US 20040157188A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2004/0157188 A1

Luth et al. (43) Pub. Date: Aug. 12, 2004

(54) METHOD AND DEVICE SYSTEM FOR REMOVING MATERIAL OR FOR WORKING MATERIAL

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(21) Appl. No.: **10/472,654**

(22) PCT Filed: **Mar. 25, 2002**

(86) PCT No.: **PCT/EP02/03334**

(30) **Foreign Application Priority Data**

Mar. 26, 2001 (DE) 101 14 910.7

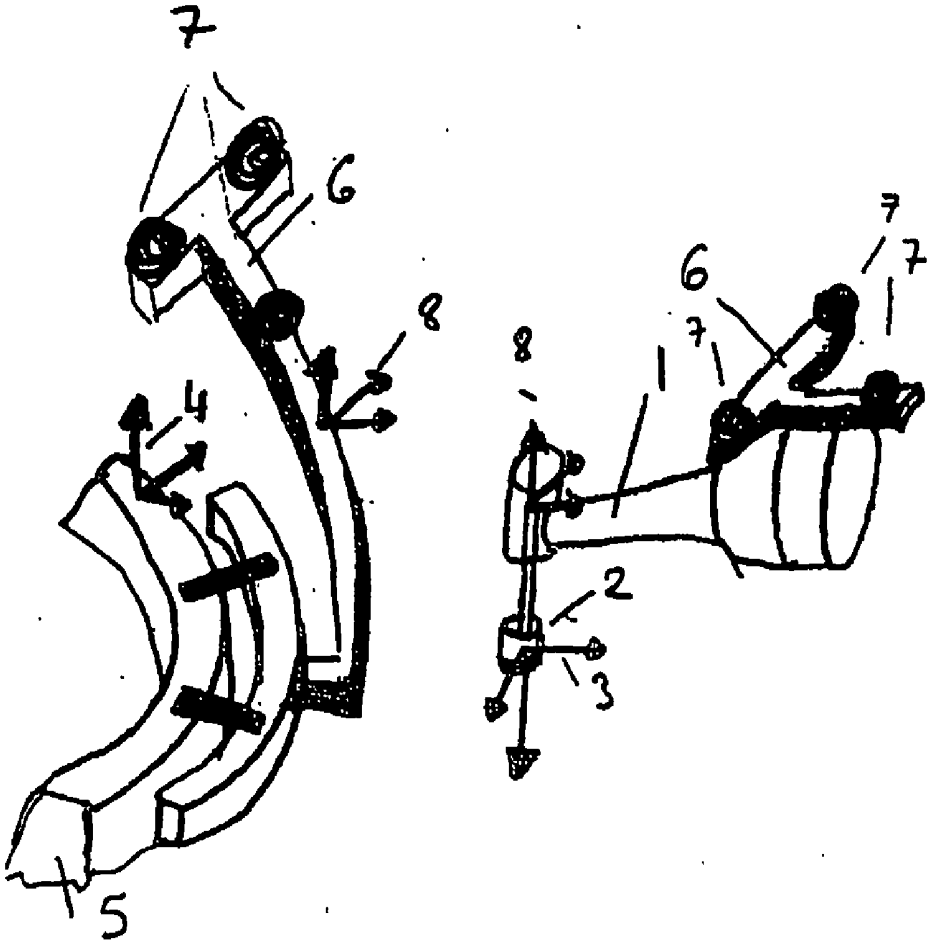
Publication Classification

(51) **Int. Cl.**[7] **A61C 3/00**

(52) **U.S. Cl.** **433/75**

(57) **ABSTRACT**

The invention relates to a method and device system, which are provided for removing material or tissue or for working material or tissue and which can be used in the fields of medicine and dentistry as well as for the most varied types of material working in different areas of application and model working. The invention is particularly advantageous in that an exact removal of material or a highly precise, reproducible material working can be realized within the shortest amount of time by acquiring, storing and computer processing data pertaining to position and/or orientation of the effector and their changes relative to the position of at least one reference body. In addition, commands for controlling and/or regulating are initiated in such a manner that, according to a predetermined working volume and/or material removal volume and/or material remaining volume, the effector is switched into an on/off function or, in the on function, is controlled and/or regulated with regard to its power and/or parameterization. The inventive device system is characterized in that a first marking support (**6**) with markings (**7**) is arranged on a handpiece (**1**) with the effector (**2**), in that the handpiece (**1**) is connected to a control unit (**22**), and in that a second marking support (**6**) with markings (**7**) is attached to the material object or tissue object (**5**).



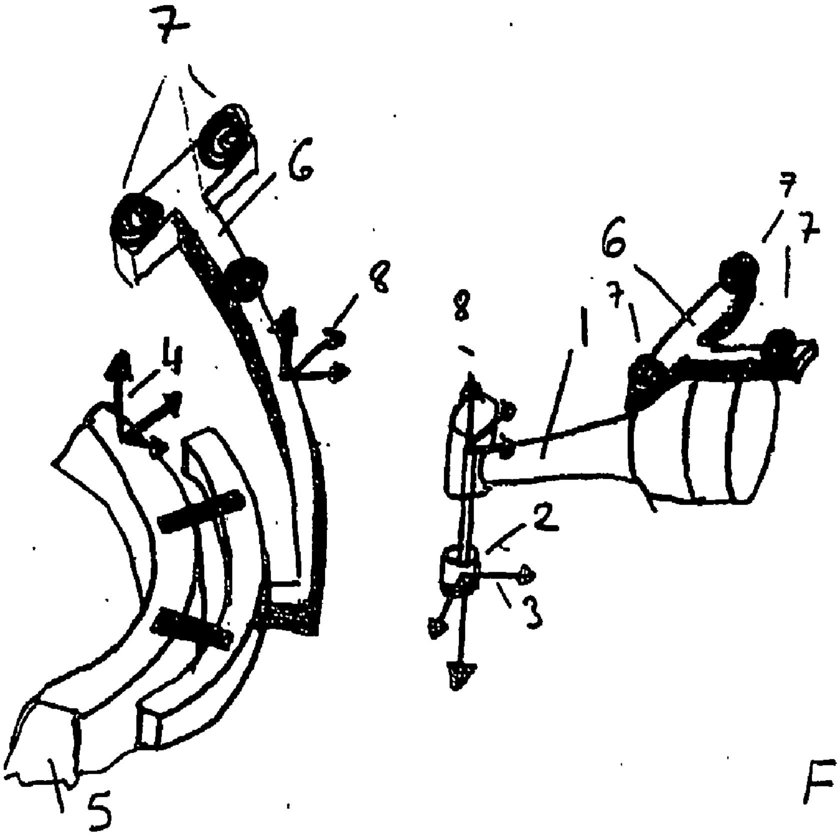


Fig. 1

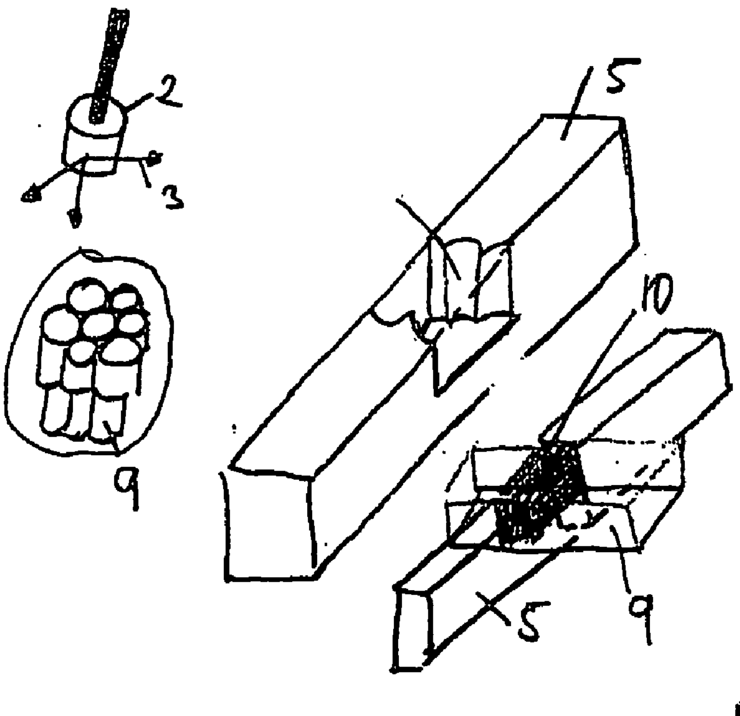


Fig. 2

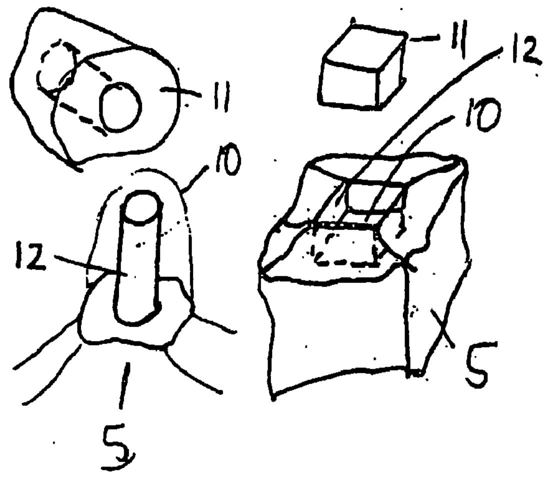


Fig. 3

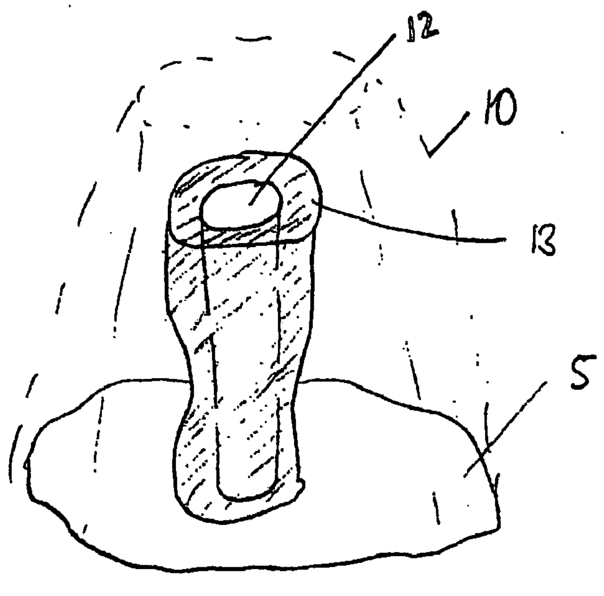


Fig. 4

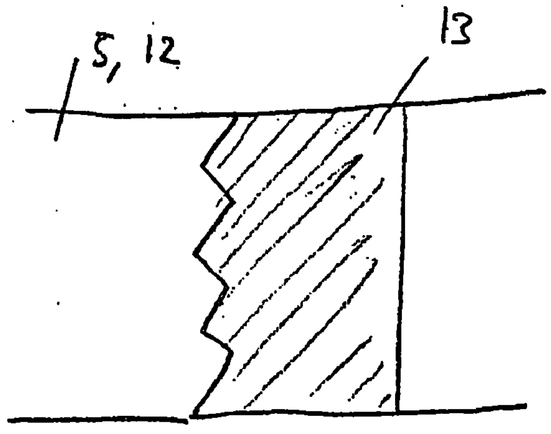


Fig. 5

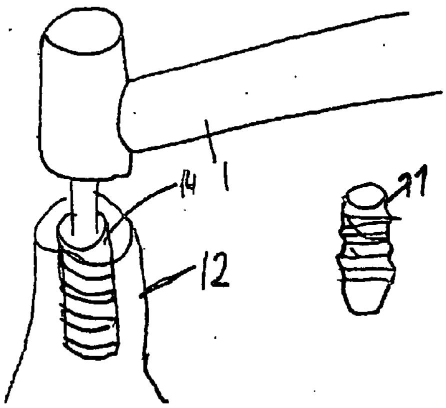


Fig. 6

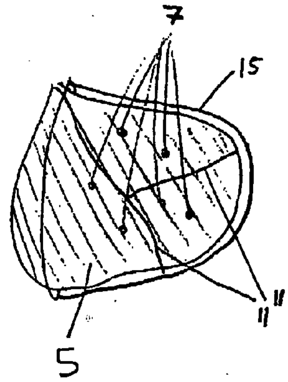


Fig. 7

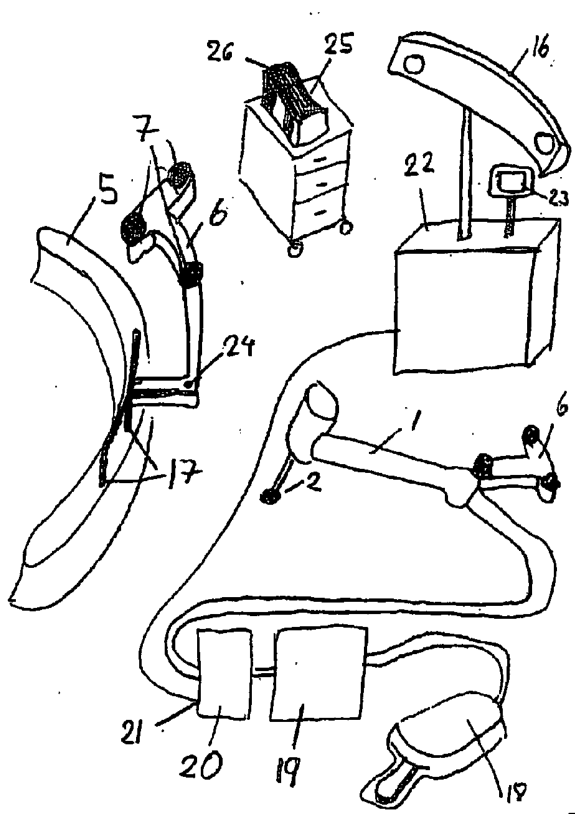


Fig. 8

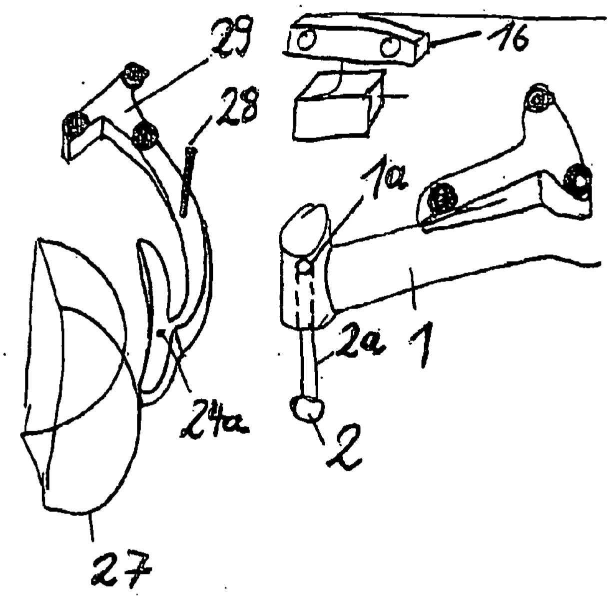


Fig. 9

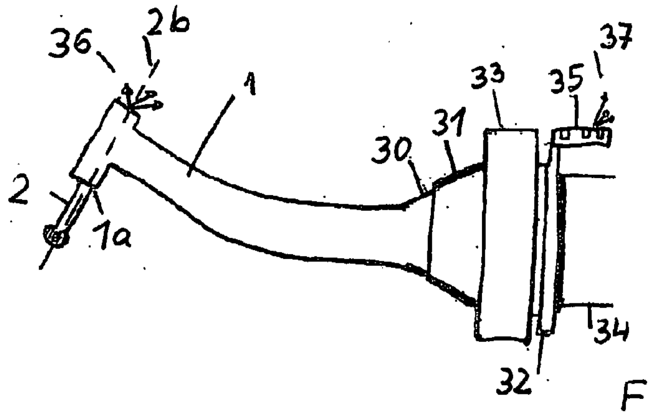


Fig. 10

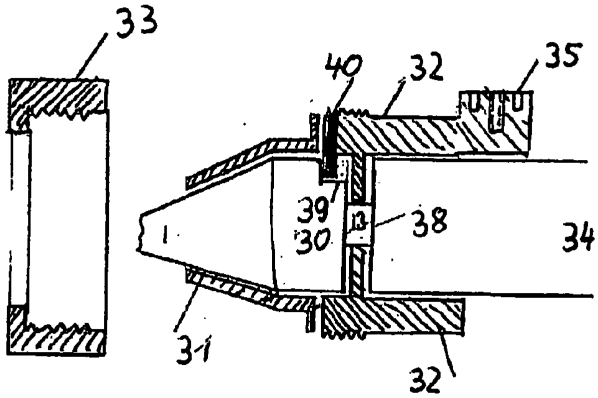


Fig. 11

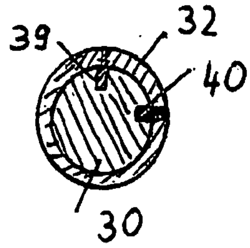


Fig. 12

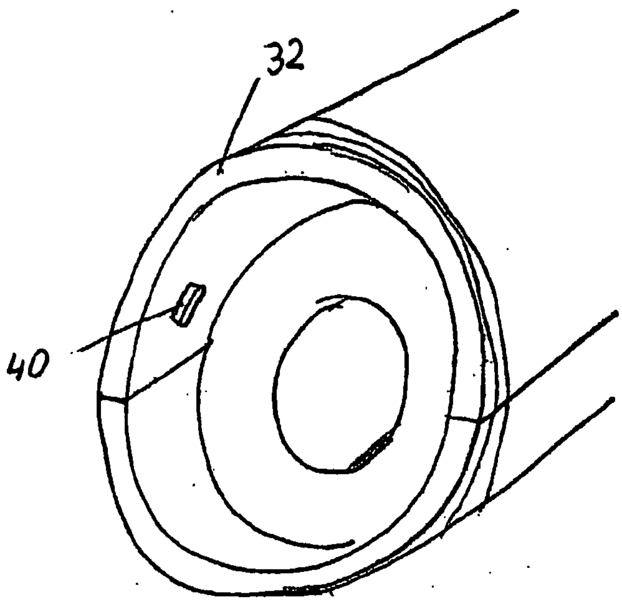


Fig. 13

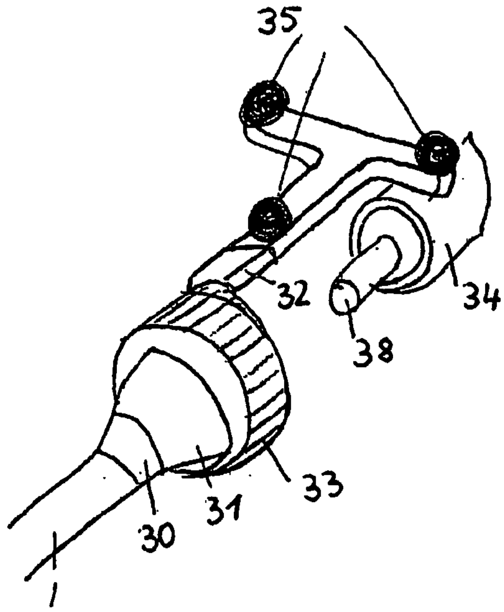


Fig. 14

METHOD AND DEVICE SYSTEM FOR REMOVING MATERIAL OR FOR WORKING MATERIAL

[0001] The invention relates to a method and system for removing material or tissue and for treating material or tissue and can be applied in medicine and dentistry as well as for different types of material processing and model working according to the preamble of claim **1**.

[0002] The methods of the invention and the system can be applied, for example, to controllably arrange and guide handpieces as well as to switch on and off, to control or parameterize of the effector power in surgery and dentistry for optimally removing tissue in preparation for conservation and for the insertion of implants, inlays and onlays. In addition, high-precision cuts can be set up.

[0003] Currently, instruments such as drills, cutters and saws, which are inserted in the chuck of a medical handpiece, are mostly used in medicine for removing tissue. Sometimes, laser systems are used which can separate and/or remove soft and hard tissue.

[0004] In tissue removal, tissue cuts, tissue openings and tissue cavities or passageways are produced which should satisfy medical criteria (e.g., residual tissue is free of tumors, bacteria, caries, or the residual tissue has a high firmness) and/or additional criteria (e.g., the geometry of the removed tissue has a particular fitted shape for inserting a mating piece).

[0005] Coordinate measurement systems that can be used to measure the position (position and orientation) of a tool relative to a reference coordinate system are known from measurement technology.

[0006] Medical navigation systems are known from computer-assisted surgery which enable to display the position (position and orientation) of the instrument relative to a patient's tissue after registration of the tissue.

[0007] Medical robot systems are also known from robot-assisted surgery whereby the instruments can be moved by a robot on predefined pathways, so that for example a bore can be placed at a certain position (position and orientation) and a cavity with a particular geometric shape can be bored.

[0008] In addition, medical interactive systems are known from robot-assisted surgery, wherein the instruments are attached to a passive (actively braking) or to an active (actively driven) mechanism. However, a physician is able to move the instruments manually by directly guiding the instrument or the mechanism inside specified volumes, on specified surfaces and along specified pathways (straight lines, curves), in order to place, for example, a bore at a certain location (position and orientation) or to rebore a cavity with a particular desired geometric shape.

[0009] Moreover, medical tele-manipulation systems are known from robot-assisted surgery, whereby the instruments are attached to an active mechanism (slave manipulator), with a physician being able to move the instruments manually via a coupled input mechanism (master manipulator) inside specified volumes, on specified surfaces and along specified pathways (straight lines, curves), in order to place, for example, a bore at a certain location (position and orientation) or to rebore a cavity with a particular desired geometric shape.

[0010] Hand scanners, which are able to measure a 3-D-surface model with high accuracy via a streak projection or by other methods, are known in dentistry. A physician has been unable until now to use a manually guided instrument for removing tissue, so that the position and/or the geometry of the removed tissue corresponds precisely to predefined or dynamically specified medical criteria (e.g., the residual tissue is free of tumors, bacteria, caries, or the residual tissue have a high firmness) or geometric criteria (e.g., the residual tissue or the removed tissue has a particular fitted shape for inserting an object).

[0011] This is related to the observation that humans lack the ability to precisely orient their hands in a 3-D-reference coordinate system.

[0012] Even when using a navigation system, a physician has until now been unable to remove tissue with a manually guided instrument so that the position and/or the geometry of the removed tissue precisely corresponds to predefined or dynamically defined medical criteria (e.g., the residual tissue is free of tumors, bacteria, caries, or the residual tissue has a high firmness) or geometric criteria (e.g., the residual tissue or the removed tissue has a particular fitted shape for inserting an object).

[0013] Non-tactile tissue-removing effectors, such as laser beams, don't allow a user who manually treats hard tissue to detect by feel the shape of the removed tissue or the generated fitted shape. Fitted shapes (e.g., cylindrical) that satisfy certain criteria can therefore not be manually produced.

[0014] Robot-controlled, tele-manipulated or interactively robot-guided instrument inserts always significantly increase the complexity of the device which adds to its cost.

[0015] In addition, the attending medical personnel as well as the nursing staff must have a high level of training and motivation, requiring significant expenses for training and installation. The surgery often takes longer than without the use of a robot.

[0016] The patients have to be placed in a immobile position so as to achieve the desired precision when using a robot.

[0017] In dentistry, adjoining structures are frequently accidentally injured with a tissue-removing sensor and/or instrument. Even with navigation support, it is not always possible to cleanly shape a cavity. Prefabricated implants cannot be cleanly fitted. It is not possible to prefabricate inlays, onlays or bridges for a later fit. It is not possible to prefabricate a supra-construction so that it later fits perfectly. It is not possible to use high-quality standard inlays, onlays or bridges which are produced by a manufacturer of implants or similar manufacturers. It is not possible to cleanly reshape cavities so that they meet certain medical criteria (e.g., distance from bacteria-infected, tumorous tissue). It is not possible to cleanly reshape cavities so that they meet certain manufacturing criteria (e.g., shaping of the fitted piece for fabrication with three-axes cutters). It is not possible to cleanly reshape cavities so that they meet certain criteria for the integration of fitted pieces (insertion, plug-in, secured against rotation). It is not possible to cleanly reshape cavities so that they meet a combination of these criteria. It is not possible to measure and store manually removed tissue (e.g., on a model), and to use the removed tissue as a "template" for a tissue removal with identical shape on the same or on another object (e.g., a patient's tissue).

[0018] In soft tissue surgery cuts cannot be placed so as to correspond to certain medical criteria (e.g. distance to bacterial, tumorous tissue) and/or criteria for integrating transplants and implants (e.g., breast implants after tissue removal).

[0019] In knee endoprosthesis, multiple cuts cannot be produced without fixing or kinematic guiding with cleanly defined cut surfaces.

[0020] In spinal surgery, decompressions and pedicle screw insertion cannot be performed without fixing the tissue and/or kinematically guiding the instruments.

[0021] Another disadvantage of conventional solutions is that the navigation systems according to the state of the art cannot use tools whose transformation matrix is not known ahead of time. This limits the user to a tool set from a particular company. The user is unable to calibrate a new tool without problems. At least the push of a button is needed for calibration. If the tools of an instrument, such as for example a handpiece, are changed, there is a risk that an unregistered tool is being used. This can results in injury to the patient, since the position and angle values can be in error without being recognized as erroneous.

[0022] Handpieces, in particular for computer-assisted dentistry, are described in various publications. Two methods currently exist in dentistry which require marking the handpiece for a three-dimensional reference, namely on one hand manual drilling with navigated position orientation and, on the other hand, drilling with a kinematic mechanism, e.g. a robot.

[0023] U.S. Pat. No. 4,824,367 describes the device for displaying the parallel alignment of a dental handpiece, consisting of an angle sensor for generating electrical angle signals which indicate the orientation of a cutter that is operated with a dental handpiece, adjusting elements for adjusting electrical reference signals which indicate the position of a preset axis, warning elements which emit warning signals if the angle signal is outside a preset range.

[0024] U.S. Pat. No. **5,017,139** describes the device with a dental/medical surgical tool for obtaining three-dimensional contour information, consisting of a plurality of arm segments which are connected with each other sequentially, producing a structure with a front and a rear end, a first attachment element for attaching the first end of the structure to a stationary platform and a second attachment element for attaching a surgical tool at the second end of the structure, a plurality of encoders, whereby each encoder is connected with a corresponding arm segment, to produce an electric signal which displays the position of the individual segments. In this way, the position of the surgical instrument can be continuously tracked.

[0025] U.S. Pat. No. 6,000,939 describes a device for precise alignment of dental drills consisting of orientation elements for attachment to a dental handpiece, which generate a signal of the drilling angle, and comparison elements which emit warning signals, if the difference of the angle signals is located outside a predetermined range.

[0026] EP 0 741 994 A1 describes a method for visualizing the jaw of a person which includes the following steps: insertion of a device with markers for position measurements into the buccal cavity of the person; acquiring at least one image of the jaw with an imaging method, wherein the markers are also imaged, identification of the markers, wherein for visualization the following acts are performed: attaching a 3-D sensor on the outside of the respective jaw; renewed insertion of the position measurement device in the buccal cavity in the same position as during the acquisition of the image, if the device was removed in the meantime, wherein the device is provided with a 3-D sensor; determining the positional relationship between the 3-D sensor of device and the 3-D sensor on the outside of the jaw; removing the device for position measurements, generating a superposition of the optical image of the jaw with the data set in the proper positional relationship. Truppe describes the method also for visualizing a model of the jaw and/or for visualizing the model of the jaw and the jaw. Truppe also describes a method for visualizing the jaw or a model of the jaw, whereby in addition a photographic or video image of the jaw or of the model is produced, which is superimposed with the image obtained with the imaging method.

[0027] Ultrasound, optical or mechanical sensors can be used.

[0028] U.S. Pat. No. 5,688,118 describes a system for training dentists to produce cavities in teeth. A human phantom torso is placed in a dentist's chair with a model jaw. The student works with a special training units having a pneumatically driven drill and a handpiece which differ in their configuration and operation or application from a "genuine" treatment unit for treating patients. The position and orientation of the "handpiece" and/or "drill" as well as of a "mirror" can be measured in three-dimensional space with a 3-D measurement system. The system is intended to render three-dimensional images of a model jaw with teeth on a display and to represent the positions of the dental tool held by the student on the display relative to the image data of the phantom. It also has to compute and render the "image" of a dentist's mirror from the model data. It is also intended to shorten the time to train a dentist in the preparation of cavities. It should provide a sound and touch similar to that experienced when drilling a real tooth cavity. The device feeds backs to the student, so that the student can later in an actual treatment situation with a real patient and a real treatment tool properly interpret acoustic, tactile and visual information without navigation help and react accordingly. The student must drill a cavity in an artificial tooth of the phantom by taking into account a dental situation defined in the training concept. The compressed air supply to the pneumatic drive can be regulated with a valve, in order to give the student an acoustic and visual indication of the characteristics of a treatment situation. The power of the drill is reduced when simulating a hard tooth material, and is increased when simulating a soft tooth material. The controller follows in general the programmed geometric model characteristics of the simulated tooth model. For ergonomic reasons, the entire system can have the appearance of a dental treatment system. However, due to its concept and operating mode, the system cannot be used as a treatment system.

[0029] U.S. Pat. No. 5,257,203 describes a method for controlling a machine tool for, inter alia, dental modeling work. Such machines represents an excellent addition to the present invention. This machine, however, is not used with patients and is unable to later compensate for undercuts of the cavities on the patient.

[0030] U.S. Pat. No. 5,725,376 describes a method for producing drill templates. These methods have a significant disadvantage in that the drill template is difficult to affix on the mucous membrane of the mouth and a template for guiding the handpiece is placed exactly at the location where drilling occurs. The method can also not be used for producing cavities of arbitrary shape.

[0031] DE 19534590 A1 describes a method for ablation of hard tooth material. The laser power is hereby adjusted depending on the distance between the laser handpiece and the tissue. It is not possible to remove tissue with particular geometric characteristics.

[0032] DE 199 02 273 A1 describes a device for intraoperatively determining the placement of dental implants in the jawbone with a navigation system that can image the actual implant drilling position in a three-dimensional x-ray and can determine the spatial position with the help of an attached dynamic reference frame, characterized in that the dynamic reference frame consists of at least one fastening element on the teeth and/or the jaw and an associated releasable element with the dynamic reference frame. The method, however, was already in use in 1998 at the Charité and has been published.

[0033] U.S. Pat. No. 5,332,391 describes a device for supporting a plurality of dental handpieces, wherein each handpiece has a different angle of the drill axis relative to the normal orientation of the drill axis in the occlusion plane of the teeth, the device consisting of: a holder for guiding a dental handpiece, a connection in the form of a parallel structure with a free end on which a pivot point is secured for holding the orientation of the drill relative to the occlusion plane constant, and elements arranged next to the pivot point for connecting the holder with the pivot point, wherein the holder is detachable.

[0034] U.S. Pat. No. 5,989,024 describes an apparatus that cooperates with a driven tool with a longitudinal axis, whereby the apparatus holds the axis of the tool constant when the tool is moved in space, consisting of: an adjustable arm with two ends, a clamping arrangement for attaching the tool at one of the ends, a base at the other end, which can be secured to a workpiece, wherein the arm includes a first section that allows movement along the longitudinal axis of the tool.

[0035] U.S. Pat. No. 5,281,136 describes an apparatus for supporting a dental drill consisting of: a movable arm which can be affixed to a stationary reference point, and wherein the arm can be secured to an end of a dental drill, with the arm constructed so as to maintain the axis of the tool constant normal to a predefined work plane, components for stabilizing the head and the jaw of the patient, consisting of a head support which can be secured to a chair and elements for fixing the jaw on the head support.

[0036] U.S. Pat. No. 5,575,646 describes a device for supporting a dental drill consisting of: a support, an arm with two quadrilateral elements which are connected with each other in series while one of the quadrilateral elements is connected with the bearing and another with an element which holds a dental drill instrument, so that the axis of the drill instrument remains constant, an adjusting element for adjusting the direction of the work axis, wherein the bearing is provided with attachment elements for connection with the back support of a chair, wherein the quadrilateral elements are oriented with respect to each other at an angle of 90 degrees, so that one element is located above the patient and another in front of the patient.

[0037] U.S. Pat. No. 6,030,211 describes a guiding apparatus consisting of: a carriage which is secured at one point, an intermediate element, which is secured on one end on the carriage and can be moved in a first longitudinal coordinate z, and another end for receiving a connecting arm via an articulated joint, a working head disposed on the connecting arm and holding an instrument holder and two elements for moving the instrument holder along two additional longitudinal axes x and y, whereby the instrument holder is movable in x, y, z and a rotation axis.

[0038] WO98/40030 describes a system for transmitting the simulated position of dental implants from an x-ray machine to a robot which can be used to drill into an impression of the patient's jaw. The system includes a mechanical support as well as elements for fastening the impression on the support in a reproducible position. The impression includes at least two rectangular elements that are visible in an x-ray image.

[0039] The present state of the art offers no possibilities to provide the handpieces of the dentist at a later time with a marker when only small modifications are made, so that the handpieces can be easily used with a navigation system. Special handpieces exist for this application, which however have to be acquired by the dentist at a substantial cost. They cannot be used with normal turbines and the handpiece cannot be easily separated from the turbine.

[0040] Accordingly, the dentist has to have in inventory both "normal" and "navigatable" hand pieces.

[0041] It is an object of the invention to obviate the known disadvantages of the prior art and to provide a method and a system which allows a user to controllably remove and process material or tissue, and not to remove too much or too little material or tissue during the removal. The material or tissue should also be removed very accurately at the correct location and the system should make it possible to use different tools with one instrument freely and risk-free.

[0042] This object is solved according to the invention by a method and system having the features of claims **1** and **40**.

[0043] Advantageous embodiments of the invention are recited in the corresponding dependent claims.

[0044] According to an advantageous the invention, material can be removed very precisely or material can be processed very accurately and reproducibly within a short time, by measuring, storing and computer-processing data for positioning and/or orienting the effector and their changes relative to the position of at least one reference body, with the data initiating control commands such that, depending on a predetermined work volume and/or or material removal volume and/or residual material volume, the effector is switched by an on/off-function or the power and/or parameterization of the effector is controlled and/or regulated when the effector is in the on-function.

[0045] Multivalent application domains are obtained in that the position and geometry of the attained object surface is measured and stored for additional processing operations on the same object or on other objects.

[0046] The method and system for removing material or processing material is based on the observation that material from one object is processed or removed for satisfying at least one criterion and that the power and/or shape and/or position of the arranged and/or guided material-processing or material-removing effector is preferably controlled or regulated so that the position and geometry of the achieved object surface is measured and stored for additional processing operations on the same object or on different objects. Moreover, the time for creating and processing the fitted pieces to be inserted as well as the time between material removal and insertion of fabricated or existing fitted pieces is preferably shortened. The method and system can advantageously be applied, for example, for controllably arranging and guiding of handpieces as well as for switching the effector energy on and off during surgery and in dentistry for optimally removing tissue as a preparation for the conservation and insertion of implants, inlays and onlays. Moreover, cuts can be set up with high precision.

[0047] It is possible to position clean, precise cuts with a defined geometry, to set up drilled holes, to cut cavities or stumps, and to measure the movements accurately.

[0048] It is possible in dentistry to drill holes for implants freehand as precise as when using a guide mechanism. In dentistry, an inlay, onlay or a bridge can then be prefabricated and the cavities can be formed so that the prepared inlays or onlays fit perfectly in the cavities or on the stump. This obviates the need for fabricating an inlay or onlay on-site.

[0049] Inlays and onlays can be centrally manufactured at a much lower price and with a higher quality. The time between shaping and delivery is significantly reduced.

[0050] In dentistry, it is also possible to remove the tissue for medical reasons and to form at the same time in parallel a cavity or a stump for a perfect match with a fitted piece (without undercuts) while retaining most of the tissue. More complicated geometries can also be obtained.

[0051] In soft tissue surgery, a perfect tissue separation can be achieved manually when separating complicated tissue structures (visceral surgery), if simultaneously a tissue positioning measurement system is used, for example based on electromagnetic reflectors. Expensive mechanical assemblies for guiding the instruments can then be eliminated. Comparable results can also be achieved by guiding the instruments manually, without using robots. This represents a significant improvement over the current situation. The function performed by medical cutting robots can thereby be almost completely replaced.

[0052] During the tissue removal, the geometry of the removed tissue can also be measured and this geometry can then be used several times. This has advantages when transferring model work to other tissue types. Shapes can also be mirror-imaged relative to an axis or as volume models (positive shape, negative shape).

[0053] The templates can also be mirror-imaged with respect to one or more axes. Parts of the geometry can be mirror-imaged from negative into positive shapes.

[0054] A user can remove tissue with a manually guided instrument so that the position and/or geometry of the removed tissue corresponds to medical criteria that are defined ahead of time or dynamically (e.g., the residual tissue is free of tumors, free of bacteria, does not show caries, or residual tissue has a high degree of firmness) or geometric criteria (e.g. the residual tissue or removed tissue has a particular fitted shape for inserting a matching piece) with a high quality. This compensates for the inability of humans to precisely orient their hands in a three-dimensional reference coordinate system.

[0055] In dentistry, prefabricated supra-constructions, inlays, onlays or bridges can be used.

[0056] Complicated geometrical shapes can be fabricated manually. CAD data of the removed material can also be created. The geometric data can be used for fabricating implants or for removing transplants. The geometric data can be used for quality control.

[0057] In spinal surgery, openings and cut surfaces can be generated manually and more cleanly. In knee endoprosthesis, cut surfaces can be manually prepared more cleanly. Instruments can be significantly better guided in almost all areas of medicine. The method can also be used to prepare a fitted shape, that satisfies certain criteria (e.g. cylindrical), with non-tactile, tissue-removing effectors, such as laser beams, when manually processing hard tissue.

[0058] According to another advantageous embodiment of the invention, it is possible to freely work with marked tools by measuring or computing the position T_HAND with a position and orientation of a handpiece with a tool receptor, whereby the transformation matrix between the handpiece and tool receptor HAND_T_SPANN is stored and the transformation matrix between the tool receptor and the tool effector SPANN_T_WERK is known except for a missing positional degree of freedom, such as the length and a registration point P-REG.

[0059] Tools that change their geometrical shape over time are always recalibrated. All instruments all always calibrated. With the invention, the calibration process is advantageously not viewed as an obstacle, since no button has to be pushed. The calibration does not require a machine interaction, but instead only touching a point and then waiting for a signal. Accordingly, calibration of a tool can no longer be overlooked. This significantly improves the safety and operability of medical navigation systems when changing tools.

[0060] According to another advantage of the invention, conventional handpieces can be employed in the navigation system, wherein the handpiece has at least one opening for later attachment to a marker support and the opening is formed so as to be in formfitting engagement without play with a projection on the marker support when the handpiece and marker support are installed. Alternatively, the handpiece can have at least one projection for later attachment of a marker support, wherein the projection is formed so as to be in formfitting engagement without play with an opening of the marker support when the handpiece and marker support are installed.

[0061] The invention will now be described hereinafter in more detail with reference to embodiments depicted at least in part in the drawings.

[0062] It is shown in:

[0063] FIG. 1 a tissue-removing effector with a reference position to the tissue object,

[0064] FIG. 2 an effective geometry and cut geometry in the object,

[0065] FIG. 3 a fabricated fitted piece and snug fit of the removed tissue,

[0066] FIG. 4 a visualization of the difference geometry for effector guiding,

[0067] FIG. 5 an attenuator interval for controlling and regulating the effector power,

[0068] FIG. 6 a laser handpiece with fitted shape-generating effective geometry body,

[0069] FIG. 7 the setting of cuts in soft tissue,

[0070] FIG. 8 a system for manually performing optimal tissue removal,

[0071] FIG. 9 an instrument handpiece with handpiece markers,

[0072] FIG. 10 an instrument handpiece with handpiece markers,

[0073] FIG. 11 an embodiment of the interlock between marker support and handpiece,

[0074] FIG. 12 an embodiment for fixing and securing the position of marker support and handpiece cone,

[0075] FIG. 13 an embodiment of the handpiece marker support, and

[0076] FIG. 14 a handpiece with marker support and markers.

[0077] FIG. 1 shows the handpiece of a medical instrument with a tissue-removing effector **2** in a measurable effector position (position and orientation) **3** relative to a reference position **4** of a tissue object **5**. The tissue-removing geometry of the effector **2** is known to be almost unchangeable (e.g., cutters, drills) or can be measured and/or adjusted (e.g., laser). The power for removing the tissue can be at least switched on and off, or preferably controlled. The effector **2** can be implemented as a saw blade, a drill, a cutter, a water or particle beam, a laser beam, ultrasound, or as another type of effector for removing tissue. The relative position T_EFF of the tissue-removing effector **3** relative to the reference position **4** T_OBJ of the tissue object **5** can be determined, for example, by a coordinate measurement method based on artificial or anatomic measurement markers located at a known position. FIG. 1 shows marker supports **6** which are secured in a fixed position relative to the effector and/or the tissue object.

[0078] As shown in FIG. 1, a marker **7** made of reflecting glass spheres, which are used as signal reflectors in an optical coordinate measurement system, is disposed on the marker support **6**.

[0079] The marker **7** is in general a set of points, figures or bodies whose position (position and/or orientation) relative to each other as well as relative to the respective marker reference system **8** is known ahead of time and whose position relative to at least one position measurement coordinate system can be determined when needed. Different measurement methods (optical, acoustical, electromagnetic, radar-based, laser-based, line camera, area camera, video sequences, 3-D surface cameras, 3-D laser cameras, 3-D radar processes, etc. with signal transmitting, signal receiving and signal reflecting points, figures or bodies) can be used.

[0080] Alternatively, the marker **7** can be implemented as a flange for receiving a measurement sensor in a known position relative to the respective marker reference system **8**. The marker **7** can be attached to the corresponding marker support **6** or implemented as a recess and/or can form a part of the geometry of the marker support **6**. The respective marker support **6** can also be formed by the handpiece **1** of the effector **2** or by the object itself.

[0081] FIG. 2 shows an effective volume or effective geometry **9** which is computed by a spatial superposition of the effector geometry **2** with the measured effector positions **3**. The effective volume describes the maximal 3D-geometry scanned by the effector. Also shown is the cut geometry or cut volume, formed from the intersection set of tissue object volume **5** in the reference position **4**—before the tissue is removed—and the effective volume **9**. The cut volume describes the object volume actually removed by the effector **2**. The object tissue geometry relevant for the tissue removal can be generated by a depth-image or volume-image forming method (x-ray, ultrasound, laser, MRT, CT,—or surface image, etc.) or via a surface image generating method (2-D, 3-D surface scanner, video image, hand scanner) or via a tactile or non-tactile distance image generating method (distance laser, tactile measurement sensor, etc.) with subsequent generation of a surface grid. In the simplest case, the non-energized effector geometry **2** contacts the surface and performs a tactile measurement on the surface (by generating a surface grid from the measurement points), or a distance-measuring or surface-measuring sensor is attached to or integrated in the handpiece **1**.

[0082] The cut volume **10** could represent, for example in dentistry, a drilled, cut or laser-treated cavity in the tooth, in the yaw bone or in a model. The cut volume **10** can in dentistry also describe tissue that has been removed for producing a stump for a crown. Corresponding examples can also be found in surgery. The cut volume **10** can also be an cut surface for separating tissue in hard tissue surgery (osteotomy) or an cut surface in soft tissue surgery (e.g. visceral surgery).

[0083] FIG. 3 shows tissue objects **5** with removed tissue volume **10** as well as the geometry of fitted pieces **11** based on the cut volume geometry **10** as well as additional medical criteria and/or criteria for fabricating fitted pieces **11** and/or integration of fitted pieces **11** and residual tissue volume **5**, **12**. Medical criteria can be, that for example the outside or inside surface of the fitted piece **11** has a minimum distance to the removed tissue **10** or to tissue with certain tissue properties (tumorous, bacterial, hard tissue, spongiosa, outer shell, nerves, organs etc.) or that it must not have traps (cavities) for bacteria. In dentistry, the fitted piece **11** must also satisfy additional medical criteria, such as optimal occlusion (fit between the teeth of different jaws). Other criteria for fabricating fitted pieces may be that the base pieces or materials are available in inventory, or that the fitted pieces **11** can be fabricated with known and/or existing tools or machines, and that these therefore have certain material properties (e.g. firmness/stability or particular geometric shapes). Another criterion can be that the corresponding fitted piece **11** has to be in inventory.

[0084] Criteria for integrating fitted pieces **11** and residual tissue volumes **5, 12** can relate to the snug fit between fitted piece **11** and residual tissue volume, i.e. object fitted shape **12**, because hard tissue has to be prepared so that the fitted piece **11** can be cleanly fitted. This also required particular geometric shapes. This also includes enlarging or reducing size of the fitted piece, so that a desired final shape is obtained after the residual tissue volume and fitted piece **11** are joined.

[0085] The geometry of the fitted piece can also be used to measure, for example a quantity of material or a volume of material and to choose the data for fabricating the fitted piece **11** with the help of a CAD/CAM process and/or by rapid prototyping. For example, a milling machine which mills the fitted piece **11** from a base body, can be controlled.

[0086] Alternatively, a suitable base body that need only little finishing or no finishing at all, can also be selected and removed from inventory.

[0087] **FIG. 4** shows a tissue object **5** (tooth stump) having an optimum fitted shape **12** that is already known from the fitted piece **11**; however, not all the tissue that is to be removed has been removed. The figure shows the difference volume **13**, whereby the difference volume is determined from the geometry of the actual fitted piece **12** and the actual cut volume **10** by intersecting the two. The difference volume **13** or the difference geometry can be visualized on a display and/or the distance of the effector **2** from the boundary surface difference volume **13** and fitted shape **12** can be indicated acoustically. The visualization can then be used to move the effector either manually (hand-eye and/or hand-ear coordination) or under automatic control (e.g. with a robot) so that the effector should or can reach on tissue of the difference volume **13**. This optimally minimizes tissue removal. Since the cut geometry is determined continuously, the system can also be used to measure and document self-generated cavities as well as to further process the measurement data. The effector **2** can also be used as a tactile position measurement sensor head.

[0088] **FIG. 5** shows the tissue object **5** and the fitted object shape **12** as well as the difference geometry **13** which describes the tissue still to be removed. The power of the tissue-removing effector **2** is switched off no later than when the effector geometry exits the effector geometry **13** or the joint set of fitted piece geometry **11** and difference geometry **13**. The power of the tissue-removing effector **2** is switched on no later that when the effector geometry enters the difference geometry **13** or the joint set of fitted piece geometry **11** and difference geometry **13**. The power of the effector **2** is increased depending on the distance from the effector **2** to the object fitted shape **12** and reduced with decreasing distance therebetween. Preferably, the change in power is limited to an attenuation interval starting from the surface of the object fitted shape **12**.

[0089] **FIG. 6** shows a handpiece **1** (e.g. laser handpiece) with an applied effector geometry body **14**, which controllably supplies the tissue-removing energy to the boundary surface so as to form a desired fitted shape **12** for a fitted piece **11**. When using a laser and a suitable light-conducting or light-emitting effector geometry body **14**, for example, an interior or exterior thread can be cut with the laser so as to be located exactly at the desired location (position and orientation); even the end point of the exiting tread turn to can be known.

[0090] **FIG. 7** shows a soft tissue object **5** into which two cuts **11** are to be made, which in this case are to be modeled as fitted pieces. The position of the tissue is determined by markers **7** which are measured, for example, by an electromagnetic position measurement method, similar to a GPS. This method can also be used to determine the position and orientation of partial volumes of the soft tissue. The tissue is preferably located in a dimensionally stable matrix **15**, so that the tissue **5** does not move during the separation. The dimensionally stable matrix **15** should retain its shape also when the cuts are set. The matrix could be a foil when using a scalpel effector **2** or a body with a prefabricated, preferably grid-shaped foil, or when using a laser scalpel, a light-transparent, light-conducting foil that lets the laser power exit on the tissue side of the matrix **15** for removing tissue.

[0091] **FIG. 8**, when viewed in conjunction with **FIG. 1**, shows a system according to the invention which includes a position measurement systems **16** for measuring the effector position **3** of an effector **2** in a handpiece **1** relative to the reference position **4** of a tissue object **5**. **FIG. 8** depicts the position measurement system as an optical navigation system **16**, with markers **7** implemented as a spherical passive markers **7**, whose support **6** is connected to the jawbone by screws via provisional implants **17** or attached to the handpiece **1**.

[0092] The power of the power converter **19** (drive motor), which is controlled by a power controller **18** (foot switch, hand switch, sensor), for the material-removing or tissue-removing effector **2** can be switched off and/or on and/or reduced to a suitable power level by an attenuation device **20**. The attenuation device **20** can also be an integral component of the power converter **19** and can be controlled via an attenuator interface **21**.

[0093] A control unit **22**, deferral be a computer with a display **23** (e.g., a display screen with a loudspeaker) is used to read and process the measurement data from the position measurement system **16**.

[0094] If necessary, the length and the shape of the effector **2** is initially calibrated with a calibration device **24**, in the present embodiment a registration point. In conformance with defined criteria, at least one position (position and orientation) of the material or tissue **5** to be removed are identified in the controller or can be defined during operation (online). At least one fitted shape **12** and/or a fitted piece **11** are stored ahead of time or can be defined during operation (online). Alternatively or in addition, criteria for online dynamic computation of at least one fitted shape/fitted piece **11, 12** are stored ahead of time or the corresponding criteria can be defined during operation (online). An object geometry **5** is stored in the controller during operation. The object geometry **5** is either known ahead of time, has been calibrated before use or is measured during the procedure shortly before the tissue is removed. The controller computes, as necessary or quasi-continuously, the effective volume **9**, the cut volume **10**, selects or calculates the geometry of the fitted piece **11** and the suitable fitted shape **12** and computes the difference geometry **13**. The difference geometry is suitably displayed on the monitor and allows the handpiece to be manually arranged and guided, so that the difference geometry can be selectively removed. The controller **22** can switch the power to the effector **2** off and on via the attenuation interface **21** or attenuate the power, as described above. They already prepared appropriate fitted piece is taken out of inventory **25** (for example by a dental technician or fabricated as a standard shape by a dental supplier) or can be fabricated later (by the dental technician or a machine). The fitted piece is integrated with the fitted shape and suitably finished, wherein the power reduction can be gradually disabled. In the case of a model, the same machining process can be performed on another model or on a patient's tissue.

[**0095**] For producing cavities in hard tissue for implants, the method and a corresponding system are employed as follows.

[**0096**] A measurement marker **7** is attached to the hard tissue **5**, so that the position of the hard tissue geometry can be determined or measured quasi-continuously relative to a reference coordinate system **8**. The hard tissue **5** can be stationary or freely movable. The position of the hard tissue relative to the measurement markers can be determined by different methods that measure distance or volume or generate surface images. In dentistry and head surgery, a registration template can be attached to the teeth, whereas in other surgical areas surface measurements or a marker registration can be used.

[**0097**] The effector **2** can be, for example, a cutter, a drill or a laser which is guided manually via a corresponding handpiece **1** (but can also be kinematically supported, braked, damped or driven). A measurement marker **7** can also be disposed on the handpiece **1**. A position and/or or location measurement system **16** can be used to measure the relative position of the markers and thereby also the marker reference systems **8**. Optical, electromagnetic and acoustic navigation systems as well as navigation systems that measure a distance from a surface and/or navigation systems with fixed or variable marker geometries can be used. Optical navigation systems with passive markers can be used with particular ease in dentistry. The geometry and the position of the effector **2** relative to the marker reference system **8** of the handpiece **1** is known ahead of time, or is calibrated by touching a registration point **24** or is calibrated with a registration form. When using a laser handpiece, the focal point can be adjusted accordingly or its position can be measured. In this way, the position **3** of the tissue-removing effector geometry can be measured with the navigation systems quasi-continuously by a coordinate transformation relative to the position **4** of the object tissue **5**. Tissue is removed with the effector **2** manually or with the help of a mechanism, wherein—preferably with a computer—the positions and orientation of the tissue-removing effector geometry are logged and an effective geometry **9** is computed from the superposition of the effector geometries. The geometry of the removed tissue volume **10** is computed by intersecting the object geometry **5** with the effective geometry **9**. In other words, the geometry of the removed tissue is directly computed. During tissue removal, the physician will try to follow certain criteria. These can include information about the tissue, which can be, for example, identified visually (color, chips), through smell (odors), through tactile information (tissue firmness or changes in the tissue firmness) or acoustically and directly transformed. These can also be information from a preplanning stage, where certain positions, orientations or geometries of the cavities were defined. Cavities can be shaped, for example, for receiving implants. In the simplest case, the cavity is prepared for a predefined implant or transplant. Alternatively, an implant can be selected from a selection of different implants stored in inventory by taking into consideration additional criteria. In this case, the cavity also has to conform to the fitted shape **12** for a fitted piece **11** of the implant. For this reason, a difference body **13** is computed which encloses the tissue that must still be removed to form the fitted shape **12** for the fitted piece **11**. This difference geometry **13** is used to optimally arrange and guide the effector **2** for tissue removal. This can be accomplished, for example, by a graphic representation for the physician on a display screen or by controlling a robot-like mechanism. Moreover, an effector geometry body **14** that directly produces a fitted shape **12** can be selected based on the difference geometry. This can be done, for example, with a tissue-removing laser by using a laser handpiece with a cylindrical effector geometry body **14** that is sufficiently transparent so that the tissue-removing laser light cuts a thread into the hard tissue **5** serving as a fitted shape **12** when exiting the effector geometry body **14**. After the fitted shape **12** is produced in the tissue **5**, the implant or fitted piece **11** can be removed from inventory **25** and directly integrated. To prevent accidental removal of tissue **5** by the manual or kinematically supported arrangement and guidance of the effector **2**, which could destroy the optimal fitted shape **12** or does not satisfy the required criteria, the tissue-removing effector power is turned off by computer control, wherein the effector **2** is located outside the difference geometry **13** and/or outside a subset of the joint set of difference geometry **13** and the geometry of the fitted piece **11**. Preferably and for safety reasons, the effector power is only switched on when the effector **2** is located inside the difference geometry **13** and/or inside a subset of the joint set of difference geometry **13** and geometry of the fitted piece **11**.

[**0098**] To achieve a particularly clean fitted shape **12**, the effector power should be decreased with decreasing distance of the effector **2** to the boundary surface between the fitted shape **12** and the difference geometry **13**, thus preventing tissue of the fitted shape **12** to be removed accidentally. A suction mechanism for suctioning off odors and vapors and other particles is preferably attached to the handpiece **1**.

[**0099**] To produce cavities in the tooth for the application of inlays, onlays or crowns, the method and a corresponding system are employed that are similar to those used for processing bone. However, the fitted piece **11** in the form of an inlay, onlay or a bridge is either taken out of inventory that contains a prepared standard body or is produced by a rapid prototyping process (cut, sintered, etc.) or is fabricated and measured ahead of time by a dental technician. However, material can also be measured and filled in the cavity and/or into a form around the fitted piece.

[**0100**] The method can be used in dentistry also for fabricating or modifying of model work and supra-constructions. In this case, work is performed not only on a patient's tissue, but also on the models or super-constructions, which however can be transferred by using known methods (registration template).

[0101] The method can also be used in the knee endoprosthesis, where a large number of cuts has to be set on the bone and matching surfaces have to be cut. In this case, a marker support can be easily screwed to the bone.

[0102] The method can also be used in decompression and preparation for screw connections of vertebrae. For separating hard tissue, the method and a corresponding system are employed as follows. The fitted piece is defined as at least one cut surface or as at least one cut volume. It is not necessary to use a fitted piece.

[0103] For separating soft tissue, for example in visceral surgery, the method and a corresponding system are employed as follows, e.g., to set clean cuts in soft tissue **5**, for example for separating and removing tissue. The position (position and orientation) **4** of the soft tissue **5** is used, for example via a soft body-GPS, whereby markers **7** are introduced into the soft tissue. The partially independent displacement and movement of tissue structures can be measured by measuring the position of the markers. Clean cuts can be set with a power-controlled effector **2** that separates the tissue. The tissue can also placed into a dimensionally stable matrix **15** ahead of time, pressed or suctioned off, before the tissue-removing power is applied. The matrix **15** itself can also be transparent for energy, so that the cuts can be suitably guided through the matrix. The cutting tool is here preferably a laser, which is scanned over the tissue and automatically measures the cut position. The power is added only at the planned cut edges or cut surfaces. The shaping matrix **15** can thereby be made of a light-conducting material.

[0104] The process of automatic calibration is explained in more detail with reference to **FIG. 9**.

[0105] **FIG. 9** shows a handpiece (**1**) with a tool receptor (**1***a*) and a chucked tool (**2***a*), whereby the position (position and orientation) of the tool effector (**2**) is to be measured. Also visible is the registration point (**24***a*), the work volume (**27**) and the calibration body (**28**) which in the present embodiment is implemented as a pin. The position is measured by the position measurement system (**16**) which also stores the transformation matrices relative to a reference coordinate system (**29**).

[0106] The figure shows this as an optical navigation system with passive reflectors.

[0107] After the system is turned on, the user receives a signal to calibrate the handpiece (**1**). The user places the handpiece (**1**) on the fitted piece. He can then clamp a tool (**2***a*), for example a drill. Before entering the work volume (**27**), the user touches with a tool tip the registration point (**24***a*) and waits for the registration signal. The user then navigates in the work volume (**27**). If he places the instrument outside the work volume (**27**), then he has to touch the registration point (**24***a*) again when he reenters the work volume (**27**). The same applies for a tool change.

[0108] **FIG. 10** shows a handpiece **1** with an effector receiver **1***a*, such as a chuck, for clamping an effector **2**, such as a drill.

[0109] The effector receiver **1***a* has an effector reference position **36**, which defines the zero position and the orientation of an effector **2** located in the effector receiver **1***a*. A handpiece marker support **32** with a handpiece marker **35** can be attached to the handpiece **1** in such a way that the handpiece marker **35** can be attached and affixed in at least one predetermined position (position and orientation) relative to the effector reference position **36**.

[0110] The handpiece marker support **32** with the handpiece marker **35** can either be permanently or removably affixed to the handpiece **1**. The handpiece **1** itself can be the hand piece marker support **32**.

[0111] **FIG. 11** shows a type of the aforedescribed attachment of the handpiece marker support **32** to the handpiece **1**. A hollow frustrated coupling cone **31** is placed over the handpiece cone **30**, serving as a counter bearing for the clamping of the handpiece marker support **32** with the handpiece **1**. The inside diameter of the coupling cone **31** is sufficiently large to be pushed over the effector receiver **1***a* to the handpiece cone **30**, but is smaller than the outside diameter of the handpiece cone **30** at its greatest circumference. The handpiece marker support **32** is affixed to the handpiece **1** with a union nut **33** that has a sufficiently large inside diameter so as to be pushed over the effector receiver **1***a* and the handpiece **1**, but is smaller than the outside diameter of the coupling cone **31** at its greatest circumference. The interior thread of the union nut **33** its screwed on the outside thread of the marker support **32**.

[0112] The handpiece marker support **32**, coupling cone **31** and union nut **33** are fabricated preferably of a lightweight, dimensionally stable and sterilizable material. All three parts obstruct neither the connection of the effector drive **34** via the coupling **38** nor the manual use of the handpiece **1**. The outer surface of the union that **33** is rough, so that it can be screwed on more easily by hand.

[0113] **FIG. 12** shows a handpiece cone **30** with at least one groove formed as a recessed opening **39** for insertion of at least one projection **40** formed as a registration spring which is attached on the side of the handpiece marker support **32**. In one embodiment, a projection **40** in form of a pin is inserted into a bore applied laterally in the outside thread. Pin **40** and recess **39** must have a snug fit to prevent rotation of the marker support with respect to the effector reference position **37**.

[0114] In order to be able to optimally mark the orientation of an angular handpiece **1** for the upper and lower jaw, the openings **39** in the form of grooves should be applied a second time, this time rotated by 180 degrees about the drive axis. Instead of implementing the pin **40** in the marker support **32** and the groove **39** in the cone **30**, the pin **40** can also be implemented in the cone **30** and the groove **39** in the support **32**.

[0115] **FIG. 13** shows an embodiment of the handpiece marker support **32** which consists of two halves which when joined produce the same geometry as in **FIG. 11**. In this embodiment, the recess **39** in the handpiece **1** can be limited to a horizontal drilling, since the two halves can be pushed on, so that the pin **40** formfittingly enters the bore **39**. Advantageously, the two halves can be implemented as a plug connection. Since the union nut **33** affixes the two halves about the handpiece, the coupling cone **31** can be eliminated in this embodiment.

[0116] **FIG. 14** shows a handpiece **1** with a marker support **32** which is fixedly connected with the handpiece **1** by the coupling cone **31** and the union nut **33** at a predetermined position. A marker **35** made of reflecting glass spheres, which can be used as signal reflectors in an optical coordinate measurement system, is disposed on the marker support **32**.

[0117] The marker **35** is generally a number of points, figures or bodies which have a known predetermined position (position and special orientation) relative to each other as well as relative to a multi-dimensional position reference coordinate system **37**, and whose position relative to at least one position measurement coordinate system can be optionally determined. Different measurement methods (optical, acoustic, electromagnetic, radar, laser, line camera, area cameras, video sequences, 3-D surface cameras, 3-D laser cameras, 3-D radar methods, etc. with signaled transmitting, signal receiving and signal reflecting points, figures or bodies) can be used.

[0118] Alternatively, the marker can be implemented as a flange for receiving a measurement sensor in a known handpiece reference position **37**. The handpiece reference position **37** (position and orientation) of the handpiece marker **35** and hence also of the effector reference position **36** can be determined with at least one position measurement system relative to the reference coordinate system of the respective position measurement system.

[0119] The handpiece marker **35** can be applied to or recessed in the handpiece marker support **32** and/or formed by a portion of the geometry of the handpiece marker support **32**.

[0120] The handpiece **1** is initially marked by applying the handpiece marker **35**. If the coupling mechanism is used, then the handpiece marker support **32** together with the handpiece cone **30** is affixed with pins via the support spring **40** and the conical recess **39**. The coupling cone **31** and then the union nut **33** are subsequently pushed over the handpiece, and the coupling cone **31** with the handpiece marker support **32** is tightened until reaching a final stop and/or until the support spring **40** is inserted into the cone recess **39** as far as possible. The position of the handpiece **1** can now be measured via the handpiece marker **35** by using a position measurement system. The drive **34** can be connected later with the coupling **38**.

[0121] The method can also be used outside the medical field, for example when removing material in manufactures or trade businesses (joiner, carpenter, wood ship building) or by do-it-yourselfers, where fully automatic computer-controlled processing machines cannot be used. This can be the case, because the machines are either too large or too expensive or cannot be acquired at all. In this case, the methods and a suitably equipped manual processing machine (electrically operated do-it-yourself equipment) can provide a result which is comparable to results obtained with a numerically controlled automatic machine. An exemplary application is here shape-grinding for restoring antique cars or sanding a glass-fiber-reinforced plastic hull of an old sailboat. A standard body is here defined on the basis of known old projections or technical drawings. The reference point of a coordinate measurement device, for example of a difference-GPS or an optical or laser- or radar-based coordinate measurement device or a measurement arm, is attached to the processed object. The effector geometry, for example of the grinding wheel, is either known or is calibrated in a form. The effector position of the tissue-removing effector geometry of the machine (grinder, cutter, polishing head) is continuously determined and the power (RPM) of the machine during grinding is defined so that the machine power is controlled as a function of the distance between actual position of the tissue-removing effector and the surface position of the standard geometry. For example, the machine operates at full power up to a distance of 2 mm from the surface and is then controlled with decreasing power to a distance of 0 mm to the surface. Other control methods can be employed depending on the application. The position of the standard body or the standard geometry relative to the object geometry can be achieved by determining the position of the object body by touching at least one symmetry axis (e.g., tip of the bow, corners of the stern, rudder base on the keel) with a tactile position sensor or by measuring the surface and registering a particularly distinct partial geometry of the object body by averaging, measuring the surface and determining a symmetry.

[0122] The method can also be used to later produce in an inaccurately and asymmetrically troweled surface a surface that satisfies specific optimization criteria, such as a low air or water resistance or symmetry with minimum material removal, etc.

[0123] The method can also be used to later insert planks or ribs at the optimal position, whereby the object body is then prepared for a snug fit with a fitted piece or the fitted piece is prepared before insertion in the object body.

[0124] The materials to be processed can be, for example, metal, glass, ceramic, wood, plastics, depending on the different fields of application.

[0125] The invention is not limited to the illustrated embodiments. Instead, it is possible to realize additional embodiments by a combination of the aforedescribed means and features, without deviating from the scope of the invention.

[0126] List of Reference Numerals

[0127] **1** handpiece

[0128] **1***a* tool receptor

[0129] **2** effector

[0130] **2***a* tool

[0131] **2***b* effector axis

[0132] **3** effector position

[0133] **4** reference position

[0134] **5** tissue object

[0135] **6** marker support

[0136] **7** marker

[0137] **8** marker reference system

[0138] **9** effective volume/geometry

[0139] **10** cut volume/geometry

[0140] **11** (geometry of the) fitted piece

[0141] **12** fitted shape/geometry

[0142] **13** difference volume

[0143] **14** effector geometry body

[0144] **15** dimensionally stabilizing matrix

[0145] **16** position measurement device

[0146] **17** preliminary implants

[0147] **18** power controller

[0148] **19** power converter

[0149] **20** attenuation device

[0150] **21** attenuation interface

[0151] **22** controller

[0152] **23** display (screen)

[0153] **24** calibration device

[0154] **24***a* registration point

[0155] **25** bearing/support

[0156] **26** processing machine

[0157] **27** work volume

[0158] **28** calibration body

[0159] **29** reference coordinate system

[0160] **30** handpiece cone

[0161] **31** coupling cone

[0162] **32** handpiece marker support

[0163] **33** union nut

[0164] **34** effector drive

[0165] **35** handpiece marker

[0166] **36** effector reference system

[0167] **37** handpiece reference system

[0168] **38** drive coupling

[0169] **39** opening

[0170] **40** projection

1. Method for removing material or for processing material with at least one effector by employing a navigation system and by using computer technology,

characterized in that

data for positioning and/or orienting the effector and their changes relative to the position of at least one reference body are measured, stored and computer-processed, said data initiating control commands such that, depending on a predetermined work volume and/or or material removal volume and/or residual material volume, the effector is switched using an on/off-function, or when the effector is in the on-function, its power and/or parameterization is controlled and/or regulated.

2. Method according to claim 1, characterized in that the position and geometry of the attained object surface is measured and stored for additional processing operations on the same object or on other objects.

3. Method according to claim 1, characterized in that the position **(3)** of a material-removing effector geometry **(2)** is measured relative to the position **(4)** of the object **(5)** quasi-continuously during a defined time interval, and that the geometry **(10)** of the removed material is computed therefrom.

4. Method according to claim 3, characterized in that the geometry **(10)** of the removed material is computed by including 3-D-surface image data from a 3-D-scanner.

5. Method according to claim 1, characterized in that the position and geometry of a material **(13)** that is still to be removed is computed based on a defined length and a defined geometry of a desired object shape **(12)** and/or based on the position and geometry of the already removed tissue **(10)**, and used for arranging and guiding the effector.

6. Method according to claim 5, characterized in that the power of the material-removing effector **(2)** is switched off no later than when the removed material **(10)** and the desired object shape **(12)** overlap.

7. Method according to claim 5 or **6**, characterized in that the power of the material-removing effector is controlled or regulated at least within the geometry of the material. **(12)** that remains to be removed based on the distance from the effector position **(3)** and/or the effector geometry **(2)** to the boundary surface between the material **(13)** to be removed and the desired object shape **(12)**.

8. Method according to one of the claims 1 to 7, characterized in that the material-removing power is supplied via an energy-transporting shaping matrix without changing the position of the effector **(2)** so as to directly obtain parts of the fitted object shape **(12)**.

9. Method according to one of the claims 1 to 7, characterized in that the desired object shape **(12)** is computed based on medical criteria and/or already removed material and/or criteria for producing the object shape and fitted piece and/or criteria for integration of object shape and fitted piece.

10. Method according to claim 9, characterized in that the position **(3)** of a material-removing effector geometry **(2)** is measured quasi-continuously and stored together with the time of the measurement, wherein the material-removing effector geometry is known and/or as needed or quasi-continuously measured, acquired and stored together with the time of the measurement and/or the position of the effector volume.

11. Method according to one of the claims 1 to 10, characterized in that an effective volume is as needed or quasi-continuously computed from the spatial overlap of the effector volume in the measured positions, and that as needed or quasi-continuously an intersecting volume is preferably formed from the intersecting set of effective volumes with an object volume, and/or its geometrical description is computed, wherein the position of the object volume relative to the effective volume is known or measured, or the intersecting volume description is used—preferably as needed or quasi-continuously—for computing the geometry of a fitted piece, wherein the geometry of the fitted piece can be suitably changed so as to satisfy additional medical criteria or criteria relating to the fabrication or integration of the fitted piece, wherein in the simplest case the description of the intersecting volumes corresponds to the shape of the fitted piece.

12. Method according to claim 9, characterized in that the geometry of the fitted piece is used for measuring a material quantity and/or for fabricating a fitted piece.

13. Method according to claim 1, characterized in that at least one table with at least one geometrical description of a fitted piece is used as a standard body.

14. Method according to claim 13, characterized in that a standard body, which satisfies an optimization criterion, is selected from a standard body table, wherein in the simplest case the standard body corresponds to the sole entry of a fitted piece in the table and wherein an inventory with already prefabricated standard bodies exists that corresponds to the table of the fitting bodies, wherein the prefabricated standard bodies require only minor finishing machining or no finishing machining at all.

15. Method according to one of the preceding claims, characterized in that the difference volume between the selected or actually computed fitted piece and the actual intersecting volume is computed.

16. Method according to one of the preceding claims, characterized in that the effector energy is switched off when the effector is located outside the geometry of the fitted piece.

17. Method according to one of the preceding claims, characterized in that the effector energy is switched on when the effector is located inside the geometry of the fitted piece.

18. Method according to one of the preceding claims, characterized in that a soft object is substantially dimensionally stabilized by a matrix which has at least one option for a defined passage or guiding of material-removing energy or a material-removing effector.

19. Method according to one of the preceding claims, characterized in that the difference volume geometry is used for arranging and guiding the effector.

20. Method according to claim 1, characterized in that removed particles, vapors and odors are suctioned off during removal.

21. Method according to claim 1, characterized in that the effector is used not only for material removal, but also for 3-D surface geometry measurements.

22. Method according to claim 1, characterized in that the effector is a laser and the tissue-removing effector geometry is achieved with an exchangeable light-conducting positive effector geometry body and/or with an opaque negative effector geometry body, which can be used to produce, for example, undercut cavities.

23. Method according to claim 1, characterized in that the object geometry is measured and computed by a volume-image-forming method (X-ray, MRT, CT, ultrasound, etc.) or by a method forming a surface image (3-D surface scanner, hand scanner, tactile sensor) either directly or via an impression.

24. Method according to claim 1, characterized in that a first material removal or tissue removal operation is performed on a model and the measured position and shape of the removed material or tissue is used for the removal on the same model, on different models as well as on patients or objects.

25. Method according to claim 1, characterized in that the removed material or tissue, which is measured via the effective geometry, the cut geometry or difference geometry or a 3-D surface scanner, is stored as a geometrical model and used in an additional material or tissue removal process on the same object or on other objects or models, whereby positive geometries can also be mirror-imaged into negative geometries, for example, to cut out transplants that fit into cavities.

26. Method according to one of the preceding claims, characterized in that based on the position and geometry of the already removed material or tissue (**10**) as well as on a defined position and defined geometry of an desired object shape (**12**), the position and geometry of the material or tissue (**13**) that still remains to be removed is graphically displayed on a display screen, and that the information about the position (**3**) of the effector (**2**) relative to the boundary surface between the fitted object shape and material or tissue (**13**) that still remains to be removed is also displayed graphically and/or acoustically and used for manually and/or kinematically arranging and guiding the effector, whereby the processed information can be outputted via an interface for controlling a placement and guidance mechanism for the effector.

27. Method according to claim 1, characterized in that the position T_HAND with a position and orientation of a handpiece (**1**) with a tool receptor is measured or computed, whereby the transformation matrix between the handpiece (**1**) and tool receptor HAND_T_SPANN is stored and the transformation matrix between the tool receptor and the tool effector (**2**) SPANN_T_WERK is known except for a missing positional degree of freedom, such as the length and a registration point P-REG.

28. Method according to claim 1, characterized in that the work volume is defined such that it need not to be exited during a normal application of the effector (**2**), whereas it is typically exited when changing a tool.

29. Method according to claim 27, characterized in that the registration point P-REG is arranged such that the operator has to pass the registration point with the handpiece (**1**) shortly before entering the work volume.

30. Method according to claim 27, characterized in that the computed position T_WERK (position and orientation) of the tool effector (**2**) is subsequently used and/or transmitted only, if the transformation matrix between the handpiece marker and the tool effector HAND_T_WERK is registered and stored.

31. Method according to claim 27, characterized in that the transformation matrix between handpiece marker and tool effector (**2**) HAND_T_WERK and consequently the registration is deleted, if the position of the tool effector (**2**) T_WERK could not be measured or computed during a predefined time interval, or if the position of the tool effector is not located in the work volume during a predefined time interval.

32. Method according to claim 27, characterized in that the computation of the missing relevant position degree of freedom of the transformation matrix HAND_T_WERK is automatically started, if the tool effector appears to be located during a predefined time interval inside a small known tolerance volume around the registration point.

33. Method according to claim 27, characterized in that the computation of the missing relevant position degree of freedom of the transformation matrix HAND_T_WERK is automatically started, if the tool effector appears to be located during a predefined time interval inside a small known tolerance volume around the registration point, whereby the missing relevant position degree of freedom of the transformation matrix HAND_T_WERK is computed by using a statistical evaluation process, as long as the tool effector (**2**) appears to continuously be located during a predefined time interval inside a small known tolerance volume around the registration point and the transformation matrix HAND_T_WERK is subsequently stored.

34. Method according to claim 27, characterized in that the state of the registration and/or the start and/or the end of the computation of the registration is signaled and/or the parameter of the computation of the registration and/or computed relevant degrees of freedom are signaled.

35. Method according to claim 27, characterized in that a transformation matrix between handpiece and tool receptor HAND_T_SPANNKAL are estimated entirely or with the exception of an irrelevant position degree of freedom, such as rotation about a symmetry axis of the clamping chuck, so that deviations between HAND_T_SPANN and HAND_T_SPANNKAL are located inside tolerance limits, but outside unfavorable calibration tolerances, and a calibration tool that preferably is configured as an alignment pin is known.

36. Method according to claim 27, characterized in that the transformation matrix between handpiece and tool receptor HAND_T_SPANN is subsequently used and/or transmitted only if the transformation matrix HAND_T_SPANN has been calibrated and stored.

37. Method according to claim 27, characterized in that the transformation matrix between handpiece and tool receptor HAND_T_SPANN, i.e. the calibration, is deleted for certain events, such as a first use, or the computation of the transformation matrix HAND_T_SPANN is automatically started when the tool receptor during a predefined time interval is located at a position where the tool receptor subsequently receives the calibration tool.

38. Method according to claim 27, characterized in that the transformation matrix HAND_T_SPANN is computed by a statistical evaluation process, as long as during a predefined time interval the tool receptor is in a position, where it appears to have received the calibration tool, and the transformation matrix HAND_T_SPANN is subsequently stored.

39. Method according to claim 35, characterized in that the calibration state or the start or end of the calibration are signaled or that parameters of the calibration result are signaled.

40. System for removing material or processing material with at least one effector by employing a navigation system and by using computer technology, wherein a first marker support **(6)** with markers **(7)** is arranged on a handpiece **(1)** with an effector **(2)** and the handpiece **(1)** is connected with a control unit **(22)** and a second marker support **(6)** with markers **(7)** is secured to the material or tissue object **(5)**.

41. System according to claim 40, characterized in that the control unit **(22)** is connected with a position measurement system **(16)** and a display **(23)**, and that a power controller **(18)**, a power converter **(19)** and an attenuation device **(20)** with an attenuation interface **(21)** is arranged between the control unit **(22)** and the handpiece **(1)**.

42. System according to claim 40,% characterized in that the second marker support **(6)** includes a calibration device **(24)**.

43. System according to claim 40 or **41**, characterized in that the power of the material-removing effector **(2)** is disconnected by the control unit **(22)** via the attenuation interface **(21)** or the attenuation device **(20)** no later than when an overlap between removed material **(10)** and the desired object shape **(12)** occurs.

44. System according to claim 40 or **41**, characterized in that the power of the material-removing effector **(2)** is controlled or regulated by the control unit **(22)** via the attenuation interface **(21)** or the attenuation device **(20)** at least inside the geometry of the material **(12)** that is still to be removed based on the distance from the effector position **(3)** and/or the effector geometry **(2)** to the boundary surface between material **(13)** to be removed and the desired object shape **(12)**, and that the effector is used not only for material removal, but also for 3-D-surface geometry measurements.

45. System according to claim 40, characterized in that the markers **(7)** are spherical passive marks.

46. System according to claim 40, characterized in that the handpiece **(1)** has at least one opening **(39)** for subsequent attachment of a marker support **(32)**, whereby the opening **(39)** is formed so as to be in formfitting engagement without play with a projection **(40)** of the marker support **(32)** when the handpiece **(1)** and marker support **(32)** are installed.

47. System according to claim 40, characterized in that the handpiece **(1)** has at least one projection for subsequent attachment of a marker support **(32)**, wherein the projection is formed so as to be in formfitting engagement without play with an opening of the marker support **(32)** when the handpiece **(1)** and marker support **(32)** are installed.

48. System according to claim 46, characterized in that the handpiece **(1)** has a second opening **(39)** that is rotationally offset by 180 degrees, for receiving a projection **(40)** for attaching the marker support **(732)** when the handpiece **(1)** is rotated by 180 degrees.

49. System according to claim 46, characterized in that the handpiece marker support **(32)** has a projection **(40)** for formfitting insertion into the handpiece opening **(39)** and that the handpiece marker support **(32)** can be attached in at least one predefined position and orientation relative to the effector reference system **(36)**, and that a handpiece marker **(35)** is applied to the handpiece marker support **(32)**, recessed in the handpiece marker support **(32)** and/or formed by a portion of the geometry of the handpiece marker support **(32)**, wherein the subsequent connection of the drive **(34)** is not hindered by the coupling **(38)**.

50. System according to claim 49, characterized in that the marker **(35)** comprises a set of points, figures or bodies having a relative position (position and/or orientation) relative to each other and/or relative to a multi-dimensional position reference coordinate system **(37)** that is known ahead of time, wherein the position of the marker **(35)** relative to at least one position measurement coordinate system can optionally be determined, whereby different measurement methods (optical, acoustic, electromagnetic, radar, laser, line camera, area cameras, video sequences, 3-D-surface cameras, 3-D-laser cameras, 3-D-radar processes, etc., with signal-transmitting, signal-receiving and signal-reflecting points, figures or bodies) are used.

51. System according to claim 49, characterized in that the marker **(35)** is implemented as a flange for receiving a measurement sensor having a known handpiece reference position **(37)** and that the handpiece reference position **(37)** (position and orientation) of the handpiece marker **(35)** and thereby also the effector reference position **(36)** can be determined by using at least one position measurement system relative to the reference coordinate system of the corresponding position measurement system.

52. System according to claim 46, characterized in that the position of the marker support **(32)** can be fixed using a union nut **(33)** and/or a union cone **(31)**.

53. System according to claim 49, characterized in that the handpiece markers **(35)** are releasably secured to the handpiece marker support.

54. System according to claim 53, characterized in that the releasable connection is implemented by latching or interlocking.

55. System according to one of the claims 46 to 53, characterized in that the essential system components are manufactured from a light-weight, dimensionally stable, disinfectable and/or sterilizable material.

56. Use of the system according to claim 40 for removing tissue in medicine and dentistry.

57. Use of the system of claim 40 for material removal for different types of material processing operations of materials, such as metal, glass, ceramic, wood, plastic in different fields of applications and for model work.

* * * * *

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专利名称(译)	用于移除材料或用于工作材料的方法和设备系统		
公开(公告)号	US20040157188A1	公开(公告)日	2004-08-12
申请号	US10/472654	申请日	2002-03-25
[标]申请(专利权)人(译)	LUTH TIM BIER JURGEN BIER ANGELIKA HEIN ANDREAS SCHERMEIER OLAF		
申请(专利权)人(译)	LUTH TIM BIER JURGEN BIER ANGELIKA HEIN ANDREAS SCHERMEIER OLAF		
当前申请(专利权)人(译)	ALL-OF-创新GMBH		
[标]发明人	LUTH TIM BIER JURGEN BIER ANGELIKA HEIN ANDREAS SCHERMEIER OLAF		
发明人	LUTH, TIM BIER, JURGEN BIER, ANGELIKA HEIN, ANDREAS SCHERMEIER, OLAF		
IPC分类号	A61C1/00 A61B18/20 A61B19/00 A61C1/08 A61C1/12 A61C1/18 A61C13/00 A61C19/04 G05B19/401 A61C3/00		
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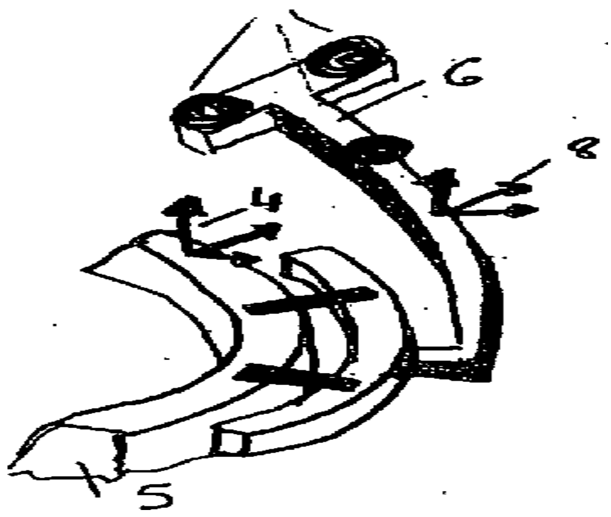
优先权	10114910 2001-03-26 DE		
其他公开文献	US7346417		
外部链接	Espacenet USPTO		

摘要(译)

本发明涉及一种方法和装置系统，其被提供用于去除材料或组织或用于工作材料或组织，并且可用于医学和牙科领域以及用于在不同区域中工作的各种类型的材料。应用和模型工作。本发明的特别有利之处在于，通过获取，存储和计算机处理与效应器的位置和/或方向及其变化有关的数据，可以在最短的时间内实现精确的材料去除或高精度，可再现的材料加工。相对于至少一个参考体的位置。另外，用于控制和/或调节的命令以这样的方式启动：根据预定的工作体积和/或材料去除体积和/或材料剩余体积，将效应器切换到开/关功能，或者关于其功率和/或参数化来控制和/或调节接通功能。本发明的装置系统的特征在于带有标记（7）的第一标记支撑件（6）与效应器（2）一起布置在手持件（1）上，其中手持件（1）连接到控制单元（22）并且，具有标记（7）的第二标记支撑件（6）附接到材料对象或组织对象（5）。



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