, distance information, brightness information, saturation information, reflection information and combinations of this information.

Those skilled in the art know how to process an updated image to reveal discriminative information. This processing involves, for example, the application of well-known masks or filters provided with image processing software. Such processing can be used, for example, to detect regions of high contrast to determine contours.

This processing in particular comprises one or more of the following known and preferred methods, namely:

- by applying a Canny filter, in particular to search for contours using the Canny algorithm;
- by applying a Sobel filter, in particular to calculate derivatives using the extended Sobel operator;
- by applying a Laplace filter, to calculate the Laplacian of an image;
- by blobdetecor detection;

- by applying a “threshold” to apply a fixed threshold to each element of a vector;

- by resizing, using relationships between pixel areas (“Resize(Area)”) or bi-cubic interpolations on the pixel environment;

- by erosion of the image using a specific structuring element;

- by dilating the image with a specific structuring element;

- by retouching, in particular using regions in the vicinity of the restored area;

- by applying a two-sided filter;

- by applying a Gaussian blur;

- by applying an Otsu filter to find the threshold that minimizes intra-class variance;

- by applying an A* filter, to find a path between points;

- by applying an adaptive threshold so as to apply an adaptive threshold to a vector;

- by applying an equalization filter to a histogram of a particular grayscale image;

- by blurDetection, to calculate the entropy of an image using its Laplacian;

- by contour detection (“FindContour”) of a binary image;

- by color fill (“FloodFill”), in particular to fill a connected element with a specific color.

The following non-limiting methods, although not preferred, can also be used:

- by applying a “MeanShift” filter, so as to find an object on a projection of the image;

- by applying a CLAHE (Contrast Limited Adaptive Histogram Equalization) filter;

- by applying a “Kmeans” filter, to determine the center of clusters and groups of samples around clusters;

- by applying a DFT filter, so as to perform a discrete, direct or inverse Fourier transform of a vector;

- by calculating moments;

- by applying a “HuMoments” filter to calculate invariants of Hu invariants;

- by calculating the integral of an image;

- by applying a Scharr filter, which calculates a derivative of the image using a Scharr operator;

- by searching for the convex envelope of points (“ConvexHull”);

- by searching for contour convexity points (“ConvexityDefects”);

- by shape comparison (“MatchShapes”);

- by checking whether points are in a contour (“PointPolygonTest”); by detecting Harris contours (“CornerHarris”);

- by searching for the minimum eigenvalues of gradient matrices to detect corners (“CornerMinEigenVal”);

- by applying a Hough transform to find circles in a grayscale image (“HoughCircles”);

- by active contour modeling (tracing the contour of an object from a potentially “noisy” 2D image);

- by calculating a field of forces, referred to as GVF (“gradient vector flow”), in a part of the image;

- by Cascade Classification;

- by “Deeplearning”.

Preferably, the discriminative information is optimized by means of an optimization method including steps C1 to C3.

In optional step d), the real acquisition conditions of step b) are roughly determined. In other words, at least the relative position of the image acquisition device at the time it took the updated image (position of the acquisition device in space and orientation of this device) is determined. Step d) advantageously limits the number of tests on virtual acquisition conditions during step e), and thus considerably speeds up step e).

Preferably, one or more heuristic rules are used. For example, the virtual acquisition conditions to be tested in step e) preferably exclude those corresponding to a position of the image acquisition device behind the teeth or at a distance from the teeth greater than 1 m.

In a preferred embodiment, as shown in Figure 7, register marks represented on the updated image, and in particular spreader register marks 12, are used to determine a region of substantially conical space delimiting virtual acquisition conditions that may be tested in step e), or “test cone”.

Specifically, at least three non-aligned register marks 12 are preferably arranged on the spreader 10, for example, and their relative positions on the spreader are precisely measured.

The register marks are then marked on the updated image, as described above. Simple trigonometric calculations can be used to determine the approximate direction in which the updated image was taken. A cone oriented in this direction, whose vertex is at the spreader and whose half-angle at the vertex is preferably less than 10°, preferably less than 5°, for example 3°, can then be defined as a “test cone”. The half cone angle corresponds to a degree of uncertainty. The smaller the half cone angle, the greater the probability that the virtual acquisition conditions corresponding to the real acquisition conditions are outside the test cone.

For example, when the updated image is taken perpendicular to the plane of the three register marks on the spreader, it can be deduced that the acquisition device was substantially in a test cone whose axis is substantially perpendicular to this plane when the updated image was taken. If the relative positions of the three register marks on the updated image are different from those occupied by the register marks on the spreader, the axis of the test cone, within which the search for the position of the acquisition device is limited when the updated image is acquired, is tilted with respect to the plane of the register marks, as shown in Figure 7.

In a particular embodiment, as shown in Figures 5a and 5c, the spreader includes independent left and right portions, each of which has at least three, preferably at least four, register marks. A left-hand test cone can thus be determined by means of the register marks on the left-hand part, and a right-hand test cone can be determined by means of the register marks on the right-hand part of the spreader. The virtual acquisition conditions that can be tested can then be limited to positions of the acquisition device in the space belonging to these two test cones. We can also consider that the best evaluation of the acquisition device's position corresponds to the average position between the best position in the left test cone and the best position in the right search cone.

The position of the register marks on the updated image also makes it possible to assess the attitude of the acquisition device when the updated image is captured. For example, if it is known that two register marks are substantially aligned in a horizontal direction when the updated image is acquired, the direction of the straight line containing these two points on the updated image provides an indication of the orientation of the acquisition device under real acquisition conditions.

Finally, the size and surface area of the register marks on the updated image, or their spacing, can be used to assess the distance between the image acquisition device and the teeth during acquisition of the updated image, and thus to reduce the test cone to a truncated cone.

In optional step d), data supplied by the acquisition device concerning its orientation, such as gyroscopic data, can also be used.

Preferably, in step d), the calibration of the real acquisition device in step b) is roughly determined.

The way in which each calibration parameter affects the acquired image is well known. In particular, the operation of an acquisition device can be conventionally modeled so that a particular calibration can be tested on the acquired image. The inventors have inverted such a model, without any particular technical difficulty, so that by analyzing the representation of the spreader, it is possible to roughly evaluate the calibration of the acquisition device in step b).

For example, the ratio between the area of the register marks on the updated image and the area of the updated image is used to estimate the focal length of the acquisition device in step b). The representation of a register mark with known optical characteristics can be used to evaluate exposure time and sensitivity.

In a preferred embodiment, a register mark is a relief that does not extend exclusively in the general plane of the spreader, corresponding to a plane parallel to the frontal (or coronal). Preferably, a register mark is a relief that extends in a plane substantially perpendicular to the general plane of the spreader. In particular, the relief can take the form of a tongue which, when the spreader is in its operating position, extends toward the bottom of the mouth.

By analyzing the representation of this relief, it is possible to evaluate the depth of field. Alternatively, two register marks that are not in the same frontal plane can be used for this purpose.

Step d) allows only a rough assessment of the real acquisition conditions. However, step d) allows determination of a restricted set of virtual acquisition conditions which are likely to correspond to real acquisition conditions, and, within this set, virtual acquisition conditions which constitute the best starting point for step e1) described below.

Step d) also detects updated images that are unsuitable for further processing, e.g. an updated image that does not show register marks. Preferably, the method is then repeated in step c) with a new, updated image.

Of course, the different methods that can be used in step d) can be combined.

The aim of step e) is to modify the initial reference model until an updated reference model is obtained that corresponds to the updated image. Ideally, then, the updated reference model is a digital three-dimensional reference model from which the updated image could have been taken had it been real.

A succession of “to-be-tested” reference models is therefore tested, the choice of a reference model to be tested preferably being dependent on the level of correspondence of the previously tested “to-be-tested” reference models with the updated image. This choice is preferably made by following a known optimization method, in particular chosen from metaheuristic, preferably evolutionary, optimization methods, in particular simulated annealing methods.

In step e1), the reference model to be tested is determined to be the initial reference model in the first execution of step e2).

Step e2) begins by determining the virtual acquisition conditions to be tested, that is, a virtual position and orientation likely to correspond to the real position and orientation of the acquisition device when the updated image is captured, but also preferably a virtual calibration likely to correspond to the real calibration of the acquisition device when the updated image is captured.

The first virtual acquisition conditions to be tested may be random. Preferably, they are chosen from the limited set determined in step d), and even more preferably, correspond to virtual acquisition conditions corresponding, according to step d), to the most promising virtual acquisition conditions, that is, constituting the best springboard for approaching real acquisition conditions as quickly as possible (step e21)).

The image acquisition device is then virtually configured under the virtual acquisition conditions to be tested in order to acquire a reference image of the reference model to be tested under these virtual acquisition conditions to be tested. The reference image thus corresponds to the image that the image acquisition device would have taken if it had been placed, relative to the reference model to be tested, and optionally calibrated, under the virtual acquisition conditions to be tested (step e22)).

If the updated image was taken when the position of the teeth was exactly the same as in the reference model to be tested, and if the virtual acquisition conditions are exactly the same as the real acquisition conditions, then the reference image is perfectly superimposable on the updated image. Differences between the updated image and the reference image result from errors in the evaluation of the virtual acquisition conditions (if they do not correspond exactly to the real acquisition conditions) and from tooth displacements between step b) and the reference model to be tested.

To compare updated and reference images, we compare the discriminative information on these two images. More precisely, a reference map depicting the discriminative information is created from the reference image (step e23)).

The updated and reference maps, both dealing with the same discriminative information, are then compared, and the difference between the two maps is evaluated by means of a score. For example, if the discriminative information is tooth contour, it is possible to compare the average distance between the points of the tooth contour that appear on the reference image and the points of the corresponding contour that appear on the updated image; the lower the distance, the higher the score.

Preferably, the virtual acquisition conditions comprise the calibration parameters of the acquisition device. The higher the score, the closer the calibration parameter values tested are to the calibration parameter values of the acquisition device used in step b). For example, if the tested aperture value is far from that of the acquisition device used in step b), the reference image has blurred and sharp regions that do not correspond to the blurred and sharp regions of the updated image. If the discriminative information is the tooth contour, then the updated and reference maps will not represent the same contours, and the score will be low.

The score can be, for example, a correlation coefficient.

The score is then evaluated using a first evaluation function. The first evaluation function is used to decide whether the cycling on step e2) should be continued or stopped. The first evaluation function can, for example, be equal to 0 if cycling is to be stopped, or equal to 1 if cycling is to continue.

The value of the first evaluation function may depend on the score achieved. For example, it may be decided to continue cycling on step e2) if the score does not exceed a first threshold. For example, if an exact match between the updated and reference images leads to a score of 100 %, the first threshold can be, for example, 95 %. Of course, the higher the first threshold, the more accurate the assessment of virtual acquisition conditions will be if the score manages to exceed this first threshold.

The value of the first evaluation function may also depend on scores obtained with previously tested virtual acquisition conditions.

The value of the first evaluation function may also depend on random parameters and/or the number of cycles of step e2) already performed.

In particular, it is possible that, despite repeated cycles, virtual acquisition conditions may not be found that are sufficiently close to real acquisition conditions for the score to reach said first threshold. The first evaluation function can then lead to a decision to quit cycling even though the best score obtained has not reached said first threshold. This decision may be based, for example, on a number of cycles in excess of a predetermined maximum number.

A random parameter in the first evaluation function may also allow further testing of new virtual acquisition conditions, even though the score appears satisfactory.

Evaluation functions conventionally used in metaheuristic, preferably evolutionary, optimization methods, in particular in simulated annealing methods, can be used for the second evaluation function.

If the value of the first evaluation function indicates that it is decided to continue cycling through step e2), the virtual acquisition conditions tested are modified (step e25)) and a cycle is repeated (step e2)) consisting of producing a reference image and a reference map, then comparing this reference map with the updated map to determine a score.

The modification of the virtual acquisition conditions corresponds to a virtual displacement in space and/or a modification of the orientation and/or, preferably, a modification of the calibration of the acquisition device. This modification can be random, provided that the new virtual acquisition conditions to be tested always belong to the set determined in step d). Modification is preferably guided by heuristic rules, for example by favoring those modifications which, according to an analysis of previous scores obtained, appear most favorable for increasing the score.

Figures 12a and 12b show, for example, the effect of a change in virtual acquisition conditions, in this case a change in focal length, on the reference image.

Cycling on e2) is continued until the value of the first evaluation function indicates that it is decided to exit this cycling and continue to step e3), for example if the score reaches or exceeds said first threshold.

Optimization of the virtual acquisition conditions in step e2) is preferably performed using a metaheuristic method, preferably evolutionary, preferably a simulated annealing algorithm. Such an algorithm is well known for nonlinear optimization.

If cycling has been terminated at step e2), without a satisfactory score having been obtained, e.g. without the score having reached said first threshold, the method can be stopped (failure situation) or resumed at step c) with new discriminative information and/or with a new updated image. The method can also be continued with the virtual acquisition conditions corresponding to the best score achieved. A warning can be issued to inform the user of the error in the result.

If cycling has been terminated in step e2) after a satisfactory score has been obtained, for example because the score has reached or even exceeded said first threshold, the virtual acquisition conditions correspond substantially to the real acquisition conditions.

Preferably, the virtual acquisition conditions comprise the calibration parameters of the acquisition device. In this way, it is possible to evaluate the values of these parameters without having to know the nature of the acquisition device or its settings. Step b) can therefore be carried out without any special precautions, for example by the patient himself using his cell phone.

Additionally, the search for real calibration is carried out by comparing an updated image with views of an initial reference model under the virtual acquisition conditions being tested. Advantageously, it does not require the updated image to show a calibration gauge, that is, a gauge whose characteristics are precisely known, enabling the calibration of the acquisition device to be determined.

WO2006/065955 describes the use of images to produce three-dimensional models for orthodontic treatment. However, this document does not describe a method for using simple photographs, typically presenting partial images of teeth, blurred image portions and variable reflections, generally taken non-simultaneously, without the need to select remarkable points on the images, and with an acquisition device whose calibration is not known.

In a method for checking tooth positioning, the updated images are not used to create a completely new, updated three-dimensional model, but only to modify the initial, highly accurate reference model. In particular, a completely new, updated three-dimensional model created from simple photographs taken without special precautions would be too imprecise for a comparison with the initial reference model to lead to any conclusions about tooth displacement.

Differences may remain between the virtual acquisition conditions determined and the real acquisition conditions, particularly if teeth have moved between steps a) and b). The correlation between the updated and reference images can then be further improved by repeating step e2), in which case the reference model to be tested is modified by moving one or more tooth models (step e3)).

The search for the reference model that best approximates the positioning of the teeth during the acquisition of the updated image can be carried out as the search for virtual acquisition conditions that best approximate the real acquisition conditions (step e2)).

In particular, the score is evaluated using a second evaluation function. The second evaluation function is used to decide whether the cycling in steps e2) and e3) should be continued or stopped. The second evaluation function can, for example, be equal to 0 if cycling is to be stopped, or equal to 1 if cycling is to continue.

The value of the second evaluation function preferably depends on the best score obtained with the reference model to be tested, that is, the differences between the updated and reference maps, under virtual acquisition conditions that best approximate said real acquisition conditions.

The value of the second evaluation function may also depend on the best score obtained with one or more previously tested reference models.

For example, it may be decided to continue cycling if the score does not exceed a second minimum threshold. The value of the second evaluation function may also depend on random parameters and/or the number of cycles of steps e2) and e3) already performed.

Evaluation functions conventionally used in metaheuristic, preferably evolutionary, optimization methods, in particular in simulated annealing methods, can be used for the second evaluation function.

If the value of the second evaluation function indicates that it is decided to continue cycling through steps e2) and e3), the reference model to be tested is modified and a cycle is repeated (steps e2) and e3)) with the new reference model to be tested.

Modifying the reference model to be tested means moving one or more tooth models. This modification can be random. Modification is preferably guided by heuristic rules, for example by favoring those modifications which, according to an analysis of previous scores obtained, appear most favorable for increasing the score.

Preferably, the displacement of a tooth model that has the greatest impact on the score is sought, the reference model to be tested is modified by displacing this tooth model, and then the cycling is continued through steps e2) and e3) so as to optimize the score. It is then possible to search for the other tooth models that have the greatest impact on score improvement, and again search for the optimal displacement of this other tooth model on the score. This approach can be continued with each tooth model.

A cycle can next be repeated on all tooth models, continuing until a score above the second threshold is achieved. Of course, other strategies can be used to move one or more tooth models into the reference model to be tested and search for the maximum score.

Cycling through steps e2) and e3) is continued until the value of the second evaluation function indicates that it is decided to exit this cycling and continue to step f), for example if the score reaches or exceeds said second threshold.

The search for a reference model with cycling through steps e2) and e3) to find the positions of the tooth models that optimize the score is preferably performed using a metaheuristic, preferably evolutionary, method, preferably a simulated annealing algorithm. Such an algorithm is well known for nonlinear optimization.

If cycling has been terminated at steps e2) and e3), without a satisfactory score having been obtained, e.g. without the score having reached said second threshold, the method can be stopped (failure situation) or resumed at step c) with new discriminative information and/or with a new updated image.

If it is decided to restart the method in step c) using another piece of discriminative information and/or another updated image because the first threshold or the second threshold has not been reached, the choice of the new piece of discriminative information and/or the new updated image may depend on the scores obtained previously, in order to favor the piece of discriminative information and/or the updated image which, with regard to these scores, appear to be the most promising.

New discriminative information, obtained for example by combining other discriminative information already tested, can be used. If necessary, the acquisition of one or more new, updated images may also be requested. Preferably, indications are provided to guide the positioning of the acquisition device for capturing this new updated image. For example, the patient may be told to take a photo of the right side of the lower arch.

If cycling has been terminated in steps e2) and e3) without a satisfactory score having been achieved, the method can also be continued with the reference model and virtual acquisition conditions corresponding to the best score achieved. A warning can be issued to inform the user of the error in the result.

If cycling has been terminated in steps e2) and e3) after a satisfactory score has been obtained, for example because the score has reached or even exceeded said second threshold, the virtual acquisition conditions correspond substantially to the real acquisition conditions and the tooth models in the reference model obtained (referred to as the "updated reference model") are substantially in the position of the patient's teeth at the time of step b).

Cycling through steps e2) and e3) advantageously improves the evaluation of the calibration parameters of the acquisition device in step b).

In step f), the updated reference model resulting from the tooth model displacement optimization is compared with the initial reference model. The updated reference model corresponds substantially to the updated image. The comparison in step f) therefore allows observation of the differences between tooth positioning in step a) (initial reference model) and during acquisition of the updated image (step b). In this way, the movements between these two steps can be precisely determined for each tooth.

By repeating steps b) and following, it is also possible to evaluate the rate of change in tooth position, and thus measure the effectiveness of orthodontic treatment, for example. A method for checking tooth positioning according to the invention can, for example, be used to remotely monitor the progress of orthodontic treatment, and thus optimize patients' appointments with their orthodontists.

In a preferred embodiment, the checking method according to the invention is carried out several times for the same patient, preferably successively with several pieces of discriminative information, preferably more than 2, more than 3, more than 5 pieces of discriminative information for each updated image and/or with several updated images, preferably more than 2, more than 3, more than 5 updated images. The evaluation of tooth displacement can thus be refined by taking into account the different scores obtained. Comparing these scores also makes it possible, where appropriate, to discard discriminative information and/or unsatisfactory updated images.

Depending on the displacement measured, practical information can be generated. If the displacement is small, this practical information may mean that no action is required. On the contrary, if one or more teeth have shifted substantially, the information may be to schedule a visit to the dentist or orthodontist. Preferably, the practical information depends on the degree of tooth displacement. In one embodiment, an appointment can be automatically booked with the dentist or orthodontist, depending on the amplitude and/or nature of the detected displacements.

In one embodiment, the practical information is used to modify the time interval after which the patient should be notified that a new, updated image is to be created.

In one embodiment, the individual device can display images or even a sequence of images showing the positioning of teeth at different dates. These images can be presented in the form of an animation, such as a slide show or film.

Preferably, the image acquisition device is a telephone that enables the results obtained by implementing the method to be transmitted, preferably securely.

For example, communication can be carried out, at least in part, over the air, preferably using at least one protocol chosen from the edge, 3G, 4G, udmsa, hpdmsa, Bluetooth and WiFi protocols, or any other protocol suitable for mobile or nomadic equipment, by wired synchronization with the personal computer, or by optical transmission.

As is now clear, a method for checking tooth positioning enables precise and effective checking of the positioning of a patient's teeth, with substantially no strain on the patient. In particular, simple photographs taken without any special precautions, for example with a cell phone, are sufficient. The patient can therefore easily implement this method.

<u>Detailed description of a method for fitting a worn orthodontic appliance</u>

The orthodontic appliance worn by the patient may be the first orthodontic appliance initially made available for his orthodontic treatment, or a replacement appliance made available at a later date.

The first orthodontic appliance can be manufactured using a conventional method.

In particular, for a treatment using aligners, the orthodontist can, at the start of the treatment, determine a first series of aligners fitted so that the teeth reach a position corresponding to an objective reference model, preferably representing a final set-up, manufactured according to a step b'), as described below. This determination can be carried out in the conventional way.

Preferably, only the first aligner in this first series is made and supplied to the patient.

The ability to assess tooth positioning using simple photographs, taken without any special precautions, particularly from a cell phone, means that more checks can be carried out during orthodontic treatment. Treatment can therefore be adapted on a regular basis, for example by adapting or changing the orthodontic appliance.

Typically, the appliance resulting from this treatment adaptation is referred to as a “replacement orthodontic appliance”. The replacement orthodontic appliance can therefore be the orthodontic appliance previously worn, referred to as “worn orthodontic appliance”, and fitted, for example by changing the archwire attached to the teeth or modifying its tension. The replacement orthodontic appliance can also be a new orthodontic appliance, in particular when active aligners are used for treatment.

A method of fitting an orthodontic appliance according to the invention comprises steps a') to f') described above, and shown in Figure 14.

Step a') is identical to step a) and may include one or more of the optional features of step a) described in the present disclosure. This leads to an initial reference model that digitally represents, in three dimensions, at least the part of the arches containing the patient's teeth to be treated. The initial reference model can be produced by all known conventional methods.

Step a') is preferably the first step. In particular, the objective reference model is typically determined from the initial reference model.

Step b') consists in producing an objective reference model which digitally represents, in three dimensions, the teeth to be treated in a position to be reached at a given point in time during the treatment, in particular at the end of the treatment (“final set-up”) or at a predetermined intermediate stage of the treatment ("intermediate set-up"), for example at a point in time when the aligner is to be changed or the tension of the archwire is to be modified.

All intermediate set-ups can be performed at the start of treatment. The number of intermediate set-ups can be greater than 1, 2, 10, 20, 30, 40, 50 or 60. The time between two successive intermediate set-ups may be less than 10 weeks, 8 weeks, 6 weeks, 4 weeks, 2 weeks or one week.

The objective reference model can be produced using all known conventional methods.

Preferably, the objective reference model results from a deformation of the initial reference model. In particular, tooth models corresponding to the teeth to be treated are conventionally moved virtually to their desired position.

Alternatively, a physical model, such as a plaster cast, representing the teeth in their desired position can also be produced and then scanned in three dimensions.

Step b') is preferably carried out at substantially the same time as step a'). However, it can be carried out at any time up to the first use of the objective reference model.

Step c') for producing an updated reference model is identical to steps b) to e) and may include one or more of the optional features of these steps described in the present disclosure.

It is preferably carried out at a time when the orthodontist decides that the patient needs a check-up on the effectiveness of his treatment, for example more than 1 week or more than 2 weeks after step a') of creating the initial reference model. It can also be decided by the patient or planned.

The updated reference model is obtained by deforming the initial reference model, preferably by moving the tooth models, using information from the updated images. More precisely, the deformation is optimized, preferably by an evolutionary method, preferably by simulated annealing, so that the updated images correspond as closely as possible ("best fit") to views of the initial deformed reference model, then referred to as the “updated reference model”. In other words, these views are substantially identical to the updated images.

Preferably, the updated reference model is made available to the orthodontist in real time. In particular, if it is determined with a patient's own device, such as a telephone, it can be sent to the orthodontist. Advantageously, the orthodontist is thus alerted and can intervene accordingly.

Using only updated images, without the initial reference model, does not allow an accurate three-dimensional model to be built. It is the use of these images to modify the initial reference model (which is highly accurate, especially when obtained by scanning) that leads to an accurate updated reference model, even though the updated images were taken without any particular precautions.

The updated reference model thus provides positioning parameter values for tooth points at the time the updated images are acquired.

Preferably, the value of a positioning parameter for a point on a tooth, such as the tooth's barycenter, is plotted on a graph.

Preferably, for each check-up cycle, the graph shows the value of this positioning parameter for this point on the tooth. Preferably, a curve connects these points. Even more preferably, the time scale, preferably on the abscissa, is linear. The dynamics of the treatment, as far as this parameter is concerned, is advantageously immediately perceptible. The orthodontist and/or the patient can thus immediately perceive a loss of efficiency of the orthodontic appliance and act accordingly.

Step d') for determining a comparison model can be carried out at any time before step e').

Preferably, the comparison model provides theoretical tooth positions, or tooth points, at intermediate times between the start and end of treatment. Preferably, the comparison model is a three-dimensional digital model. This enables visual comparison with the updated reference model. Preferably, the theoretical position of a tooth or a point on a tooth results from processing the initial reference model and the objective reference model, in particular from a preferably non-linear interpolation between the positions of this tooth or this point between these two models.

For example, the position (x,y,z) of a point M on a tooth can be defined in a three-dimensional, e.g. orthonormal, reference frame. The position of this point in the initial reference model, at time t_0, and in the objective reference model, at time t_G, can be noted as (x_0,y_0,z_0) and (x_G,y_G,z_G), respectively. If we consider that displacement is rectilinear and evolves linearly with time, the theoretical intermediate position of this point at the intermediate instant t_i in the middle of processing will be (x_i,y_i,z_i), with $x_i = (x_0 + x_G)/2$, $y_i = (y_0 + y_G)/2$ and $z_i = (z_0 + z_G)/2$.

Even more preferably, the comparison model depends on one or more previous updated reference models and/or one or more previous comparison models (established in previous checking cycles, that is, in particular previous steps c')). Accuracy is considerably improved.

Preferably, the determination of the comparison model depends on evolutions between several updated, preferably successive, reference models. For example, updated reference models may have been produced three months, two months and one month ago, at t_{-3}, t_{-2} and t_{-1}, respectively. The displacement of a tooth's barycenter along the Ox axis between t_{-3} and t_{-2} may be 100 µm, for example, and the displacement between t_{-2} and t_{-1} may be 80 µm. By simple linear extrapolation, we can then assume that the displacement along the Ox axis between t_{-1} and today (t_0) will be 60 µm, enabling creation of a comparison model at t_0 with a high degree of precision.

All conventional prediction methods can be used, a prediction method being a method that uses a predictive model to make a prediction based on known data.

A predictive model is therefore a model for simulating future tooth displacement based on past data, in particular past tooth displacements and/or past or calculated orthodontic appliance behavior.

Preferably, the predictive model takes into account the action of the orthodontic appliance on the teeth. Thus, in the example above, if it is known that the action of the orthodontic appliance on the displacement of the barycenter of a tooth along the Ox) axis decreases with time, the displacement along the Ox) axis between t_{-1} and today (t_0) could be estimated at 50 µm and not 60 µm.

Tools that simulate tooth displacements between two extreme positions, taking into account tooth interactions, such as Clincheck by Align Technology, Suresmile® by Orametrix, Virtual Setup by Harmony or Insignia by Ormco, are well known. Preferably, a model of the orthodontic appliance is also used to simulate its action, over time, on the teeth, based on their positions, and in particular their position in the initial reference model and/or their position in the updated reference model. As will be seen in more detail later in the disclosure, a method for evaluating the behavior of an orthodontic appliance makes it possible to design and/or refine such predictive models.

Preferably, a dynamic model is built, capable of providing the theoretical position of teeth or a set of tooth points, preferably of each tooth model, at any instant between the start and end of treatment or, more generally, between the instants corresponding to the initial and objective reference models. Software can be used for this purpose.

Step d') can be carried out immediately after steps a') and b') have been carried out, for example less than 3 months, less than a month or less than a week after steps a') and b') have been carried out.

Preferably, the comparison model is determined to correspond to a simulation of the position of the treated teeth at a time t_c as close as possible to the time of execution of step c'), and in particular to the time t_a at which the updated images were acquired. Preferably, these two moments are separated by less than 1 month, less than two weeks, preferably less than one week, preferably less than one day.

In Figure 13, the two instants t_c and t_a are the same, which is possible when a dynamic three-dimensional model is available, capable of providing the theoretical position of the teeth at any time between the start and end of treatment. Knowing the time t_a, it is sufficient to choose the dynamic model at time t_a as the comparison model.

In one embodiment, the comparison model is always the objective reference model. However, the precision of the orthodontic appliance is not optimal.

In step e'), the updated reference model, which corresponds to the situation observed at the time of checking, is compared with the theoretical comparison model.

The comparison can be made by the patient and/or the orthodontist.

The comparison preferably involves determining, for each point of a set of points of the teeth of the updated reference model, preferably for at least three non-coplanar points of each tooth of the updated reference model, the displacement (vector) between the representations of this point on the comparison and updated models. This displacement is preferably quantified by means of distances and/or angles in a three-dimensional reference frame Oxyz, for example in an orthonormal reference frame. For example, displacement can be determined in Cartesian or cylindrical coordinates.

Analysis of the displacement of a few points on the teeth can be difficult to present or analyze. Points on the same tooth are considered to be rigidly connected to each other. Preferably, the analysis of the displacement of the points of a single tooth is generalized to evaluate the displacement of all the points of this tooth, that is, the displacement of the corresponding tooth model.

In particular, knowledge of the displacement of three non-coplanar points on a tooth enables evaluation of the movement of this tooth between its representation (that is, the corresponding tooth model) in the updated reference model and its representation in the comparison model, or “quantity of movement”. The quantity of movement can be expressed by differences in the values of a set of positioning parameters used to fix the position and orientation of an object in space, for example Cartesian coordinates of a point on the tooth, e.g. its barycenter, and values of angles around a fixed, e.g. orthonormal, reference frame (differences between the values in the updated reference model and in the comparison model).

Preferably, for each of the positioning parameters, the path to be covered from the updated reference model to the comparison model is determined, for example the distance to be covered by the tooth barycenter along each of the axes of a fixed orthonormal reference frame and the rotation to be performed about each of these axes.

Preferably, in step e'), the displacement velocity of the points under consideration is evaluated, preferably using the initial reference model, and preferably one or more updated reference models determined previously, in particular during previous check-up cycles. The displacement speed of a point on a tooth, in one direction, between two successive updated reference models can be simply evaluated by dividing the distance between the representations of this point on these two models, in this direction, by the time elapsed between the production of these two models.

Preferably, the slowing or acceleration of tooth point displacement is evaluated by comparing the speeds of two successive periods.

If the objective reference model is a final or intermediate set-up, the comparison can be used to evaluate the quantities of movement still required to complete the processing or reach the end of the intermediate processing step, respectively. The comparison also makes it possible to evaluate the speed of tooth displacements up to the end of the intermediate step or the end of treatment, respectively.

However, this comparison cannot be used to accurately estimate whether processing is proceeding as planned unless it is carried out at a time close to the end of the intermediate step or the end of processing. Detecting an abnormal situation, or more generally a situation requiring fitting of the orthodontic appliance, then requires great analytical skills.

Therefore, preferably, as indicated above, the comparison model is one that corresponds to an estimate of the expected tooth position substantially at time t_a of step c'), for example determined at the start of treatment or following the immediately preceding check-up cycle.

The comparison between the real situation, evaluated with the updated reference model determined in step c'), and the expected situation, evaluated with the comparison model, determines whether the orthodontic appliance is performing its function correctly.

If necessary, it can also be used to determine what is lacking, such as too much force on a tooth, depending on the direction.

The comparison result is considered unsatisfactory if a difference between the updated reference model and the comparison model exceeds a threshold value. For example, if the comparison model corresponds to a tooth positioning predicted for the creation time of the updated reference model, a deviation of more than 50 µm in the position of the barycenter along the Ox axis) can be considered unsatisfactory. If the comparison model is the objective reference model, the threshold value to be exceeded for a deviation to produce an unsatisfactory result naturally depends on the time remaining to reach the position corresponding to the objective reference model.

The comparison preferably results in a quantification of the deviations, preferably performed and presented by a computer. Preferably, the computer presents the results of the comparison, highlighting the most significant differences.

The comparison can also be visual. Preferably, an orthodontist visualizes and compares the updated reference model and the comparison model. Preferably, a computer screen displays an image highlighting the deviations.

Whether or not a deviation is unsatisfactory may depend on a decision by the orthodontist and/or the result of a computer calculation.

Preferably, the comparison carried out in step e') leads to recommendations which are presented to the orthodontist. In particular, the method enables the behavior of the orthodontic appliance to be finely determined, and thus the factor(s) or that need to be modified to optimize its effectiveness.

In one embodiment, step e') leads to the generation of a report specifying how to modify the arch tension of the installed orthodontic appliance or how to manufacture a new aligner.

In one embodiment, step e') leads to the generation of an “updated” score that can be compared with a reference score for equivalent treatments. Preferably, these scores are presented to the patient. Advantageously, successful treatment is presented as a playful objective, with the scores motivating the patient, especially children, to follow the treatment as closely as possible in order to increase their updated score.

Preferably, step e') leads to the generation of information presenting the situation and the various options available to the patient. In the event of an unsatisfactory deviation, the patient can, for example, decide to extend his treatment or choose a new objective reference model.

Preferably, the results of the comparison are transmitted, preferably in real time, to the patient, preferably on his cell phone. Advantageously, the patient can thus become aware of the consequences of poor compliance with treatment.

In step f'), if the result is unsatisfactory, a replacement orthodontic appliance is made, either by modifying the worn orthodontic appliance or by making a new orthodontic appliance.

Step f') is a step typically performed during an orthodontic check-up.

According to the invention, however, the manufacture of a replacement orthodontic appliance is only carried out if the check-up, preferably carried out remotely, indicates that it is necessary.

In one embodiment, the production of the replacement appliance is carried out remotely, so that when the patient visits the orthodontist, the replacement orthodontic appliance can be fitted immediately. In particular, an archwire or aligner can be prepared based on of the evaluation carried out in step e'). The archwire or aligner can be produced in a laboratory far from the orthodontist's office, and then mailed to the orthodontist.

In one embodiment, the aligner can be sent directly to the patient, without the intervention of the orthodontist.

Preferably, in step f'), the treatment schedule is modified according to the modification made to the orthodontic appliance.

In one embodiment, several replacement orthodontic appliances that can immediately replace the worn appliance are determined, preferably according to the patient's desired treatment speed, with increased speed potentially corresponding to additional pain. Preferably, the patient is offered a choice of treatment speed, and the replacement orthodontic appliance to be produced is determined accordingly.

Of course, in step f'), if the result is unsatisfactory, a series of replacement orthodontic appliances can be produced, and preferably sent to the orthodontist or patient.

In particular, a new series of aligners can be determined, as at the start of treatment with aligners, so that the teeth reach a position corresponding to the objective reference model. This determination can be carried out in the conventional way. Preferably, however, a single aligner is manufactured and, preferably, sent to the patient.

Check-up cycles

Preferably, the method includes a number of check-up cycles comprising steps c'), d'), e') and f'), each preferably performed at a time determined, for example, at the start of treatment and/or at the orthodontist's request and/or on the patient's initiative.

Two consecutive check-up cycles are preferably separated by less than 10 weeks, preferably less than 8 weeks, preferably less than 6 weeks, preferably less than 4 weeks, preferably less than 3 weeks, preferably less than 2 weeks.

Preferably, the number of check-up cycles during treatment is greater than 1, greater than 3, greater than 5, greater than 10, greater than 15, or even greater than 20.

Preferably, a reminder is sent to the patient, for example by SMS, to carry out a check-up cycle.

In a preferred embodiment, the comparison model of a step d') of a check-up cycle is determined from the updated reference model produced in step c') of a previous check-up cycle, in particular the immediately preceding check-up cycle, or from several updated reference models produced in steps c') of previous check-up cycles, for example by extrapolation.

Figure 13 shows a method involving several check-up cycles. It depicts the curves of the theoretical (C_T) and real (C_R) temporal evolutions of a tooth's momentum parameter, and more precisely, the temporal evolution of the position of a point M of a tooth, for example the barycenter of this tooth, along the Ox) axis, in percentage with respect to the desired value at the end of treatment.

A check-up cycle was carried out every week.

Each week, a point on each curve was therefore determined, using a comparison model based on a dynamic model simulating an anticipated evolution of the teeth of the initial reference model (point on the curve C_T), and an updated reference model based on photographs taken by the patient that week (point on the curve C_R).

The first check-up cycles quickly revealed a drift. The orthodontic appliance tended to move the point M too quickly. This information was presented to the orthodontist, along with recommendations on how to modify the orthodontic appliance, for example to reduce the tension exerted by the archwire between two specific teeth.

An appointment between the patient and the orthodontist was arranged for the third week. The orthodontic appliance was modified during this appointment. This change brought the two curves closer together in the following weeks.

After five weeks, the two curves crossed. The orthodontic appliance was modified again at week 8. The two curves then slowly converged, until week 18.

They then diverged substantially again, leading to further modification of the orthodontic appliance in week 20.

By the end of week 25, the target had been substantially met, within the original time frame. Treatment is now complete.

In one embodiment, the patient receives, for example on his phone, information enabling him to compare the updated reference model and the objective reference model, for example pictorials of these two models. If an objective reference model represents the teeth at the end of the treatment (“final set-up”), he can decide for himself how to end the treatment.

The theoretical time trend curve can be determined in its entirety at the start of treatment, taking into account the orthodontic appliance modifications planned during treatment.

This curve can also be recalculated to take account of changes to the orthodontic appliance that were not originally planned. For example, if the modification of the orthodontic appliance carried out in week 3 was not initially planned, the predictive model used to establish the comparison model used after week 3, and therefore the theoretical time trend curve, were preferably modified to take account of this unforeseen modification. The predictive model has thus advantageously taken into account a much slower evolution of the displacement of point M along the Ox) axis than initially anticipated.

As is now clear, the fitting method makes it possible to diagnose the situation and even product a replacement orthodontic appliance, without the patient having to visit an orthodontist.

<u>Detailed description of a method for evaluating the behavior of an orthodontic appliance</u>

By multiplying the number of check-up cycles, it is possible to acquire a wealth of data that can be used to establish correlations between orthodontic appliance parameters, behavior and tooth configurations.

Preferably, the values of the parameters of the orthodontic appliance initially used, but also, at each check-up cycle, the parameters of the replacement orthodontic appliance, are stored in a computer. Orthodontic appliance parameters comprise intrinsic parameters, such as the material or shape of an aligner, or the material and diameter of an archwire. They also comprise extrinsic parameters, resulting from its use, such as the points of attachment of the archwire to the teeth or the tension of the archwire.

This computer also has access to the various three-dimensional models established as part of the treatment.

An analysis module enables all collected data to be compared using conventional statistical analysis methods. The result is a better understanding of the behavior of the orthodontic appliance, based on the values of its parameters and the corresponding tooth configurations.

Preferably, the data collected comes from several processes, preferably more than 10, more than 100, more than 1,000, more than 10,000, more than 100,000 processes.

This improves the accuracy of statistical analysis.

The data thus make it possible to observe that, in similar tooth configurations, one type of orthodontic appliance or one parameter of an orthodontic appliance is particularly effective in ensuring displacement in a particular direction.

They can therefore be used to model orthodontic appliance behavior with a high degree of accuracy, enabling better evaluation of its future behavior in a particular situation.

In one embodiment, data analysis is used to quantify the difficulty of a treatment, by comparing it with equivalent treatments. In this way, the orthodontist can inform the patient about the chances of success and the nature of potential difficulties. The orthodontist may also decide to modify the treatment initially envisaged, in particular by modifying the intermediate set-ups.

The knowledge acquired in this way can be used to optimize

- orthodontic appliance design, and/or
- the choice of braces for a particular treatment, and/or
- diagnosis by the orthodontist, and/or
- the manufacture of a replacement orthodontic appliance, and/or
- determination of a predictive model to build the comparison model.

This optimization can advantageously lead the orthodontist or appliance designer to take into account an appliance parameter conventionally considered negligible.

Advantageously, correlations between parameters of the orthodontic appliance and its behavior can be established without the need for a theoretical understanding of this correlation, that is, an understanding of how these parameters produce this behavior.

Detailed description of a method for checking the shape of teeth

A method for checking the shape of a patient's teeth is described. In step a), however, the definition of tooth models is not essential for this check.

Preferably, in step e), for each updated image, a search is done for an updated reference model corresponding to the shape of the teeth at the time of acquisition of the updated image, the search preferably being carried out by means of a metaheuristic method, preferably evolutionary, preferably by simulated annealing, in particular using one of the metaheuristic methods previously described.

Preferably, as described for step e), this search comprises two nested optimization loops.

In the first optimization operation, virtual acquisition conditions are first optimized in a reference model to be tested, which is initially the initial reference model, to match the real acquisition conditions as closely as possible. In particular, we search for the virtual position of the acquisition device relative to the reference model to be tested that offers the view of this reference model to be tested, that is, the reference image, which is closest to the updated image.

Preferably, as described above, a virtual calibration is also sought that may correspond to the real calibration of the acquisition device when the updated image is captured.

In the second optimization operation, the reference model to be tested is then modified, the first optimization operation is repeated, and these two operations are repeated until the reference model to be tested and the virtual position of the acquisition device are found, resulting in the reference image that is closest to the updated image.

These operations are similar to those described for the method for checking tooth positioning, and the optional features of the latter check are optionally applicable.

However, according to the method for checking tooth positioning described above, the reference model is modified by displacing one or more tooth models. No deformation of tooth models or the initial reference model is required.

To check the shape of the teeth, the reference model is modified by changing the shape of the reference model to be tested, in particular one or more tooth models. Tooth models do not need to be moved.

Of course, it is preferable to perform both types of modifications to the reference model to be tested, in order to determine an updated reference model that takes into account both tooth displacement and tooth deformation.

For example, a third optimization operation can be implemented for tooth displacement, framing the first two optimization operations, with the second optimization operation focusing on the shape of the tooth models or reference model to be tested. It is also possible to carry out only the first two optimization operations, possibly simultaneously modifying the shape and position of the tooth models in the second optimization operation.

Alternatively, a third optimization operation can be carried out on the shape of the tooth models or reference model to be tested, framing the first two optimization operations, with the second optimization operation focusing on moving the tooth models. For example, a search is first done for an updated reference model “to be tested” which takes account, at best, of the displacement of the tooth models, the updated reference model to be tested corresponding to the updated reference model of a step e) of a method for checking tooth positioning described previously, and then a search is done to see whether a deformation of the updated reference model to be tested can lead to a better “matching” with the updated image. For this search, the updated reference model to be tested is deformed, the first two optimization operations are repeated and then, depending on the match obtained, the search is stopped or continued by performing a new deformation of the updated reference model to be tested and re-running the first two optimization operations.

Preferably, the first optimization operation and/or the second optimization operation and/or the third optimization operation, preferably the first optimization operation and the second optimization operation and the third optimization operation, implement a metaheuristic method, preferably evolutionary, preferably simulated annealing, in particular one of the metaheuristic methods mentioned above.

Preferably, to check tooth deformation, step e) comprises

- a first optimization operation to search for virtual acquisition conditions corresponding as closely as possible to the real acquisition conditions in a reference model to be tested, determined from the initial reference model, and

- a second optimization operation to find, by testing a plurality of said reference models to be tested, the reference model that best corresponds to the shape of the patient's teeth when the updated image is acquired in step b), preferably best corresponding to the shape and positioning of the patient's teeth when the updated image is acquired in step b).

Preferably, a first optimization operation is performed for each test of a reference model to be tested in the second optimization operation.

Step e) may in particular include the following steps:

e'1) defining the reference model to be tested as the initial reference model, then

e'2) in line with the following steps, testing virtual acquisition conditions with the reference model to be tested in order to precisely approximate said real acquisition conditions;

e'21) determining virtual acquisition conditions to be tested;

e'22) producing a two-dimensional reference image of the reference model to be tested under said virtual acquisition conditions to be tested;

e'23) processing the reference image to produce at least one reference map representing, at least partially, said discriminative information;

e'24) comparing the updated map and reference map so as to determine a value for a first evaluation function, said value for the first evaluation function depending on the differences between said updated map and reference map and corresponding to a decision to continue or stop the search for virtual acquisition conditions approximating said real acquisition conditions more accurately than said virtual acquisition conditions to be tested which are determined at the last occurrence of step e'21);

e'25) if said value for the first evaluation function corresponds to a decision to continue said search, resuming in step e'21) by modifying the virtual acquisition conditions to be tested;

e'3) otherwise determining a value for a second evaluation function, said value for the second evaluation function depending on the differences between the updated map and reference map under the virtual acquisition conditions best approximating said real acquisition conditions and resulting from the last occurrence of step e'2), said value for the second evaluation function corresponding to a decision to continue or stop the search for a reference model approximating the shape, and optionally the positioning of the teeth at the time of acquiring the updated image more accurately than said reference model to be tested which is used in the last occurrence of step e'2), and

if said value for the second evaluation function corresponds to a decision to continue said search, modifying the reference model to be tested by deforming one or more tooth models, or the reference model to be tested, and optionally by displacing one or more tooth models, then returning to step e'2).

The result of this method is a reference model to be tested, referred to as the “updated reference model”, which corresponds to the initial reference model deformed to match the updated image as closely as possible.

Comparing the initial and updated reference models involves comparing the spatial coordinates of the points on the surfaces defined by these two reference models. In this way, any changes in shape between step a) and step b) can be deduced.

Preferably, the tooth is mapped to show changes in shape. Preferably, as shown in Figure 8, the color of an area of the map is based on the extent to which that area changes shape. In particular, Figure 8 shows an area 16 indicating a tooth fracture.

Of course, the method for checking the shape of a patient's teeth can be used to detect the addition or subtraction of material, as well as constant-volume deformation. This method can also detect tooth displacements, even without a tooth model. However, in the absence of a tooth model, it cannot distinguish between tooth deformation and tooth displacement.

Detailed description of a method for checking the appearance of teeth

Checking the evolution of tooth color from photographs taken in different camera positions or in different light environments shows that this comparison does not allow evaluation of an evolution in the appearance of these teeth.

This type checking of tooth color therefore requires special precautions, particularly in terms of precisely defining the position of the camera and its lighting environment.

There is therefore a need for a method that makes it possible to check the color, and more generally an appearance property, of teeth in a simpler way, and in particular by avoiding these special precautions.

Also disclosed is a method for checking an appearance property of a patient's teeth, said method comprising steps A. to E. described above, shown in Figure 9.

As will be seen in more detail later in the description, this method makes it possible to evaluate whether the appearance, in particular the color, of one or more of the teeth has been altered, even when the conditions for acquiring photographs of a patient's teeth are not predefined, for example because the photographs were taken in a light environment or in any position of the acquisition device, in particular by the patient.

By “appearance property” we mean a property relating to appearance. The appearance property can be selected in particular from the group consisting of color, opalescence, fluorescence, brightness, transparency and combinations of these properties.

The term “appearance” refers to a value or set of values used to quantify an appearance property. Unless otherwise indicated, the “appearances” mentioned in the present disclosure refer to the appearance property that the method makes it possible to check.

Steps A. and B.

Steps A. and B. can be performed in the same way as step b) above.

Steps A. and B. are preferably performed by the patient or someone close to the patient, but can also be carried out by a dentist.

The time interval between these steps can be as described above between steps a) and b), for example greater than 1 week, 2 weeks, 1 month or 3 months.

The first acquisition device may be the same as or different from the second acquisition device. It can be an acquisition device chosen from those that can be used for step b), in particular a camera or a cell phone.

Preferably, the acquisitions in steps A. and/or B. are carried out using flash. Results are improved. Preferably, the initial and/or updated image is overexposed.

The reference gauges used for each of steps A. and B. have the same appearance. Preferably, in each step, they are arranged in the same position relative to the patient's teeth.

Preferably, dental spreaders are used for each of steps A and B. These spreaders can be identical or different. Preferably, the reference gauge is carried by a spreader for at least one of steps A. and B., preferably for each of steps A. and B. Preferably, even if the spreaders used for each of steps A. and B. are different, the reference gauges are arranged on the spreaders in the same position relative to the spreader opening 14 which reveals the patient's teeth (Figure 5a).

Preferably, the reference gauge is positioned on the spreader so as to be proximate to the teeth whose appearance property is to be checked. Preferably, the reference gauge is located less than 3 cm, preferably less than 2 cm, more preferably less than 1 cm from the part of the spreader intended to be introduced into the patient's mouth.

Preferably, each spreader has several identical or different reference gauges. Preferably, several different reference gauges of the same spreader have different appearances. The conclusions drawn from the comparison of normalized images can advantageously be richer.

A reference gauge can be, for example, a point on the spreader whose appearance is known, e.g. whose color parameters L*, and/or a* and/or b*, measured according to NF ISO 7724, are known. The reference gauge can be, for example, a register mark of a spreader as described above.

The acquisition conditions specify the spatial position and/or orientation of the acquisition device relative to the spreader.

To improve the accuracy of appearance checking, it is preferable for the acquisition conditions to be substantially the same in steps A. and B. For example, it is preferable for the two images to be taken substantially from the front. Preferably, the image acquisition device used for at least one, and preferably for each of steps A. and B., includes coding means to facilitate its positioning relative to the patient prior to image acquisition.

The coding means preferably interact with register marks on the spreader. Preferably, the acquisition device is programmed so as to, in real time, locate the register marks on the spreader, analyze their relative positions or dimensions and, as a result, inform the user of the acquisition device so that he can modify the position of the acquisition device in relation to the patient's teeth accordingly.

These coding means may have one or more of the features of the coding means described above for step b).

Preferably for at least one, and preferably for each of steps A. and B., an acquisition kit is used, and preferably an acquisition method comprising steps (a) to (e). Preferably, the target acquisition conditions are the same in the memory of the first and second acquisition devices, so that the acquisition device guides its user so that the initial and updated images are taken under substantially identical acquisition conditions.

Preferably, the target acquisition conditions are determined according to the teeth whose appearance property is to be checked. For example, the target acquisition conditions preferably correspond to an image taken facing the patient for a check on an incisor, and they preferably correspond to a lateral image taken for a check on a molar.

Step C.

Step C. consists in normalizing, that is, “correcting” the initial image and/or the updated image so that, after correction, the reference gauge representations on these images have the same appearance. Since the reference gauge has not changed its appearance between steps A. and B., any differences in appearance presented by the representations of the teeth on the initial and updated normalized images therefore correspond to real differences in appearance on said teeth.

First, we search for the reference gauge on the initial image and on the updated image. A simple image analysis is all that is needed.

Normalization can be carried out on the initial image only, in order to modify the representation of the reference gauge so that its appearance is identical to that of the representation of said reference gauge on the updated image. Alternatively, normalization can be carried out on the updated image only, in order to modify the representation of the reference gauge so that its appearance is identical to that of the representation of said reference gauge on the initial image. Finally, normalization can be carried out on the updated image and on the initial image to modify the representations of the reference gauges so that their appearance is identical to that of a standard gauge.

Image normalization is a well-known technique in image processing. White balance is an example of image normalization.

Step D.

Before or after step C., it is necessary to identify, on each of the initial and updated images, a region of the teeth whose appearance it is desired to evaluate.

The use of register marks or gauges is possible, but imprecise. Preferably, the initial and updated images are analyzed to represent discriminative information, of the type described above, such as tooth contours.

The analysis of the initial and updated images may include one or more of the features of step c), in particular relating to the nature of the discriminative information and the processing to determine the discriminative information. The discriminative information is preferably optimized by means of an optimization method comprising steps C1 to C3.

We then look for discriminative information common to both the initial and updated images.

The discriminative information common to both the initial and updated images can then be used as a reference to locate said region on these two images. For example, the contour of the gums may show a succession of “points” between the teeth. This contour depends on the teeth under consideration and can therefore be used as a reference.

In an improved embodiment, the initial and updated images are referenced to a reference model, preferably produced in accordance with step a) (initial reference model) or resulting from the implementation of a method for checking tooth shape and/or positioning according to the invention (updated reference model).

This referencing can be carried out as described above to reference the updated image as part of methods for checking tooth shape and/or positioning. Unlike these methods, however, modification of the initial reference model to arrive at the updated reference model is optional.

To locate an image in relation to the reference model, simply search for the virtual acquisition conditions under which the acquisition device would have acquired said image by observing said reference model. This search is preferably carried out using a metaheuristic method, such as those described above.

This search is preferably carried out using a method for evaluating real acquisition conditions, as described below. This method is preferably carried out for each of the initial and updated images using the reference model. It allows these images to be "projected" onto the reference model, and thus to locate a point on the reference model.

A region of the teeth whose appearance is to be evaluated can thus be identified with great precision on each of the initial and updated images.

<u>Step E.</u>

It is then possible to measure the appearances of said region on each of the initial and updated images and compare them in order to detect and evaluate differences in the appearance property.

A method for checking the appearance of teeth according to the invention can be used for therapeutic or non-therapeutic purposes. In particular, it can be used to:

- detect and/or measure a change in tooth color or the appearance and/or evolution of stains on teeth, or detect and/or measure calcification of teeth;

- check the effects on the appearance of teeth of a dietary habit or food hygiene or a treatment, for example a whitening treatment, or of a product, in particular a toothpaste, in particular to whiten teeth or to combat calcification or the appearance of stains.

For example, a method for checking the appearance of teeth can be used to check the effects on the appearance of teeth of chewing gum or drinking coffee or tea, or smoking or taking drugs, or brushing teeth.

In a preferred embodiment, the patient simply takes regular photographs with his cell phone to establish up-to-date images. Preferably, owing to an application loaded on this phone, he can then compare the appearances of the teeth on these photographs.

In one embodiment, the application normalizes the photographs to make them comparable, then proposes a dynamic visualization of the corrected photographs, for example in the form of a slide show or film.

Detailed description of a method for evaluating real acquisition conditions

Particularly for the implementation of a method for checking the shape, positioning and/or appearance of teeth according to the invention, or for optimizing the quality of discriminative information, a method is also disclosed for evaluating, from a two-dimensional image of a patient's dental arches, referred to as "acquired image", real acquisition conditions (position of the acquisition device in space, orientation of this device and, preferably, calibration of the acquisition device) of said acquired image, said method comprising the following steps:

001) creating a digital three-dimensional reference model of at least part of an arch of the patient, preferably an arch, preferably both of the arches, of the patient,

002) analyzing the acquired image and producing a map relating to discriminative information, referred to as the "acquired map";

003) searching for virtual acquisition conditions optimally approximating said real acquisition conditions, according to the following steps 01) to 05):

01) optionally, determining rough virtual acquisition conditions approximating said real acquisition conditions, preferably by analyzing the representation, on the acquired image, of a spreader used during acquisition of the acquired image;

02) determining virtual acquisition conditions to be tested;

03) producing a two-dimensional reference image of the reference model observed under the virtual acquisition conditions to be tested;

04) processing the reference image to produce at least one reference map representing said discriminative information;

05) comparing the acquired map and reference map so as to determine a value for an evaluation function, said value for the evaluation function depending on the differences between said acquired map and reference map and corresponding to a

decision to continue or stop the search for virtual acquisition conditions approximating the real acquisition conditions more accurately than said virtual acquisition conditions to be tested;

06) if said value for the evaluation function corresponds to a decision to continue said search, modifying said virtual acquisition conditions to be tested, then returning to step 03); otherwise, evaluating real acquisition conditions by said virtual acquisition conditions to be tested.

Preferably, the real acquisition conditions to be evaluated comprise one or more of the following calibration parameters: aperture value, exposure time, exposure time, focal length and sensitivity.

In the evaluation method, the modification made to the virtual acquisition conditions to be tested in step 06) is preferably carried out by means of a metaheuristic method, preferably evolutionary, preferably by simulated annealing, preferably by means of one of the metaheuristic methods mentioned above.

An evaluation method is preferably used whenever it is necessary to evaluate the real acquisition conditions of an image. This image, which may in particular be an updated image acquired in step b) or B. or an initial image acquired in step A., is referred to as an “acquired image”.

The reference model produced in step 001) may include one or more of the features, even if optional, of step a).

The acquisition of the acquired image may include one or more of the features, even if optional, of step b). Preferably, it implements an acquisition kit, and preferably a method.

Step 01) for determining the rough virtual acquisition conditions may include one or more of the features, even if optional, of step c).

Steps 02) to 06) may include one or more of the features, even if optional, of steps e21) to e25), respectively.

<u>Detailed description of a method for optimizing discriminative information</u>

A process for optimizing or “selecting” discriminative information is designed to improve the reliability of initial discriminative information extracted from a two-dimensional image of a patient's dental arches, or “acquired image”, in particular an initial image from step A. or an updated image from step B. or b), acquired under real acquisition conditions. The “optimization” of discriminative information is therefore a selection of discriminative information, following an iterative approach, so as to select from the image the most relevant discriminative information to best check the positioning and/or shape of the patient's teeth.

This method is based on a digital three-dimensional reference model of at least one part of a patient's arch, in particular an initial reference model from a step a). As shown in Figure 10, it includes the following steps:

C1. assessing the quality of the initial discriminative information and of a quality threshold, filtering so as to retain only the initial discriminative information, preferably all of the initial discriminative information with a quality higher than the quality threshold, and defining the “discriminative information to be tested” as the discriminative information retained;

C2. matching test between the discriminative information to be tested and the reference model;

C3. based on the result and a test result evaluation function:

- adding non-retained discriminative information to the discriminative information to be tested and/or deleting discriminative information from the discriminative information to be tested, then resuming at step C2., or

- defining optimal discriminative information as the discriminative information to be tested.

In particular, the discriminative information can be any of the discriminative information described above. For example, the discriminative information can be contour information.

The initial discriminative information typically results from the analysis of the acquired image, as described for step c).

The methods that use such initial discriminative information implement optimizations that provide better results if the discriminative information is both abundant and of good quality. One aim of the optimization method is therefore to improve the quality of the initial discriminative information.

In step C1., the quality of the initial discriminative information is evaluated. In the case of a contour, for example, contrast analysis provides more or less reliable information: an area of high contrast can be assimilated to an area corresponding to a contour with a high probability, and the quality of the points in this area will therefore be high. On the contrary, an area of low contrast, such as a blurred zone, can be assimilated to an area corresponding to a contour with low probability, and the quality of the points in this area will therefore be low. In this example, the probability of a point in the acquired image belonging to the contour can be chosen as an indicator of the “quality” of the discriminative information.

A quality threshold is used to filter the initial discriminative information. If the quality threshold is high, the discriminative information retained after filtering will be low in number, but highly reliable. If the quality threshold is low, the discriminative information retained will be abundant, but unreliable. In the case of contour information, image analysis will result in the retention of “false” contour points, that is, points which, as a result of the analysis, will be mistakenly considered as belonging to the contour of teeth and gums.

In a preferred embodiment, the quality threshold is high in order to retain only highly reliable discriminative test information.

In step C2, the matching is tested, that is, a degree of matching is determined, between the discriminative information to be tested and the reference model.

Preferably, an “acquired” map of the discriminative information to be tested is produced by processing the acquired image.

Preferably, steps 01) to 06) are followed, and in particular the following steps:

02) determining virtual acquisition conditions to be tested;

03) producing a two-dimensional reference image of the reference model observed under the virtual acquisition conditions to be tested;

04) processing the reference image to produce at least one reference map representing the discriminative information;

05) comparing the acquired map and reference map so as to determine a value for an evaluation function, said value for the evaluation function depending on the differences between said acquired map and reference map and corresponding to a decision to continue or stop the search for virtual acquisition conditions approximating the real acquisition conditions more accurately than said virtual acquisition conditions to be tested;

06) if said value for the evaluation function corresponds to a decision to continue said search, modifying said virtual acquisition conditions to be tested, then returning to step 03); otherwise, evaluating real acquisition conditions by said virtual acquisition conditions to be tested.

In step 04), the reference image is processed to produce a reference map representing said discriminative information. The criteria used to select the discriminative information represented on the reference map may be the same as or different from that used to select the discriminative information to be tested.

Preferably, the discriminative information represented on the reference map is selected using the same criteria as the discriminative information to be tested.

In the example of a contour, reference image processing can consist of retaining reference image points corresponding to a contour with a high probability.

The probability of a point in the reference image belonging to the contour can be determined in the same way as for acquired image processing, and also serves as an indicator of the quality of the discriminative information. The quality threshold can also be identical to that used for processing of the acquired image. The contour shown on the reference map is then similar to that shown on the acquired map, and in particular has a substantially identical length.

Steps 01) to 06) use the reference model to determine virtual acquisition conditions that approximate the real acquisition conditions of the acquired image. Observing the reference model under these virtual acquisition conditions therefore provides a view that best matches the acquired image. However, the search for virtual acquisition conditions is based on the discriminative information to be tested. The degree of matching therefore depends on the discriminative information to be tested. The higher the quality and quantity of the discriminative information to be tested, the better the degree of matching between the view of the reference model under virtual acquisition conditions and the acquired image, and the higher the degree of matching between the discriminative information to be tested and the reference model.

The degree of matching can be measured, for example, by the inverse of the difference between

- the reference map relative to the image of the reference model observed under virtual acquisition conditions that best approximate the real acquisition conditions as a result of carrying out steps 01) to 06), and

- the “acquired” map representing the discriminative information to be tested, corresponding to the acquired image

weighted by the amount of discriminative information to be tested.

For a contour, for example, the degree of matching can be the ratio of the number of points belonging to both the reference map contour and the acquired map contour, to the total number of points in the acquired map contour, or the product of the inverse of the average distance between the contours represented on said acquired and reference maps, and the length of the contour represented on the acquired map.

The “best guess” approximation of real acquisition conditions based on the discriminative information to be tested can be evaluated by a result or “score”, for example by the degree of matching. The cycle of steps C2. and C3. is designed to optimize this result by acting on the discriminative information to be tested.

This optimization is similar to that used for methods for checking tooth positioning and/or shape. However, these methods act on the initial reference model, by moving the tooth models and/or deforming the reference model, whereas the method for optimizing discriminative information acts on the discriminative information used to establish the acquired map.

The operation performed in step C3. is determined by an evaluation function of the test result in step C2. Preferably, the evaluation function takes into account results obtained in previous cycles C2.-C3.

In particular, the method can be stopped if the evaluation function indicates that further cycles C2.-C3. do not improve the result, for example because one or more cycles C2.-C3. have failed to improve it or have failed to improve it significantly. The discriminative information tested during the cycle C2.-C3. that led to the best result is then considered optimal.

Otherwise, a new cycle C2.-C3. can be launched, after modifying the discriminative information to be tested. The modification to be made to the discriminative information just tested may consist in adding or deleting discriminative information. Discriminative information can be added, for example, if the last result was the best obtained so far and if, according to the evaluation function, the result can be further improved. Preferably, the discriminative information added is that which, among the discriminative information not selected in step C1. and not yet tested, has the best quality.

For example, when the discriminative information is contour information, the addition of discriminative information may consist in adding points of the image not initially retained, never added before and whose quality, as evaluated in step C1, is the highest, that is, whose addition is most likely to improve the test result in step C2.

Discriminative information may be removed, for example, if the last result is worse than the previous one. In particular, the discriminative information added in the previous cycle can be deleted and further discriminative information can be added, as described above.

The discriminative information to be added and/or removed can be determined randomly. Preferably, however, it results from the implementation of a metaheuristic method, preferably evolutionary, preferably by simulated annealing, preferably of the type described above.

Example

By way of example, Figure 11 shows a reference map of reflection information (discriminative information) superimposed on the acquired image.

The acquired image, preferably acquired by means of an acquisition kit, is a photograph taken in a particular position and orientation of the camera. This position and orientation constitute the real acquisition conditions for the acquired image.

It is well known that, in the acquired image, the higher the brightness of a point, the higher the probability that this point belongs to a reflection area. The brightness can therefore be used as an indicator of the "quality" of reflection information.

The filtering in step C1. can consist of retaining only those areas of the acquired image that have a brightness above a quality threshold, for example 70 %.

The acquired map represents these areas, which constitute the discriminative information to be tested. In step C2, steps 01) to 06) are used to test whether the selected areas match the observation of the reference model.

In step 01), the acquired image is analyzed to roughly evaluate real acquisition conditions by virtual acquisition conditions. This evaluation is preferably based on an analysis of the position and/or shape of the representation, on the acquired image, of the register marks of a spreader used during acquisition.

The virtual acquisition conditions roughly evaluated can form the "virtual acquisition conditions to be tested" in step 02).

In step 03), by observing the reference model from the virtual acquisition conditions to be tested, a reference image is obtained.

In step 04), as shown in Figure 11, vectors (black lines 20) of equal length, perpendicular to the faces of the reference model, can be projected onto the reference image. Circles 22 represent these vectors when viewed along their length. The reference map is thus formed by these black lines 20 and circles 22. Those skilled in the art will know that circles 22 normally correspond to areas of the image corresponding to reflections. On the reference map, the discriminative information, that is, the reflection information, is therefore represented by the black lines 20 and by the circles 22, the inverse of the length of the black lines being used as an indicator of the "quality" of the reflection information on the reference map, a circle corresponding to zero length, and therefore to maximum quality.

In step 05), a comparison of the acquired and reference maps may consist, for example, in checking whether the lines 20 and circles 22 are inside areas of the acquired map (which initially correspond to a brightness of over 70 %). The evaluation function can be, for example, the ratio R between

- the difference between the number of circles 22 and the number of lines inside acquired image areas, and
- the total number of circles 22.

The decision may be to continue the search by modifying the virtual acquisition conditions to be tested until a maximum is reached for the acquisition function.

In step 06), if this maximum is considered to have been reached, the loop of steps 03) to 06) is exited. Otherwise, a modification to the virtual acquisition conditions to be tested is determined, preferably by means of a metaheuristic, preferably evolutionary, method, and step 03) is repeated.

At the end of steps 03) to 06), the ratio R for this acquired image is therefore at its maximum, e.g. 95 %. This ratio R then represents the result of the matching test carried out in step C2.

In step C3, this result is evaluated using an evaluation function.

This evaluation function determines whether the result is optimal or not. If the result is considered optimal, for example because no better result can be obtained after several cycles of steps C2. - C3., it is considered that the areas of the corresponding acquired map constitute optimal discriminative information.

Otherwise, the acquired map is modified, for example by adding points from the acquired image, for example by adding points with a brightness greater than 71 %. This addition leads to the addition of circles in the acquired map areas, which improves the ratio R, but also to the addition of black lines, which degrades the ratio R. Conversely, it is possible to extract points with a brightness greater than 69 %. This deletion leads to the deletion of circles in the acquired map areas, which degrades the ratio R, but also to the deletion of black lines, which improves the ratio R.

The modification to be made is preferably guided by a metaheuristic method, preferably evolutionary.

Using the newly acquired map, which defines the discriminative information to be tested, we return to step C2.

The cycling of steps C2. and C3. can be continued until an optimum result is determined. The discriminative information to be tested is then considered optimal.

As is now clear, a method for optimizing discriminative information enables the construction of good-quality, abundant discriminative information. In particular, it enables a partial but good-quality initial contour to be gradually built into a more complete but still good-quality contour.

Of course, the invention is not limited to the above-described and illustrated embodiments.

In particular, unless otherwise indicated, the optional features described in the context of a step of a first method are applicable in the context of an analogous or identically referenced step of a second method.

The method for checking tooth positioning and/or shape can be implemented successively for each of the two arches, or simultaneously for both arches. Additionally, several different devices can be used for these methods. For example, acquisition can be carried out using a cell phone, and subsequent steps using a desktop computer.

Finally, the patient is not limited to a human being. In particular, a method for checking tooth positioning can be used for another animal.

PATENTKRAV

1. System til fremstilling af en ortodontisk anordning til udskiftning af en ortodontisk anordning, der bæres af en patient, hvilket system omfatter:

- en scanner til fremstilling af en digital tredimensional referencemodel af mindst én del af en patients tandbue eller en “initial referencemodel”;

- en computer til fremstilling af en digital tredimensional referencemodel, benævnt en “objektiv referencemodel”, svarende til en ønsket positionering af tænderne i den mindst ene del af patientens tandbue på et behandlingstidspunkt;

- en billedopnåelsesindretning til opnåelse af mindst ét opdateret todimensionalt billede, hvor billedopnåelsesindretningen er positioneret og orienteret i rum, i forhold til patientens tænder, under såkaldte “reale” opnåelsesbetingelser;

- en computer til deformering af den initiale referencemodel ved bevægelse af tandmodeller, indtil der opnås en opdateret referencemodel, som svarer til tændernes positionering i det opdaterede todimensionale billede;

- en indretning til fremstilling af en ny ortodontisk anordning, hvis en sammenligning, der udføres af en computer,

- af den opdaterede referencemodel med

- den objektive referencemodel

fører til et utilfredsstillende resultat, hvor den nye ortodontiske anordning konfigureres på basis af resultatet.

2. System ifølge det umiddelbart foregående krav, hvor computeren, til deformering af den initiale referencemodel, er konfigureret til at udføre følgende trin:

c) analysering af hvert opdateret billede og fremstilling, for hvert opdateret billede, af et opdateret kort angående diskriminerende informationer;

d) eventuel bestemmelse, for hvert opdateret billede, af grove virtuelle opnåelsesbetingelser, der tilnærmer sig de reale opnåelsesbetingelser;

e) søgning, for hvert opdateret billede, efter en opdateret referencemodel svarende til tændernes positionering på tidspunktet for opnåelse af det opdaterede billede, hvor søgningen fortrinsvis udføres ved hjælp af en metaheuristisk fremgangsmåde, der fortrinsvis er evolutionær, fortrinsvis ved simuleret annealing, hvor trin e) omfatter følgende trin:

e1) definition af en referencemodel, der skal testes som den initiale referencemodel, derefter

e2) testning, i overensstemmelse med følgende trin, af virtuelle opnåelsesbetingelser med referencemodellen, der skal testes, med henblik på præcist at tilnærme sig de reale opnåelsesbetingelser;

e21) bestemmelse af de virtuelle opnåelsesbetingelser, der skal testes;

e22) fremstilling af et todimensionalt referencebillede af referencemodellen, der skal testes, under de virtuelle opnåelsesbetingelser, der skal testes;

e23) behandling af referencebilledet til fremstilling af mindst ét referencekort, der, mindst delvist, angiver de diskriminerende informationer;

e24) sammenligning af det opdaterede kort og referencekortet med henblik på at bestemme en værdi for en første evalueringsfunktion, hvor værdien for den første evalueringsfunktion afhænger af forskellene mellem det opdaterede kort og referencekortet og svarer til en beslutning om at fortsætte eller standse søgningen efter virtuelle opnåelsesbetingelser, der tilnærmer sig de reale opnåelsesbetingelser mere nøjagtigt end de virtuelle opnåelsesbetingelser, der skal testes, og som blev bestemt ved den sidste forekomst i trin e21);

e25) modificering, hvis værdien for den første evalueringsfunktion svarer til en beslutning om at fortsætte søgningen, af de virtuelle opnåelsesbetingelser, der skal testes, derefter tilbagevenden til trin e22);

e3) bestemmelse af en værdi for en anden evalueringsfunktion, hvor værdien for den anden evalueringsfunktion afhænger af forskellene mellem det opdaterede kort og referencekortet under de virtuelle opnåelsesbetingelser, der bedst tilnærmer sig de reale opnåelsesbetingelser og er en følge af den sidste forekomst i trin e2), hvor værdien for den anden evalueringsfunktion svarer til en beslutning om at fortsætte eller standse søgningen efter en referencemodel, der tilnærmer sig tændernes positionering på tidspunktet for opnåelse af det opdaterede billede mere nøjagtigt end referencemodellen, der skal testes, og som anvendes i den sidste forekomst i trin e2), og modificering, hvis værdien for den anden evalueringsfunktion svarer til en beslutning om at fortsætte søgningen, af referencemodellen, der skal testes, ved bevægelse af én eller flere tandmodeller, derefter tilbagevenden til trin e2).

3. System ifølge et hvilket som helst af de foregående krav, hvor den objektive referencemodel viser de tænder, der skal behandles, i en position, som skal opnås ved behandlingens afslutning.

4. System ifølge et hvilket som helst af de foregående krav, hvor billedopnåelsesindretningen er en patients telefon, der er konfigureret til at udføre søgningen efter den opdaterede referencemodel og overføre den opdaterede referencemodel til en ortodontist.

5. System ifølge et hvilket som helst af de foregående krav, hvor den nye ortodontiske anordning er en ortodontisk skinne til udskiftning af den bårne ortodontiske anordning.

6. System ifølge det umiddelbart foregående krav, der endvidere omfatter midler til afsendelse af den nye ortodontiske anordning til patienten.

7. System ifølge et hvilket som helst af de foregående krav, hvor indretningen til fremstilling af en ny ortodontisk anordning er konfigureret til at fremstille en række ortodontiske anordninger, hvis sammenligningen, der udføres af computeren,

- af den opdaterede referencemodel med
- den objektive referencemodel

fører til et utilfredsstillende resultat.

8. System ifølge det umiddelbart foregående krav, der omfatter midler til afsendelse af rækken af ortodontiske anordninger til patienten.

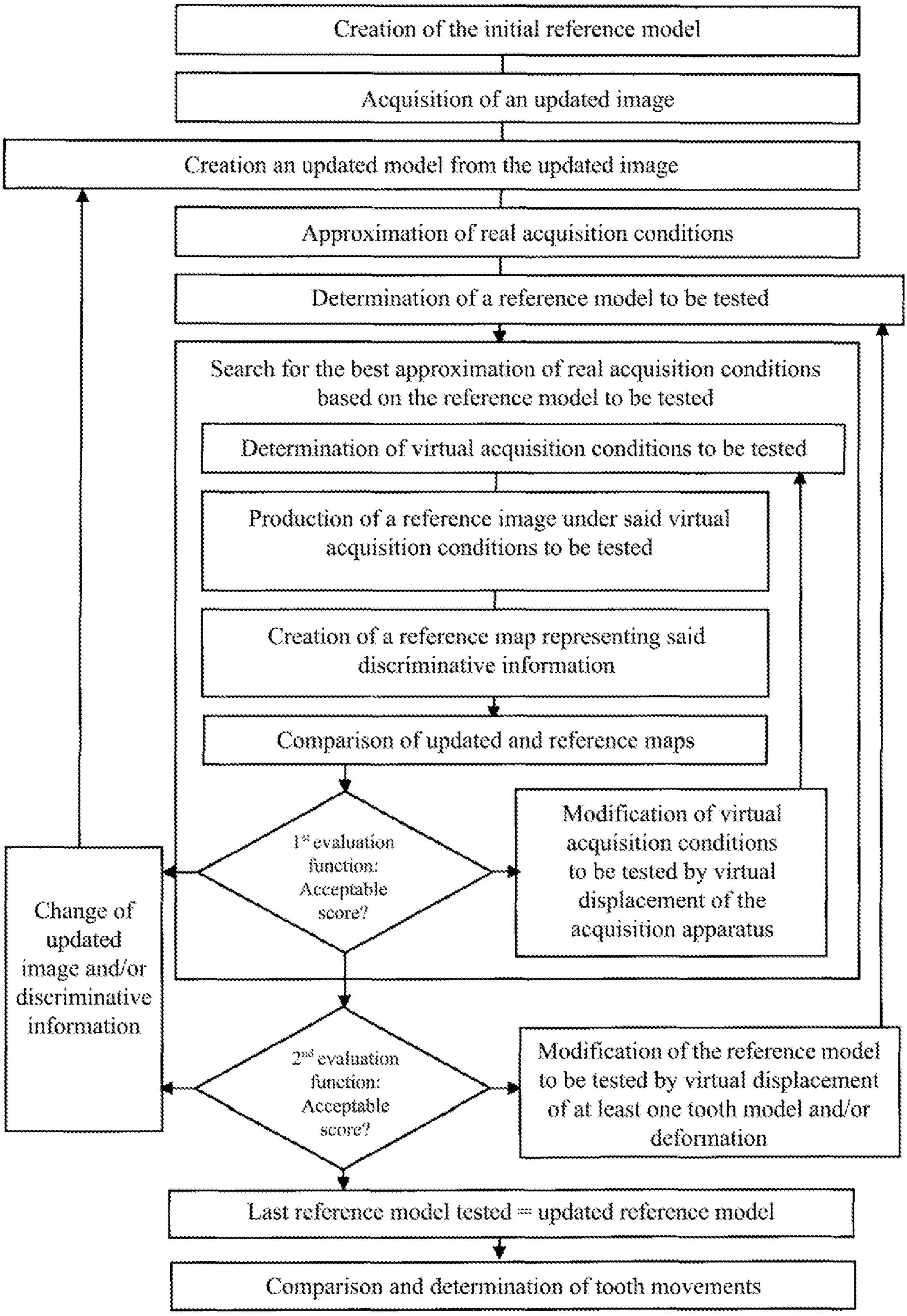
Creation of the initial reference model
Acquisition of an updated image
Creation an updated model from the updated image
Approximation of real acquisition conditions
Determination of a reference model to be tested
Search for the best approximation of real acquisition conditions based on the reference model to be tested
Determination of virtual acquisition conditions to be tested
Production of a reference image under said virtual acquisition conditions to be tested
Creation of a reference map representing said discriminative information
Comparison of updated and reference maps
1st evaluation function: Acceptable score?
Modification of virtual acquisition conditions to be tested by virtual displacement of the acquisition apparatus
Change of updated image and/or discriminative information
2nd evaluation function: Acceptable score?
Modification of the reference model to be tested by virtual displacement of at least one tooth model and/or deformation
Last reference model tested = updated reference model
Comparison and determination of tooth movements

Figure 1

Figure 2

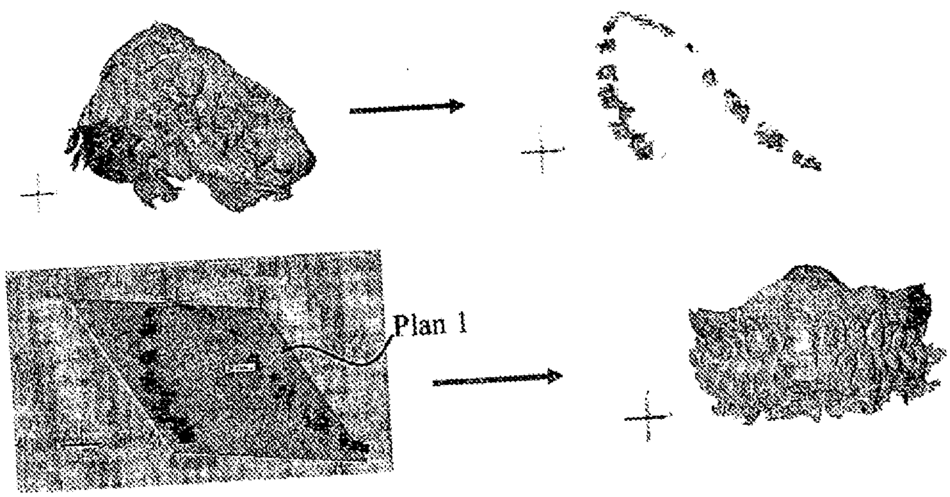

Figure 3

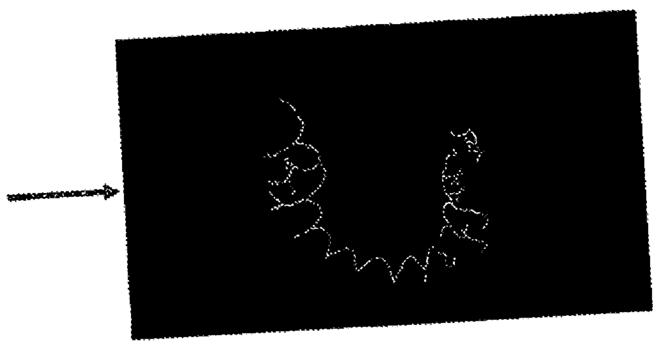

Figure 4b

Figure 4a

Figure 4c

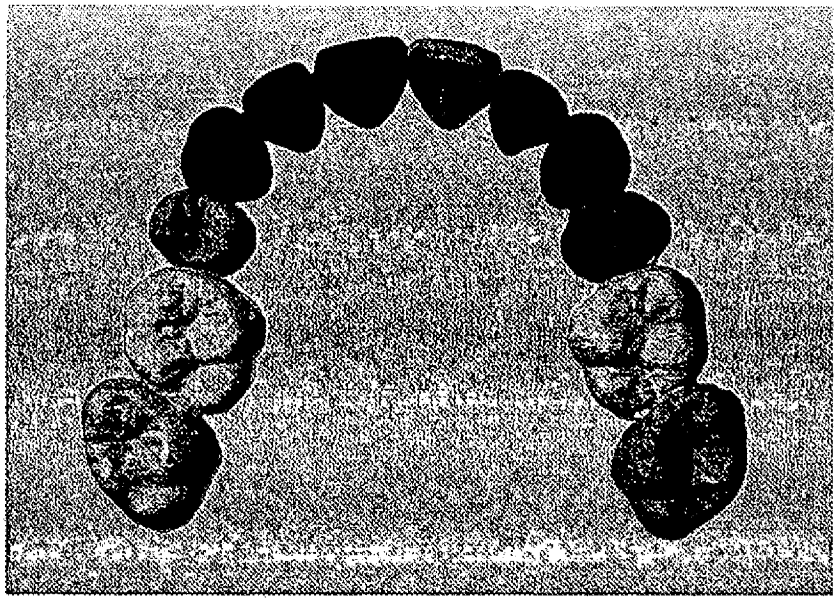

Figure 4d

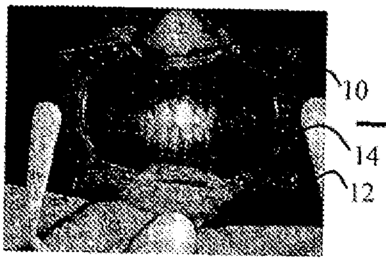

Figure 5a

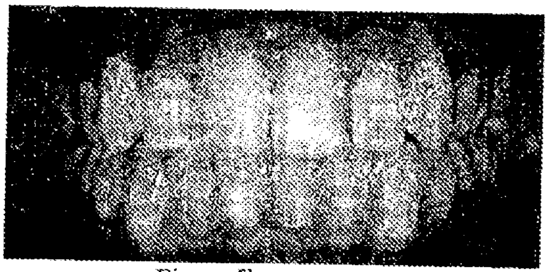

Figure 5b

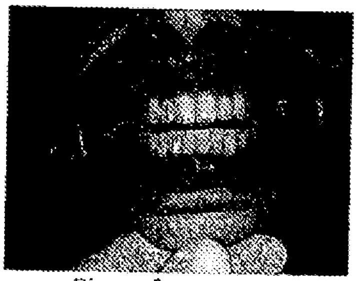

Figure 5c

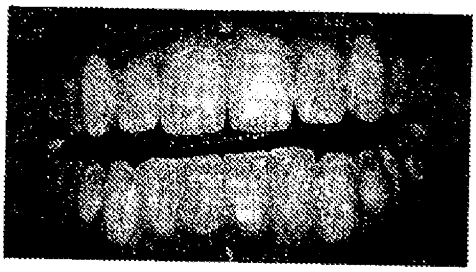

Figure 5d

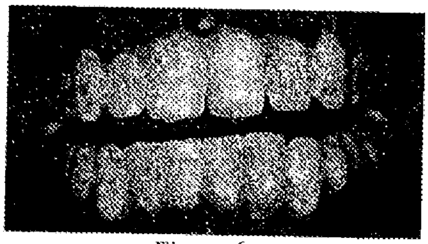

Figure 6a

Figure 6b

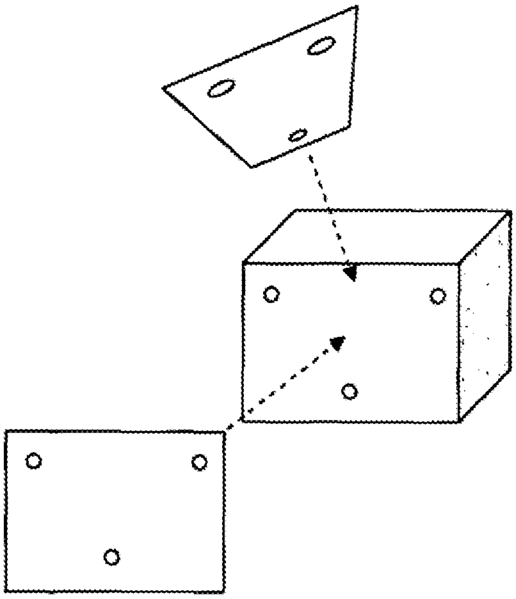

Figure 7

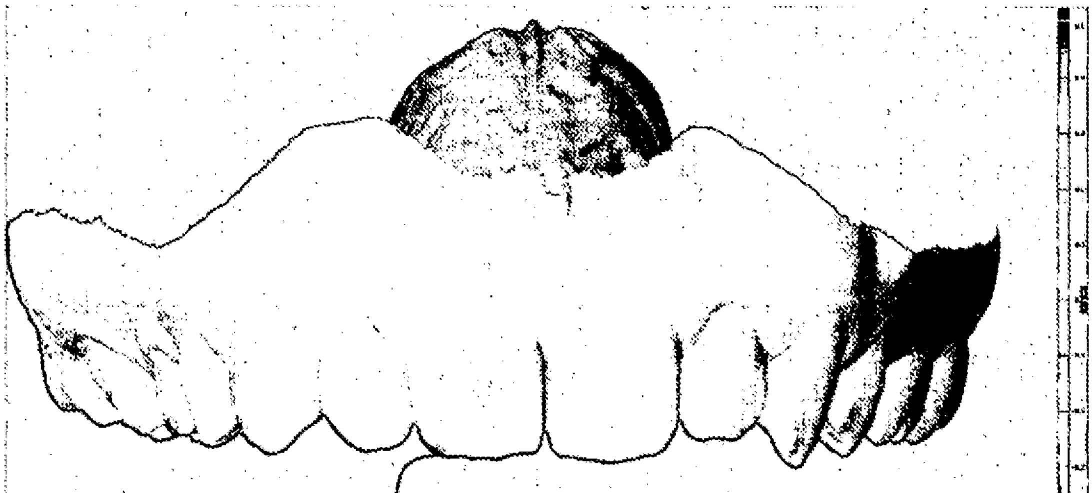

Figure 8

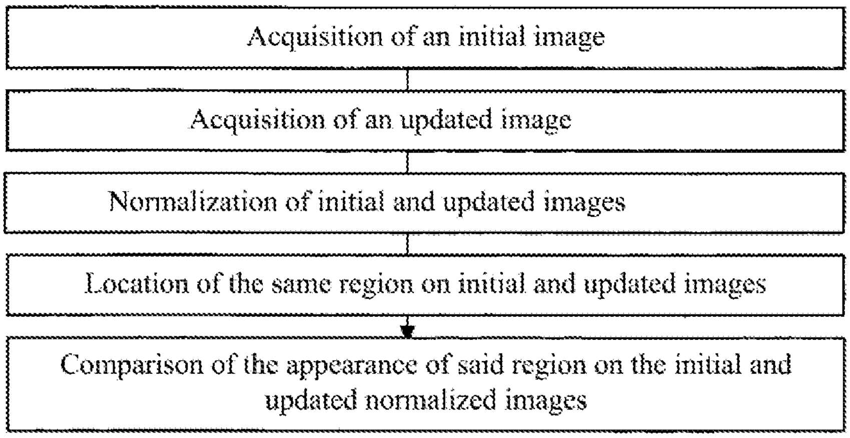

Figure 9

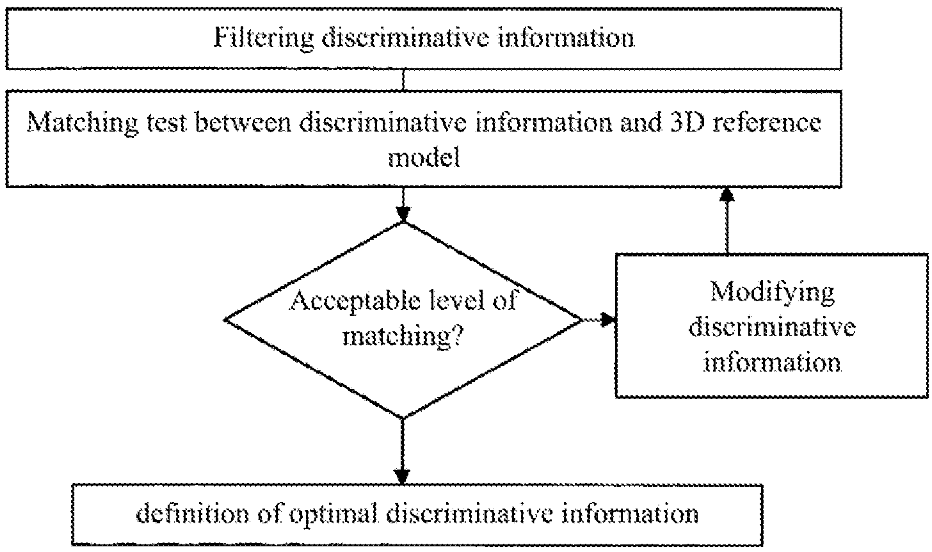

Figure 10

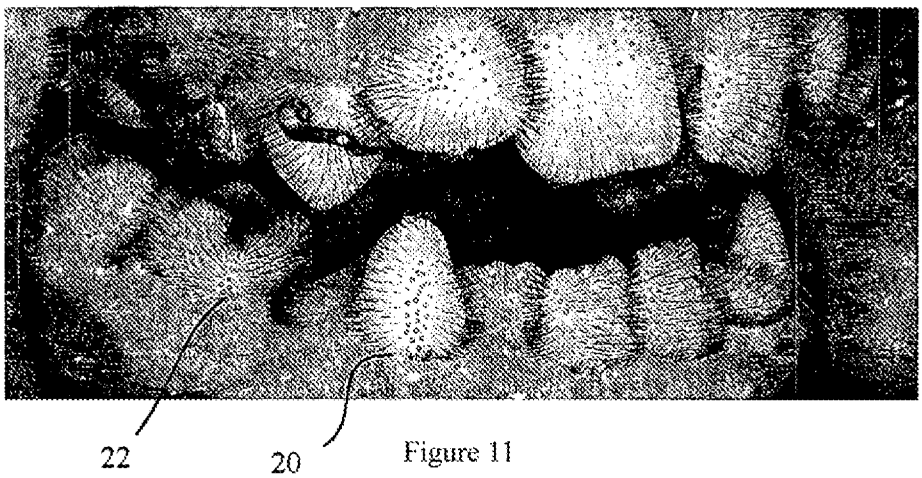

Figure 11

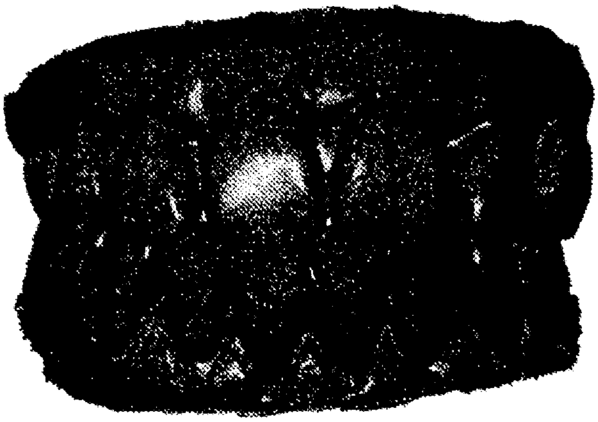

Figure 12a

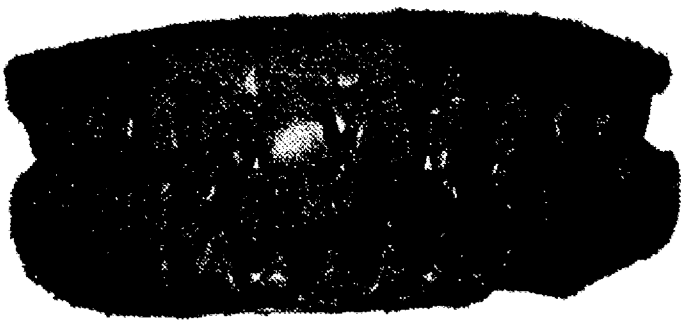

Figure 12b

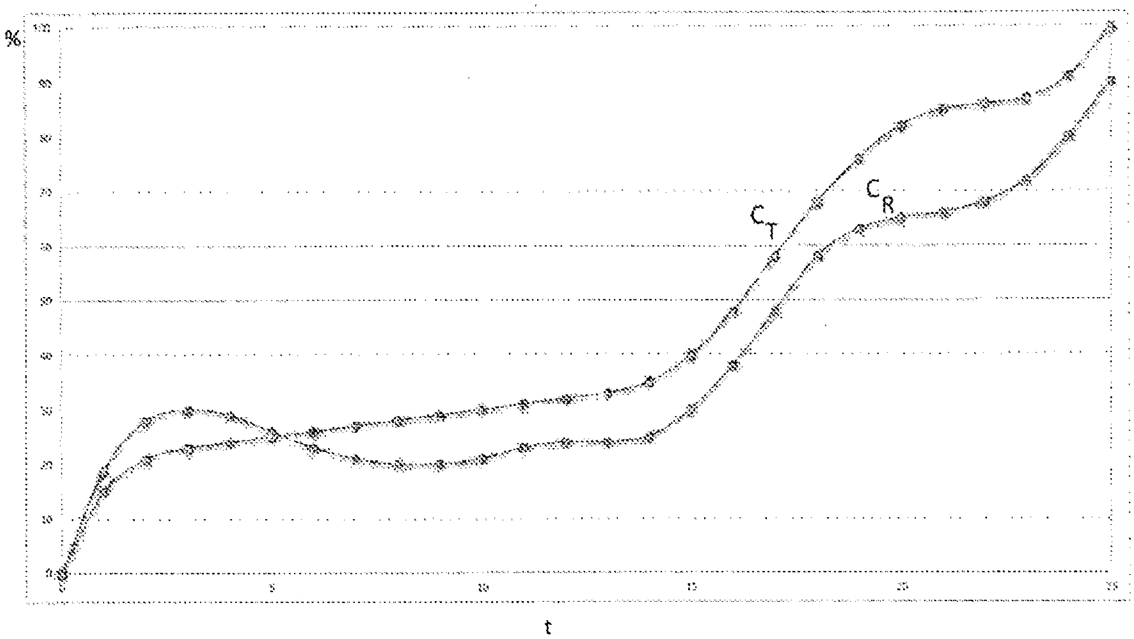

Figure 13

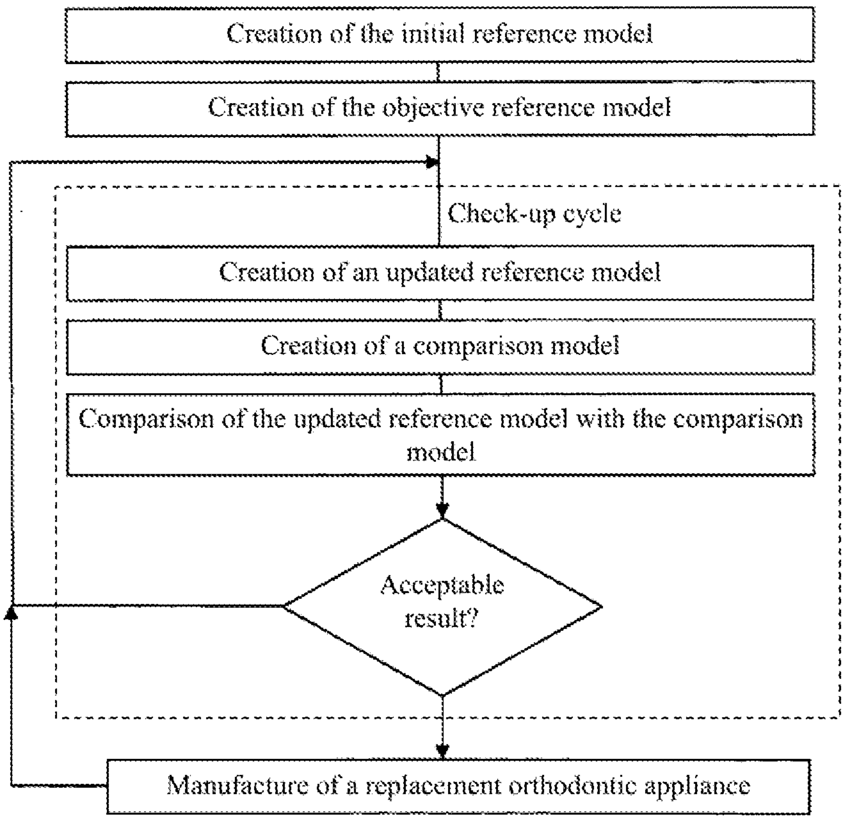

Figure 14