Apparatus for automatically carrying out detection and cleaning operations and a method for controlling same

The invention relates to an apparatus for automatically carrying out detection and cleaning operations and to a method for controlling same.

The cleaning of surfaces in the oral cavity is known. Commercially available manual toothbrushes, interdental cleaners and dental floss are used for this purpose.

In particular, a large number of electric toothbrushes are also available on the market. These predominantly have a brush head that is moved electrically while the toothbrush is moved over the teeth by hand.

Conventional oral and dental cleaning is accordingly carried out either entirely mechanically or in a partially automated manner. In the most highly automated form, the brushing movement is motorised and the contact pressure is communicated to the user by an LED lighting up. However, in every embodiment, the cleaning head is moved and angled by the user. This entails several problems because, for example, right-handed persons clean the right side of the dentition less effectively and some regions of the dentition are generally difficult to reach. Furthermore, the cleaning time per tooth is not always the same, which can result in some teeth being brushed incompletely. Owing to all these problems, tartar may form or, in the worst case, caries may develop.

The object of the invention is to provide an apparatus for carrying out detection and cleaning operations that enables automated cleaning of the oral cavity on the basis of collected individual data.

The object is achieved by the features of claim 1. Advantageous further developments are characterised in the dependent claims.

A further object is to provide a method for controlling the apparatus that enables reliable cleaning.

The object is achieved by a method having the features of claim 34.

Advantageous further developments are characterised in the dependent claims dependent thereon.

In order to carry out error-free automatic cleaning of a dentition, an apparatus is required that measures and detects the shape of the dentition and biomarkers, calculates therefrom a perfect personalised curve for the care routine and allows a care operation to follow this curve without errors or harm to the user.

For this purpose, the apparatus may in particular comprise a first detection device and a second cleaning device.

The two devices may be structurally separate and configured as two devices or structurally combined and configured as one device. In this respect, in the first case, the measurement, detection and care operations may be carried out in one stage.

If the two devices are structurally separate and are therefore operated as two devices, the operations are carried out in a two-stage process. Decoupling of the measurement and detection routines from the care routine is thereby ensured, and the precision can be increased.

If the two devices of the apparatus are structurally separate and provided as two devices, they are preferably based on the same fundamental operating principle.

Each of the devices comprises at least one functional unit that can be introduced into the oral cavity. The functional unit is in particular either a functional unit for carrying out measurement and detection operations or a functional unit for carrying out care operations.

In particular, the functional units are movable and rotatable heads, such as a detection head or a cleaning head. These heads can be introduced into an oral cavity and positioned therein by means of actuator devices. They are thus moved over the teeth without being influenced by the user. The heads may also perform independent movements.

The apparatus or each of the devices additionally comprises a holding device that forms the apparatus, in the case of a structurally integrated apparatus, or forms the devices such that they can be held by the teeth. The holding device also serves as a reference point for determining and defining location data and for generating a reference system between the position data of the devices of the apparatus and the position data of regions of interest in the oral cavity.

In the preferred embodiment, this reference point is a bite device on which the user preferably bites with only a few teeth. These are preferably the incisors. However, a plurality of bite

devices used to provide a reference point are also conceivable. Possible gaps in the data at the positions of the bite devices must, however, be taken into account.

The detection device comprises two or four movable functional units, in particular functional heads, that encompass the dentition on at least two sides and preferably on three sides.

When four functional units are provided, one functional unit is provided for each quadrant of the mouth.

In addition, two further non-movable second functional units may be provided that are fixedly arranged around the reference point. These provide the necessary overlap between the measurement and detection data of the movable functional units at the front incisors of the upper and lower jaws.

These non-movable second functional units may, for example, be arranged on the outer side of the jaw because the dentition has a larger radius at this location, meaning that gaps in the data can occur more easily there.

Non-movable functional units on the inner side of the jaw are conceivable but have the disadvantage that sensors for detecting and measuring biomarkers must be introduced into the inner region of the mouth, which is more uncomfortable for the user. This embodiment comprising movable functional units and non-movable second functional units has the advantage that a continuous data profile can be generated for each half of the dentition, thereby enabling a complete 3D recording of all biomarkers on a dentition.

The cleaning device likewise comprises two or four movable functional units that encompass the teeth on at least two sides and, in a preferred embodiment, on three sides.

A further double functional unit may additionally be provided that can simultaneously care for the upper and lower jaws using a common drive unit.

This unit is in particular mounted so as to be movable by a motor through 20 to 40 mm and is arranged around the reference point in the region of the incisors.

A very wide double functional unit is conceivable, but this has disadvantages because it is more uncomfortable for the user.

Compared with the nevertheless possible use of two individual functional units, a double functional unit has the advantage that neither the drive unit nor the movable unit for movement in the longitudinal direction of the dentition has to be provided twice.

Two individual functional units may enable care to be adapted more specifically in the case of uncommon dentition shapes.

The double functional unit could additionally be equipped with further drive units in order to move it upwards or downwards and towards or away from the tooth. This has advantages in terms of adaptation to uncommon dentition shapes and permits more complicated care routines on the front teeth. However, it makes the cleaning device larger precisely at the locations at which very little space is already available because the reference point and the further functional units are also located in this region.

By providing two movable functional units for the molars and one movable double functional unit at the front teeth, an overlap of the care routines in the region of the canines can be ensured.

As already explained, in order to ensure the repeatability of the operations, at least one reference point is provided for each device or for the apparatus in order to determine and define location data and generate a reference system between the position data of the devices of the apparatus and the position data of regions of interest in the oral cavity. All movements of the movable functional units are also referenced to this reference point.

This reference point is in particular formed by a bite device at different locations of the dentition. However, it may also be supported, either individually or additionally, by chin supports, attachments to the ears, nose or head, or supports in the oral cavity, for example a palate support.

The reference point may additionally be equipped with sensors.

The sensors may be pressure sensors for measuring the biting pressure, 2D mesh sensors for measuring more accurately a rotation or displacement of the bite during two stages, position sensors for determining movements of the head together with the apparatus or device, or time-of-flight sensors inside or outside the mouth for recording displacements relative to the face and thus allowing all movements of the functional units to be related more accurately to the reference point.

All these measures make it possible to ensure decoupling between the physical reference point and differences occurring when the apparatus is introduced into the mouth of a user during two stages and also during prolonged use over weeks or months.

The accuracy of measurements and detections, and also of care routines, can thereby be increased in order to achieve better results in the diagnosis of diseases and to carry out more comfortable and less abrasive care routines that target biomarkers such as biofilm or tartar more accurately while simultaneously protecting the gums.

The non-movable functional units in the region of the interdental spaces between the front teeth may additionally be used to define the reference point even more accurately. This makes it possible in some cases to replace the 2D mesh sensors.

In one embodiment, the non-movable functional units are combined with a pressure sensor and two time-of-flight sensors outside the mouth.

The pressure sensor ensures that the user holds the device or devices at the same height in the mouth. The two non-movable functional units and the two time-of-flight sensors make it possible to measure rotations and tilting movements of the devices or the apparatus in the mouth and displacements about the longitudinal axis of the dentition.

In order to measure accurately the movement of the movable functional units relative to the reference point and thereby ensure that the movement is referenced, the apparatus or the devices preferably comprise similar drives for the functional units.

In a preferred spindle drive, the speed of movement of the functional units and the positioning accuracy depend on the spindle pitch and are controlled by encoders, Hall sensors on the spindle, or current and angle sensors.

If the apparatus comprises two structurally separate units, namely a detection unit and a cleaning unit, it is advantageous to use different spindle pitches. This makes it possible, for example, to perform measurement or detection more accurately than is necessary for the care routine or care operation.

The speed of the care routine or care operation can thereby be increased, and the time required by the user can thus be reduced.

Further drives for upward, downward, tilting and rotational movements of the functional units are advantageous so that the functional units can adapt to any dentition shape and so that, when only two functional units are used, it is possible to change from the upper jaw to the lower jaw.

For the measurement or detection routine or operation, it may be advantageous for the movement over the teeth to take place passively because this provides greater sensitivity to changes in the shape of the dentition.

This is particularly useful when a plurality of detection and measurement processes are carried out over several days, weeks or months in order to improve the accuracy of long-term biomarkers or to measure changes in the shape of the dentition, the height of the teeth or gums, or displacements and rotations of teeth.

In this case, preferably four functional units, which in this case are detection heads, are guided over the teeth by a spindle drive. The lateral and upward or downward movement is configured passively by means of a spring system. The spring systems may each be arranged to act passively in both directions, namely upwards and downwards or to the left and to the right.

In the case of passive height adjustment, this may possibly be dispensed with, and the functional units on the upper jaw may be capable only of tilting downwards while the functional units on the lower jaw may be capable only of tilting upwards. This has the advantage that space is saved, thereby making the device more comfortable for the user.

In order to traverse more complicated tooth geometries, such as rectangular dentition shapes or displaced teeth, more accurately and comfortably using a functional unit, the passive pivoting movement in the plane of the dentition may additionally be superimposed with one or more mechanisms that deflect the functional units through a minimum angle. This lateral adjustment causes the passive pivoting movements to be capable of assuming at least this angle. This has the advantage that the functional unit cannot become caught in tooth gaps or between severely displaced teeth because it would otherwise no longer be able to exit the gaps by passive movement alone.

The care operation is intended to be carried out as precisely as possible. The inventors have recognised that a rigid drive for the functional units is preferably to be provided for this purpose.

In principle, all movements of the at least one functional unit in three-dimensional space are conceivable.

These movements include translational movements along the longitudinal axis of the dentition, pivoting and tilting movements, rotations about the longitudinal axis of the dentition, and rotations and tilting movements relative to the vertical axis of the dentition.

Translational movements are to be carried out as rigidly as possible in order to enable the curve specified by the measurement and detection routine to be followed precisely.

Tilting movements for adjusting the height of the functional unit or functional units are also to be as rigid as possible so that a precise pressure can be applied to the occlusal surfaces of the teeth.

Pivoting movements are generally rigid but may be superimposed with a slight degree of passive movement. This has the advantage that, particularly when only one stage is used for detection and care or when the detection routine is still somewhat inaccurate, an excessively forceful care operation is not performed. Instead, the functional unit centres itself about the longitudinal axis of the dentition as a result of the passive movement.

Rotational movements about the longitudinal axis of the dentition should also be carried out as rigidly as possible. This enables, on the one hand, precise rotation from the upper jaw to the lower jaw, which is necessary particularly when only two movable functional units are used. On the other hand, it enables the functional unit to be rotated into interdental regions, thereby permitting better cleaning and, particularly at the rearmost molars where space is in any case limited, allowing a smaller functional unit to provide somewhat greater reach.

This is advantageous for increasing user comfort.

Rotational movements about the vertical axis of the dentition should be implemented as rigidly as possible so that the functional unit is always parallel to the dentition and an optimum care routine can be achieved. A rigid rotation of the functional unit is additionally necessary in order to rotate the functional unit into the appropriate position when changing from the upper

jaw to the lower jaw. This has the advantage that the functional unit can be made as large as necessary without causing discomfort to the user during the change.

Tilting movements relative to the vertical axis of the dentition are preferably not carried out because this increases the complexity without achieving any improvement in care or cleaning. However, this may have the advantage that the spindle can be shortened and the device can thereby be constructed with smaller dimensions because the functional unit is tilted towards the rearmost molars.

The configuration of the functional units will be discussed in greater detail below.

A measurement and detection head serving as a functional unit may be configured differently depending on its use.

Preferably, all necessary sensors are integrated either directly into the measurement and detection head or into the mechanism of the actuator devices or drive units.

In particular, three cameras are located directly in each functional unit, one for each side of the tooth. The non-movable functional units are equipped with two cameras on the outer side of the dentition.

In addition to the cameras in the functional units, sensors are arranged on the actuator units that make it possible to generate an accurate 3D profile of the dentition and to project the camera data and the data from all additionally integrated sensors for biomarkers onto this 3D profile.

In a preferred embodiment, all biomarkers are detected and measured solely by means of the cameras and special optical components, such as high-pass and low-pass filters and polarisers.

This projection of the biomarkers, above all biofilm, caries, discolouration of the teeth and gums, wear of the teeth, displacement of the teeth and recession of the gums, makes it possible to calculate a personalised and adapted curve for the care routine, referred to below as the golden curve. This curve is then followed by a cleaning device using a functional unit for care, in particular a cleaning head.

Encoders and current sensors are arranged on the drive units for the translational movements in order to measure and calculate this golden curve. The encoders make it possible to store the exact position of the extended state. The current sensors additionally help to detect

whether movement is taking place against an obstacle. On the one hand, this provides greater comfort for the user because excessive pressure against the teeth is prevented. On the other hand, it allows the lateral adjustment to be triggered on the basis of measurement data from these current sensors. Encoders are provided for the lateral adjustment in order to ensure precise readjustment of the minimum angle. Angle sensors for the tilting angle and pivoting angle are additionally arranged on the actuator device or drive unit. This makes it possible to measure the current angle of the extended functional unit.

A cleaning head or care head, and thus the functional unit for care, may be configured in different ways. This depends in particular on the application.

In particular, a cleaning head may be provided with filaments, lips, threads, wires or other mechanical structures that are configured to act on a surface. In particular, these structures are configured to detach coatings such as biofilm from a surface in a gently abrasive manner.

Preferably, a cleaning head is configured only with thin bundles of filaments, which have the advantage that precise poking and wiping movements can be performed therewith. Additional sensors may be arranged on the actuator devices and/or on the drive unit.

The mode of operation of the detection device will be discussed below.

The measurement and detection routine is divided into phases.

The first phase is used to calibrate a rough golden curve. This takes place particularly when the device is introduced into the mouth for the first time but may also take place over several cycles.

Preferably, the first measurement is used for a rough calibration of the golden curve, which is then refined with each subsequent performance of the measurement and detection routine.

The older measurement data may be weighted more heavily because, during the first scans, the functional unit is preferably guided more slowly over the teeth and more accurate measurement data are therefore available. In particular, a memory is used that stores the most recent measurement data in addition to the calculated golden curve. This makes it possible to compare large changes in the position, rotation, spacing, recession or wear of teeth or gums with the golden curve. This has the advantage that potential measurement errors occurring during an individual cycle and exhibiting a large deviation from the golden

curve can be filtered out, and a response can be initiated only after the large change has been confirmed.

For the calibration, it is expedient to reference all sensor data to the reference point.

The precise calibration sequence is as follows, wherein some or all of the steps are carried out in the stated order or in a different order:

- Biting onto the reference point, namely the bite device, in order to establish a reference.
- The non-movable functional units capture an image that identifies the central interdental space and thus establishes the first reference relative to the jaw.
- The time-of-flight sensors record the distance from the face in order to refine the reference.
- Subsequently, all movable functional units capture an image in order to start the data recording.
- The functional units for the upper jaw are then extended. However, this has no influence on the results, and it is also possible to start with the lower jaw.
- Starting from the initial positions of the functional units, the functional units are moved towards the teeth by the motor unit.
- Images are captured by the functional units at a constant frame rate. This is not essential but has the advantage that known distances are always travelled at equal time intervals and at a known speed. In addition to the encoders and motor currents, this allows the golden curve to be refined because, particularly after several scans, the approximate size of a tooth and thus the distance between two images are known.
- The functional units are guided over the teeth until the motor current becomes too high.
- If the motor current is too high and contact with the teeth is thereby registered, the respective functional unit is deflected through a certain minimum angle by means of the lateral adjustment. This reduces the force required to continue moving over the

teeth and allows comfortable calibration. Contact is preferably registered when the motor current exceeds a predetermined threshold value corresponding to a certain force. This force is in particular from 0.5 N to 2 N.

- This is repeated until:

a. No setting of the lateral adjustment can be found at which the motor current is sufficiently low.

b. The end of the range of the motor unit is reached.

c. The cameras register an end of the dentition.

- When the end is reached:

a. The functional units are either moved back to the initial position along the recorded path.

b. Or the entire procedure is carried out in reverse so that the recorded path is further improved.

- This is then repeated for the lower jaw.

- Throughout the entire routine, the time-of-flight sensors or any 2D mesh sensors at the reference point provide further data relating to displacements and rotations so that the measured data can be corrected relative to the original reference point.

- Preferably, after completion of the detection or measurement routine, all the images are joined together in order to generate a coherent image stream.

- This image stream is examined by a machine learning algorithm. The algorithm is trained for tooth and gum segmentation and divides the image stream into teeth and gums.

- On these teeth, biomarkers are then detected:

a. Either by means of a threshold algorithm that detects biomarkers such as biofilm, discolouration or caries.

b. Or by means of a machine learning algorithm trained to recognise biofilm and other biomarkers such as discolouration or caries, thereby permitting more accurate detection thereof.

c. Both methods or further methods may be combined in order to improve the results.

- The results of this detection are projected onto the individual teeth.

- With the aid of the data from the encoders, current sensors and angle sensors, a 3D reconstruction of the dentition is generated from this image stream and the mapped tooth and gum data, with all biomarkers being projected onto the 3D reconstruction.

- This allows a golden curve to be calculated that is to be followed by a care routine in order to ensure the best possible care.

- In addition, the optimum point at which the change from the upper jaw to the lower jaw is to take place is calculated therefrom.

- From the second measurement or detection onward, the calculated golden curve is preferably used as the starting point for step number 4 and the subsequent steps. All data continue to be recorded, but the device automatically identifies which data points of the golden curve are considered correct and which still contain potential errors. As a result:

a. The frame rate of the images or of the detection may, for example, be reduced in order to save data.

b. Higher speeds may be used without introducing new errors into the measurement data.

c. Specific regions of the golden curve may be approached in order to measure biomarkers more accurately at these locations.

It will be explained below how the obtained results are used to influence the care operation or care routine and how this operation or routine proceeds.

If the mechanism of the device for the measurement and detection operation is not exactly the same as that of the device for the care operation, or if the reference point permits

excessively large errors when the device is inserted into the mouth, a plausibility check of the data of the golden curve may be carried out in both devices before these data are used to calculate an improved path.

Preferably, the device for the measurement and detection operation transmits the golden curve to the device for the care operation, and the latter checks whether the data are plausible.

The check includes checking the plausibility of whether the golden curve does not lie, in some regions, outside the mechanically travelable limits of the device for the care routine, namely the device for the cleaning operation, whether the golden curve does not lie in regions that were identified as a tooth or dentition shape in previous measurements, and whether there are regions that cannot be approached by a functional unit of the device for the cleaning operation in such a manner because this could cause harm to the user.

In addition, curves such as splines are preferably fitted to the data points if the golden curve contains too few of these data points. This has the advantage that known dentition-curve geometries can be used to bridge missing data in the best possible manner. As a further optimisation step, dentition shapes are corrected on the basis of planar and interplanar dentition symmetries. While the former correction is directed towards symmetries between the left and right halves of the dentition, interplanar corrections use the symmetries between the upper and lower rows of teeth. Large deviations in a region can thereby be compensated for.

Sensors such as encoders, current sensors, angle sensors or Hall sensors are arranged on the drive units for the functional unit for cleaning or care in order to follow the calibrated and generated golden curve during the care operation.

In particular, the translational movement is generated by means of a spindle drive provided with an encoder on the motor and with current sensors.

A separate motor having an encoder and current sensors is used for each of the pivoting and tilting movements relative to the longitudinal axis of the dentition.

In addition, a strain gauge may be arranged close to each functional unit in order to measure pressure on the occlusal surfaces of the teeth.

In the preferred embodiment, in order to rotate the functional unit about the longitudinal axis of the dentition, the entire spindle, including the stroke of the translational drive, is rotated. This has the advantage that the motor can be located far towards the rear and outside the mouth. Encoders, current sensors and Hall sensors are used on the motor for this purpose.

Encoders, current sensors and Hall sensors are used on the motor for rotating the functional unit about the vertical axis of the dentition.

It may be advantageous if the device for the cleaning operation additionally comprises a camera at a position very similar to that of the camera in the non-movable functional unit of the device for the measurement and detection operation, as well as two time-of-flight sensors, in order to measure displacements and rotations relative to the original reference point.

By using all these sensors, it is possible to follow the golden curve perfectly in three-dimensional space and to accomplish this using only two functional units because a change can be made from the upper jaw to the lower jaw.

In the preferred embodiment, the device for the cleaning operation receives the golden curve and carries out a plausibility check.

If the golden curve appears plausible, the sequence is as follows:

- Biting onto the reference point in order to establish a reference.
- The camera captures an image that identifies the central interdental space and thus calculates the first reference in comparison with the device for the measurement and detection operation.
- The time-of-flight sensors record the distances from the face.
- The golden curve is modified for the first time on the basis of these new references.
- The functional units for the upper jaw are then extended along the golden curve. However, this has no influence on the results, and it is also possible to start with the lower jaw.

- The golden curve is followed, and the care routine is adapted depending on the 3D structure of the dentition, the height of the teeth and gums, or the quantity and position of different biomarkers. This adaptation may comprise:

a. A higher intensity.

b. Remaining for a longer period at a certain point on the golden curve.

c. Moving to the left or right or upwards or downwards at certain points on the golden curve.

d. Rotating and tilting away from or towards the tooth or interdental space at certain points on the golden curve.

e. A combination of all these methods.

- While the golden curve is being followed, the time-of-flight sensors and 2D mesh sensors or the camera at the central interdental space are used to carry out further plausibility checks or to adapt the path such that the golden curve is followed in the best possible manner.

- This is carried out until:

a. The end of the golden curve is reached.

b. A plausibility check no longer identifies any mechanically approachable point.

c. The current sensors indicate an excessively high current, thereby indicating that the functional unit has contacted something and that the golden curve cannot be followed.

d. The routine is otherwise stopped by the user.

- When the end is reached, the golden curve is followed again in the reverse direction.

- The same procedure is subsequently started on the lower jaw.

A cycle is thereby completed.

An advantage of the invention is that a fully integrated process for data collection, data transfer and use of the obtained data is achieved, wherein comparable devices are used to collect data and to perform care using the data.

The invention thus relates in particular to an apparatus for automatically carrying out detection and cleaning operations, comprising a device for detecting conditions of at least one surface and a device for caring for the surface, wherein the detection device is configured to scan, by means of sensors, at least the surface, including with respect to its three-dimensional profile, and to transfer the obtained data to the device for caring for the surface, wherein both devices provide a reference point relative to the surface, the detection device provides the data normalised with respect to the reference point, and the care device uses the data normalised with respect to the reference point in order to traverse the surface.

A further development provides that the detection device and the care device form a structural unit within the apparatus.

A further development provides that the detection device and the care device are structurally separate.

A further development provides that the devices are configured to detect surfaces in an oral cavity or to care for surfaces in an oral cavity.

A further development provides that each of the devices comprises at least one functional unit that can be introduced into the oral cavity, wherein the functional unit is either a functional unit for carrying out measurement and detection operations or a functional unit for carrying out care operations.

A further development provides that the functional units are movable and rotatable heads, such as a detection head or a cleaning head.

A further development provides that the heads can be introduced into an oral cavity and positioned in the oral cavity by means of actuator devices.

A further development provides that the apparatus or each of the devices additionally comprises a holding device which, in the case of a structural unit, configures the apparatus or respectively the two devices such that they can be held by the teeth.

A further development provides that the holding device serves as a reference point for determining and defining location data and for generating a reference system between the position data of the devices of the apparatus and the position data of regions of interest in the oral cavity.

A further development provides that the at least one reference point is at least one bite device on which the user bites with at least one tooth of the upper jaw and one tooth of the lower jaw.

A further development provides that the detection device comprises two or four movable functional units that encompass the dentition on at least two sides.

A further development provides that, when four functional units are provided, one functional unit is provided for each quadrant of the mouth.

A further development provides that two additional non-movable second functional units are provided that are fixedly arranged around the reference point.

A further development provides that the non-movable second functional units are arranged on the outer side of the jaw.

A further development provides that the cleaning device comprises two or four movable functional units that encompass the teeth on at least two sides.

A further development provides that a double functional unit is provided that can simultaneously care for the upper and lower jaws using a common drive unit.

A further development provides that the double functional unit is mounted so as to be motor-driven through 20 to 40 mm and is arranged around the reference point in the region of the incisors.

A further development provides that the double functional unit is equipped with additional drive units in order to move it upwards or downwards and towards or away from the tooth.

A further development provides that the reference point is supplemented, individually or additionally, by chin supports, attachments to the ears, nose or head, or supports in the oral cavity, for example a palate support.

A further development provides that the reference point is additionally equipped with sensors.

A further development provides that the sensors comprise one, several or all of the following group: pressure sensors, 2D mesh sensors, position sensors, time-of-flight sensors, laser distance sensors and ultrasonic sensors.

A further development provides that a detection head serving as a functional unit of the detection device contains sensors, wherein all necessary sensors are either integrated directly into the measurement and detection head and/or arranged in the mechanism of the actuator devices or drive units of the detection head.

A further development provides that three cameras, one for each side of the tooth, are arranged in the detection head serving as a functional unit of the detection device.

A further development provides that the non-movable functional units are equipped with two cameras on the outer side of the dentition.

A further development provides that, in addition to the cameras in the detection head serving as a functional unit of the detection device, sensors are arranged on the actuator units that make it possible to generate an accurate 3D profile of the dentition and to project camera data and data from all additionally integrated sensors for biomarkers onto this 3D profile.

A further development provides that all biomarkers are detected and measured by means of the cameras and special optical components, such as high-pass and low-pass filters and polarisers.

A further development provides that a cleaning head is provided with filaments, lips, threads, wires or other mechanical structures that are configured to act on a surface and are in particular configured to detach coatings such as biofilm from a surface in a gently abrasive manner.

A further development provides that a cleaning head is configured only with thin filament bundles.

A further development provides that additional sensors are arranged on the actuator devices and/or on the drive unit.

A further development provides that the non-movable functional units are combined with a pressure sensor and two time-of-flight sensors outside the mouth.

A further development provides that the functional units comprise spindle drives.

A further development provides that, in the case of two structurally separate units, namely a detection unit and a cleaning unit, different spindle pitches are provided, thereby enabling more accurate measurement or detection than is necessary for the care routine or care operation.

A further development provides that further drives for upward, downward, tilting and rotational movements of the functional units are provided.

A further aspect of the invention relates to a method for controlling an apparatus for automatically carrying out detection and cleaning operations, in particular an apparatus according to any one of the preceding claims, characterised in that the condition and the coordinates are initially recorded by means of the detection device, wherein a reference is initially generated by biting onto the reference point, followed by at least the following steps:

- The non-movable functional units capture an image that identifies the central interdental space and thus establishes the first reference relative to the jaw.
- The time-of-flight sensors record the distance from the face in order to refine the reference.
- Subsequently, all movable functional units capture an image in order to start the data recording.
- The functional units for at least a first jaw are then extended.
- Starting from the initial positions of the functional units, the functional units are moved towards the teeth by the motor unit.
- Images are captured by the functional units, in particular at a constant frame rate.
- The cameras register an end of the dentition.

- The functional units are either moved back to the initial position along the recorded path, or the entire procedure is carried out in reverse so that the recorded path is further improved.

- The sequence is repeated for the second jaw.

A further development provides that the functional units are guided over the teeth until the motor current becomes too high, wherein, if the motor current is too high and contact with the teeth is thereby registered, the respective functional unit is deflected through a certain minimum angle by means of the lateral adjustment so that the force required to continue moving over the teeth is reduced.

A further development provides that contact is registered when the motor current exceeds a predetermined threshold value corresponding to a certain force. This force is in particular from 0.5 N to 2 N, wherein this is repeated until no setting of the lateral adjustment can be found at which the motor current is sufficiently low or until the end of the range of the motor unit is reached.

A further development provides that, throughout the entire routine, the time-of-flight sensors or any 2D mesh sensors at the reference point provide further data relating to displacements and rotations so that the measured data can be corrected relative to the original reference point.

A further development provides that, after completion of the detection or measurement routine, all the images are joined together in order to generate a coherent image stream.

A further development provides that the image stream is examined by a machine learning algorithm that is trained for tooth and gum segmentation and divides the image stream into teeth and gums.

A further development provides that biomarkers such as biofilm, discolouration or caries are detected on the teeth either by means of a threshold algorithm, or that a machine learning algorithm is used that is trained to recognise biofilm and other biomarkers such as discolouration or caries and thereby permits more accurate detection thereof, wherein the results of this detection are projected onto the individual teeth and, with the aid of the data

from the encoders, current sensors and angle sensors, a 3D reconstruction of the dentition is generated from this image stream and the mapped tooth and gum data, with all biomarkers being projected onto the 3D reconstruction, thereby enabling the calculation of a golden curve that is to be followed by a care routine in order to ensure the best possible care.

A further development provides that the golden curve is transmitted from the detection device to the cleaning device and that the cleaning device checks whether the data are plausible, wherein the check comprises checking the plausibility of whether the golden curve does not lie, in some regions, outside the mechanically travelable limits of the cleaning device, whether the golden curve does not lie in regions that were identified as a tooth or dentition shape in previous measurements, and whether there are regions that cannot be approached by a functional unit of the cleaning device in such a manner because this could cause harm to the user.

A further development provides that sensors such as encoders, current sensors, angle sensors or Hall sensors are arranged on the drive units for the functional unit for cleaning or care in order to follow the calibrated and generated golden curve during the care operation.

A further development provides that the translational movement is generated by means of a spindle drive provided with an encoder on the motor and with current sensors.

A further development provides that a separate motor having an encoder and current sensors is used for each of the pivoting and tilting movements relative to the longitudinal axis of the dentition.

A further development provides that a strain gauge is arranged close to each functional unit in order to measure pressure on the occlusal surfaces of the teeth.

A further development provides that, in order to rotate the functional unit about the longitudinal axis of the dentition, the entire spindle, including the stroke of the translational drive, is rotated.

A further development provides that encoders, current sensors and Hall sensors are used on the motor in order to rotate the functional unit about the vertical axis of the dentition.

A further development provides that, in the cleaning device, a camera positioned very similarly to the camera in the non-movable functional unit of the detection device, as well as two time-

of-flight sensors, are used in order to measure displacements and rotations relative to the original reference point.

Claims

1. Apparatus for automatically carrying out detection and cleaning operations, comprising a detection device for detecting conditions of at least one surface and a care device for caring for the surface, wherein the detection device is configured to scan, by means of sensors, at least the surface, including with respect to its three-dimensional profile, and to transfer obtained data to the care device, wherein both devices provide a reference point relative to the surface, the detection device provides the data normalised with respect to the reference point, and the care device uses the data normalised with respect to the reference point in order to traverse the surface, wherein the at least one reference point is at least one bite device on which a user bites with at least one tooth of an upper jaw and one tooth of a lower jaw.

2. Apparatus according to claim 1, characterised in that the detection device and the care device form a structural unit within the apparatus.

3. Apparatus according to claim 1, characterised in that the detection device and the care device are structurally separate.

4. Apparatus according to any one of the preceding claims, characterised in that the devices are configured to detect surfaces in an oral cavity or to care for surfaces in an oral cavity.

5. Apparatus according to any one of the preceding claims, characterised in that each of the devices comprises at least one functional unit that can be introduced into the oral cavity, wherein the functional unit is either a functional unit for carrying out measurement and detection operations or a functional unit for carrying out care operations.

6. Apparatus according to any one of the preceding claims, characterised in that the functional units are movable and rotatable heads, such as a detection head or a cleaning head.

7. Apparatus according to any one of the preceding claims, characterised in that the heads can be introduced into the oral cavity and positioned in the oral cavity by means of actuator devices.

8. Apparatus according to any one of the preceding claims, characterised in that the apparatus or each of the devices additionally comprises a holding device which, in the case of a structural unit, configures the apparatus or respectively the two devices so as to be held by the teeth.

9. Apparatus according to any one of the preceding claims, characterised in that the holding device serves as a reference point for determining and defining location data and for generating a reference system between position data of the devices of the apparatus and position data of regions of interest in the oral cavity.

10. Apparatus according to any one of the preceding claims, characterised in that the detection device comprises two or four movable functional units that encompass a dentition on at least two sides.

11. Apparatus according to any one of the preceding claims, characterised in that, when four functional units are provided, one functional unit is provided for each quadrant of the mouth.

12. Apparatus according to any one of the preceding claims, characterised in that two additional non-movable second functional units are provided that are fixedly arranged around the reference point.

13. Apparatus according to any one of the preceding claims, characterised in that the non-movable second functional units are arranged on an outer side of the jaw.

14. Apparatus according to any one of the preceding claims, characterised in that the cleaning device comprises two or four movable functional units that encompass the teeth on at least two sides.

15. Apparatus according to claim 14, characterised in that a double functional unit is provided that can simultaneously care for the upper and lower jaws using a common drive unit.

16. Apparatus according to claim 15, characterised in that the double functional unit is mounted so as to be motor-driven through 20 to 40 mm and is arranged around the reference point in the region of the incisors.

17. Apparatus according to claim 15 or 16, characterised in that the double functional unit is equipped with additional drive units in order to move it upwards or downwards and towards or away from the tooth.

18. Apparatus according to any one of the preceding claims, characterised in that the reference point is supplemented, individually or additionally, by chin supports, attachments to the ears, nose or head, or supports in the oral cavity, for example a palate support.

19. Apparatus according to any one of the preceding claims, characterised in that the reference point is additionally equipped with sensors.

20. Apparatus according to claim 19, characterised in that the sensors comprise one, several or all of the following group: pressure sensors, 2D mesh sensors, position sensors, time-of-flight sensors, laser distance sensors and ultrasonic sensors.

21. Apparatus according to any one of the preceding claims, characterised in that a detection head serving as a functional unit of the detection device contains sensors, wherein all necessary sensors are either integrated directly into the measurement and detection head and/or arranged in a mechanism of the actuator devices or drive units of the detection head.

22. Apparatus according to any one of the preceding claims, characterised in that three cameras, one for each side of the tooth, are arranged in the detection head serving as a functional unit of the detection device.

23. Apparatus according to any one of the preceding claims, characterised in that the non-movable functional units are equipped with two cameras on the outer side of the dentition.

24. Apparatus according to any one of the preceding claims, characterised in that, in addition to the cameras in the detection head serving as a functional unit of the detection device, sensors are arranged on the actuator units that make it possible to

generate an accurate 3D profile of the dentition and to project camera data and all additionally integrated sensors for biomarkers onto this 3D profile.

25. Apparatus according to any one of the preceding claims, characterised in that all biomarkers are detected and measured by means of the cameras and special optical components, such as high-pass and low-pass filters and polarisers.

26. Apparatus according to any one of the preceding claims, characterised in that a cleaning head is provided with filaments, lips, threads, wires or other mechanical structures that are configured to act on the surface and are in particular configured to detach coatings such as biofilm from the surface in a gently abrasive manner.

27. Apparatus according to any one of the preceding claims, characterised in that a cleaning head is configured only with thin filament bundles.

28. Apparatus according to claim 21 or 22, characterised in that additional sensors are arranged on the actuator devices and/or on the drive unit.

29. Apparatus according to any one of the preceding claims, characterised in that the non-movable functional units are combined with a pressure sensor and two time-of-flight sensors outside the mouth.

30. Apparatus according to any one of the preceding claims, characterised in that the functional units comprise spindle drives.

31. Apparatus according to any one of the preceding claims, characterised in that, in the case of two structurally separate units, namely a detection unit and a cleaning unit, different spindle pitches are provided, thereby enabling more accurate measurement or detection than is necessary for a care routine or care operation.

32. Apparatus according to any one of the preceding claims, characterised in that further drives for upward, downward, tilting and rotational movements of the functional units are provided.

33. Method for controlling an apparatus according to any one of the preceding claims, characterised in that the condition and coordinates of the three-dimensional profile of the surface to be detected are initially recorded by means of the detection device,

wherein a reference is initially generated by biting onto the reference point, followed by at least the following steps:

- the non-movable functional units capture an image that identifies a central interdental space and thus establishes a first reference relative to the jaw,
- the time-of-flight sensors record a distance from the face in order to refine the reference,
- subsequently, all movable functional units capture an image in order to start the data recording,
- the functional units for at least a first jaw are then extended,
- starting from initial positions of the functional units, the functional units are moved towards the teeth by a motor unit,
- images are captured by the functional units, in particular at a constant frame rate,
- the cameras register an end of the dentition,
- the functional units are either moved back to the initial position along a recorded path, or the entire procedure is carried out in reverse so that the recorded path is further improved, and
- the sequence is repeated for a second jaw.

34. Method according to claim 33, characterised in that the functional units are guided over the teeth until a motor current becomes too high, wherein, if the motor current is too high and contact with the teeth is thereby registered, the respective functional unit is deflected through a certain minimum angle by means of a lateral adjustment so that the force required to continue moving over the teeth is reduced.

35. Method according to claim 34, characterised in that the contact is registered when the motor current exceeds a predetermined threshold value corresponding to a certain force, wherein this force is in particular from 0.5 N to 2 N, and wherein this is repeated until no setting of the lateral adjustment can be found at which the motor current is sufficiently low or until the end of the range of the motor unit is reached.

36. Method according to any one of claims 33 to 35, characterised in that, throughout the entire routine, the time-of-flight sensors or any 2D mesh sensors at the reference point provide further data relating to displacements and rotations so that the measured data can be corrected relative to the original reference point.

37. Method according to any one of claims 33 to 36, characterised in that, after completion of a detection or measurement routine, all the images are joined together in order to generate a coherent image stream.

38. Method according to claim 37, characterised in that the image stream is examined by a machine learning algorithm that is trained for tooth and gum segmentation and divides the image stream into teeth and gums.

39. Method according to any one of claims 33 to 38, characterised in that biomarkers such as biofilm, discolouration or caries are detected on the teeth either by means of a threshold algorithm, or a machine learning algorithm is used that is trained to recognise biofilm and other biomarkers such as discolouration or caries and thereby permits more accurate detection thereof, wherein results of this detection are projected onto the individual teeth and, with the aid of data from the encoders, current sensors and angle sensors, a 3D reconstruction of the dentition is generated from this image stream and mapped tooth and gum data, with all biomarkers being projected onto the 3D reconstruction, thereby enabling the calculation of a golden curve that is to be followed by the care routine in order to ensure the best possible care.

40. Method according to any one of claims 33 to 39, characterised in that a golden curve is transferred from the detection device to the cleaning device and the cleaning device checks whether the data are plausible, wherein the check comprises checking the plausibility of whether the golden curve does not lie, in some regions, outside the mechanically travelable limits of the cleaning device, whether the golden curve does not lie in regions that were identified as a tooth or dentition shape in previous measurements, and whether there are regions that cannot be approached by a functional unit of the cleaning device in such a manner because this could cause harm to the user.

41. Method according to any one of claims 33 to 40, characterised in that sensors such as encoders, current sensors, angle sensors or Hall sensors are arranged on the drive

units for the functional unit for cleaning or care in order to follow the calibrated and generated golden curve during the care operation.

42. Method according to any one of claims 33 to 41, characterised in that the translational movement is generated by means of a spindle drive provided with an encoder on the motor and with current sensors.

43. Method according to any one of claims 33 to 42, characterised in that a separate motor having an encoder and current sensors is used for each of the pivoting and tilting movements relative to the longitudinal axis of the dentition.

44. Method according to any one of claims 33 to 43, characterised in that a strain gauge is arranged close to each functional unit in order to measure pressure on the occlusal surfaces of the teeth.

45. Method according to any one of claims 33 to 44, characterised in that, in order to rotate the functional unit about the longitudinal axis of the dentition, the entire spindle, including the stroke of the translational drive, is rotated.

46. Method according to any one of claims 34 to 45, characterised in that encoders, current sensors and Hall sensors are used on the motor in order to rotate the functional unit about the vertical axis of the dentition.

47. Method according to any one of claims 33 to 46, characterised in that, in the cleaning device, a camera positioned very similarly to the camera in the non-movable functional unit of the detection device, as well as two time-of-flight sensors, are used in order to measure displacements and rotations relative to the original reference point.