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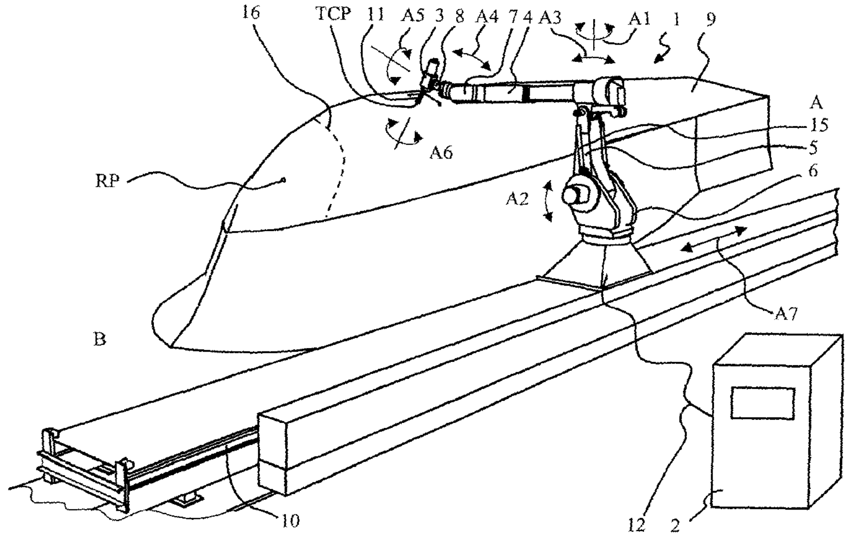
(54) **Title:** PROCESSING AN OBJECT



(57) **Abstract:** The present invention relates to generation of instructions for actuator apparatus (1) that is adapted to process an object (9) by means of a thereto attached processing device (3) based on said instructions. In accordance with the method control parameters are generated based on data of the object, the control parameters being associated with the orientation of the processing device (3) during the processing of the object (9) and being generated for a plurality of locations on the object so that each of the locations is assigned with at least one control parameter. A reference point (RP) is selected. A desired orientation of the processing device (3) at the reference point is determined and at least one reference parameter that associates with the desired orientation of the processing device at the reference point is determined. Said generated control parameters that associate with locations on the object (9) within a predefined area (16) are then modified based on information of said at least one reference parameter.

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Processing an object

Field of the Invention

The present invention relates to processing an object, and in particular, but not exclusively, to generation of control instructions for actuator apparatus used for provision of movable support for a processing device.

Background of the Invention

During manufacture of goods the workpieces for the goods may be subjected to various processing stages by a processing device, such as a machining tool. The processing may include operations where a tool is brought into a contact with or closely follows a surface or boundary of a workpiece to be processed. Appropriate tools may be used, for example, for machining operations such as milling, tooling, boring, reaming, cutting, deburring, grinding, polishing, finishing and so on. Appropriate processing devices may also be used for operations such as spraying, washing, painting, welding, water jet or laser beam cutting or finishing, brushing and so on.

A tool or other processing device is typically attached to a holder assembly. The holder assembly may be moved by actuator apparatus adapted to provide movement of the processing device relative to the workpiece. The holder assembly typically comprises means for providing a firm grip of the tool or other device so that the drive force that is required for the relative movement can be properly transmitted to the processing device and in order to prevent the position of the processing to change relative to the holder. The skilled person is aware of various possible alternatives for the gripping means, and thus they will not be explained in more detail.

The actuator apparatus include industrial robots and manipulators and similar apparatus capable of moving the tool holder assembly. The movement may be provided in a three dimensional space (e.g. in x,y,z co-ordinates). The actuators are typically arranged to provide movements along a predefined number of axis i.e. to provide a predefined number of degrees of freedom for a point of the processing device. Conventional machining centres and similar machining apparatus are typically adapted to move along three or four, and in maximum along five axis. Robot-like actuators and similar manipulators may provide movements along six or even more axis i.e. they provide six or more degrees of freedom. In the refereed xyz coordinate system the six degrees of freedom are provided by the three axis (xyz) and rotation around each of the axis. The possible axis as well as provision thereof will be explained later in this specification.

To be able to move the processing device correctly and accurately relative to the object, the operation of the various components of the actuator is controlled based on a predefined set of instructions. More particularly, the movements of the actuator are typically controlled by a controller that follows a processing program. The controller instructs various components of the actuator apparatus such that the actuator apparatus provides a desired movement of the processing device relative to the object. The program may be based, for example, on a prewritten program code and/or on other information obtained e.g. through a machine vision system or from drawings illustrating the object.

The skilled person is aware of the possibilities how to use a beforehand prepared program to control the operation of an actuator, and thus the control function as such is not discussed here in full detail. It is sufficient to note that e.g. a machining program may be run such that a machining tool is moved relative to a workpiece by means of the actuator such that a predefined amount of material becomes removed from the surface thereof in order to provide a predefined geometry of the object (shape and dimensions). The machining program may be retrieved from a machining program library, e.g. after recognition of the object by a machine vision system or a request by an operator. Typically a machining program is structured such that it progresses from a location to a next location on the object. These locations will be referred to in the following as points, although no real or visible points may not be provided on the surface of the object. In other words, the tool progresses via subsequent points on the surface of the object based on the instructions in the program.

Each of the points is assigned with parameters that are required so that the controller knows how the object should be processed in each of the points. The parameters may define features such as position and orientation of the processing device and direction of the movement thereof. Typically the position and orientation of the processing device, such as the machining tool, is defined for so called tool centre point (TCP). The tool centre point or any other predefined point in the processing device is provided with the above referenced degrees of freedom. It should be appreciated that in the following a reference to tool centre point (TCP) is a reference to any appropriate control point that may have been assigned for a processing device.

The controller controls the positioning, angular relations and movements of the various components of the robot based on the TCP parameters. The angular relation between the components are often referred to as joint angles. That is, the programmer does not necessarily need to beforehand decide any parameters regarding the position and orientation of said components, but the controller may determine them based on the TCP parameters at each point on the object. The controller applies the TCP parameters at each of the points and automatically interpolates the movement between two points based on approximations that are based on TCP parameters of the previous and the next point on the machining path. Therefore it is not necessary to create beforehand instructions for the positioning and orientation of the various components of the robot or for the various possible parameters for the entire surface area (i.e. at each predefined point) of the object. Instead, it is sufficient if the TCP parameters are defined at said points.

At least some of the TCP orientation parameters may be defined as vectors. Instead of or in addition to the vectors, so called Euler angles may be used. In the latter scheme the orientation data is defined by means of degrees. More particularly, the Euler angles can be used to define the orientation of a point in a coordinate system, such as in a xyz coordinate system, relative to the axis of the coordinate system. The point can be the TCP or any other control point assigned for the processing device.

Control of actuators that employ five axis (i.e. the TCP has five degrees of freedom) may require use of a parameter that defines the angle in which the tool should approach the surface of the object, i.e. so called approach vector. Actuators with five degrees of freedom at most can typically be programmed to take this into account by means of conventional programming tools, such as by means of CAD/CAM techniques (computer aided design/computer aided manufacturing).

Figure 1 illustrates an example of a six axis actuator, that is an industrial robot 1. The actuator apparatus of Figure 1 is also shown to be provided with a seventh axis A7 by mounting the six axis robot 1 on tracks 10. Thus a robot type actuator apparatus may need to be programmed to perform movements relative to six or more different axis (degrees of freedom). The addition of the sixth degree of freedom may require use of an orientation vector or corresponding parameter in order to be able to define the actual orientation of a predefined control point of the processing device relative to the object.

As is illustrated by Figure 1, various components of the robot 1, such as arms 4 and 5, a wrist 8, and the body 6 of the robot 1 may perform various movements so as to provide six degrees of freedom for the tool centre point TCP. The wrist 8 of robot 1 on Figure 1 provides said sixth degree of freedom for the movements. Thus the wrist necessitates use of an orientation vector so that the system may control orientation of the tool centre point.

The robot or other actuator unit typically forms a closed kinetic system. That is, all axis of a robot belong to a single kinetic chain. The controller of the robot may control this closed kinetic chain based on the processing program and the TCP parameters. However, various processing applications may require use of one or several so called external axis. The external axis can be provided e.g. by means of rotating table or a conveyor on which the workpiece is attached or by any other device that is a part of a different kinetic system. In Figure 1 axis A7 provided by the tracks 10 forms an external axis and provides a seventh degree of freedom for the robot system. It should be appreciated that the number of freedom axis of the entire robot system may be even greater than the shown seven, this being an implementation issue.

The further or external axis may not be controlled by the controller of the robot. In applications where the controller may provide full or partial control of the external axis, the controller may have to perform the control of the two kinetic systems on different basis. The simultaneous control of the internal and external axis may cause also some other problems. It is possible that the separated control of the internal and external axis leads to somewhat different and/or non-synchronised control instructions (i.e. where and how to proceed) or even instructions that are in contradiction to each other in one or several points of the object. The different sets of instructions for internal and external axis may lead to a situation where the positioning and/or orientation of the components of the robot is no longer optimal and/or where the object cannot be reached at all (either the processing device or the object has moved out of the working area). This may be especially the case when complex surfaces and/or boundaries, such as curved or double curved surfaces are to be processed. Therefore a decision may be required how the processing should be proceeded in such situations.

As mentioned, the orientation of the tool centre point TCP may be defined by means of orientation vectors or Euler angles in the used coordinate system. Each point on the surface of the object to be processed is assigned with required parameters, e.g. orientation vectors or angles in degrees during the preparation of the machining program. The orientation of the arms of the robot is typically set to an optimal (=as good as possible) position at the starting point of the machining operation. In Figure 1 the starting point may be at the rear end A of the boat mould 9. However, although the orientation of the TCP and the various components of the actuator apparatus are set to optimal in the beginning of the processing cycle, the complex surface may lead to a situation where the orientation and/or position thereof are less optimal. The problem may be worsened if the processing includes use of an additional kinetic system.

In a typical processing application it is advantageous if the arms and the wrist can be kept as “straight” as possible. It may also be advantageous to keep the position of the wrist as constant as possible during the processing cycle. By means of this it is possible to avoid unnecessarily rapid accelerations and/or decelerations during the machining process, especially between the various axis of the robot itself. Such rapid changes may influence the process and affect negatively the final result of e.g. a machining or painting process.

The optimisation of the orientation of the arm and the wrist does not usually cause any major difficulties as long as the surface to be processed does not change in direction. However, the processing may be applied e.g. to a surface with double-curvature and/or a curved surface that narrows towards one end thereof. An example of this type of surfaces is the front end of the boat 9 of Figure 1. In this type of surfaces parallel tool movement paths will cross or join in a common point. In this type of application a situation may occur that is referred to as ‘working area overrun’.

In addition, the processing devices usually have a desired orientation in which it should be applied to the object. For example, the controller tries to apply a rotating tool in a substantially normal orientation to the surface of the object throughout the surface of the object (that is, the approach vector of the tool centre point is tried to be kept substantially normal to the surface of the object). However, this may lead to problems that relate to the orientation of the wrist and/or arms of the robot. Problems may be expected especially if two kinetic systems are involved in the processing. Difficulties may be also expected when automated or semi-automated programming techniques are used. These techniques may not be able to generate correct control instructions for all components of the robot due to the complexity of processing the complex surfaces, and thus one or more of the axis of the robot may 'overrun' the working area thereof during the processing of e.g. a double curved surface. For example, when processing spherical or curved surfaces or otherwise complicated surfaces the controller may try to meet all given instructions regarding the orientation of the processing device and may drive the wrist in an extremely angled position that is outside the working area. In addition, while the controller may try to keep the orientation of the processing device constant relative to the object, it may cause other parts of the actuator apparatus to collide the object or any other object within the operational range of the actuator.

Spherical surfaces are believed to be the most problematic. To illustrate the problems that associate therewith, lets assume a situation where a human arm advances from a first point in the equator in the north-to-south direction or east-to-west direction to a second point in the opposite side of the globe. If one tries to keep at least one finger either in the direction of the longitude or the latitude, he will notice that the position of his arm in the second point will be different depending whether the globe was circulated along the equator or over the north pole.

Thus it may be computationally difficult to maintain a constant position of the wrist or another component at the outer end of an actuator arm when processing an object by an actuator provided with at least six axis and/or to prevent occurrence of overruns. The present proposals to overcome this include use of an automatic programming tool that monitors whether any predefined limits of the movements of the actuator will be exceeded by the actuator. If a limit is detected to be exceeded, the tool may warn the programmer so that the program may be changed such that the parts of the actuator will not overrun the working area thereof. However, the inventors have found that if the value of orientation vector parameter is changed manually in one point this may cause too rapid movement in the orientation of one or several components of the actuator and/or the tool. The changes may cause, among other things, discontinuities in the machining path and have a negative affect to the results of the processing.

Summary of the Invention

The embodiments of the present invention aim to address one or several of the above problems.

According to one aspect of the present invention, there is provided a method of generating instructions for actuator apparatus, said actuator apparatus being adapted to process an object by means of a thereto attached processing device based on said instructions, comprising: generating control parameters based on data of the object, said control parameters associating with the orientation of the processing device during the processing of the object and being generated for a plurality of locations on the object so that each of the locations is assigned with at least one control parameter; selecting a reference point; determining a desired orientation of the processing device at the reference point; determining at least one reference parameter that associates with the desired orientation of the processing device at the reference point; and based on said at least one reference parameter, modifying those of the control parameters that associate with locations on the object within a predefined area.

In a more specific embodiment the at least one parameter is changed in all locations within a predefined distance from the reference point. The at least one parameter may also be changed linearly throughout a path of movement of the processing device relative to the surface of the object between the reference point and a point substantially on the edge of the predefined area. The processing device may be provided with at least six degrees of freedom for the movement thereof.

The method may comprise further steps of determining during the generation of the control instructions that an undesired orientation of the processing device will occur in a location on the object; selecting said location to form a reference point; and modifying the control parameters within a distance from said selected reference point.

At least one of the control parameters assigned for a location on the object may associate with an axis that is external for the kinetic system of the actuator apparatus. The external axis may be provided by means of moving the object relative to the actuator apparatus or moving the entire actuator apparatus relative to the object.

More than one reference point may be selected.

According to another aspect of the present invention there is provided a method of processing an object by means of a processing device attached to actuator apparatus, said actuator apparatus being arranged to move the processing device relative to the object, comprising: generating data regarding the contour of the object to be processed; generating control parameters based on said data for controlling orientation of the processing device when processing the object, the control parameters associating with a plurality of locations on the object so that each location is assigned with at least one control parameter; selecting a reference point that associates with the object; determining at least one reference parameter that associates with a desired orientation of the processing device at the reference point; and based on said at least one reference parameter, modifying said control parameters at locations that are within a predefined area; and processing the object based on the modified control parameters.

According to another aspect of the present invention there is provided a method of generating instructions for actuator apparatus for processing an object by means of a processing device attached to the actuator apparatus, said actuator apparatus providing the processing device with a first number of degrees of freedom in a three dimensional space, comprising the steps of: defining information of the contour of the object to be processed; generating a first set of instructions by means of an instruction generation tool based on said information of the contour, said first set of instructions being for controlling movements of an actuator capable of providing the processing device with a second number of degrees of freedom, said second number being less than said first number; determining additional information that associates with at least one further degree of freedom; and generating a second set of instructions based on said first set of instructions and the additional information for use in the control of the operation of the actuator apparatus for processing the object with the processing device provided with the first number of degrees of freedom.

The first set of instructions may be generated by means of a computer aided design and manufacture programming technique and provides the processing device with five degrees of freedom. The actuator apparatus may comprise an industrial robot enabled to provide at least six degrees of freedom for the processing device.

According to another aspect of the present invention there is provided an apparatus for generation of instructions for actuator apparatus adapted for processing an object by means of a processing device attached to the actuator apparatus based on said instructions, comprising: a data input for input of data defining the shape of the object; processor means for generating control parameters based on the input data for the control of the orientation of the processing device during the processing of the object, the processor means being adapted to generate said control parameters for a plurality of locations on the object so that each of the locations becomes assigned with at least one control parameter; processor means for determining a desired orientation of the processing device at a reference point that associates with the object; processor means for determining at least one reference parameter that associates with the desired orientation of the processing device at the reference point; and processor means for modifying, based on said at least one reference parameter, control parameters that associate with locations on the object within a predefined area.

According to another aspect of the present invention there is provided a system for processing objects, comprising: actuator apparatus adapted to move a processing device attached to the actuator apparatus relative to an object to be processed; a controller for controlling the operation of the actuator apparatus; and an apparatus for generating instructions for the controller, said instructions defining control parameters for the control of the orientation of the processing device during the processing of the object for a plurality of locations on the object so that each of the locations becomes assigned with at least one control parameter, wherein the apparatus for generating the instruction is adapted to modify the control parameters that associate with locations on the object within a predefined area based on information of at least one parameter that associates with a desired orientation of the processing device at a selected reference point.

According to another aspect of the present invention there is provided an arrangement for generating instructions for actuator apparatus for processing an object by means of a processing device attached to the actuator apparatus, said actuator apparatus providing the processing device with a first number of degrees of freedom in a three dimensional space, the arrangement comprising: means for defining information of the contour of the object to be processed; processor means for generating a first set of instructions by means of an instruction generation tool based on said information of the contour, said first set of instructions being for controlling movements of an actuator capable of providing the processing device with a second number of degrees of freedom, said second number being less than said first number; processor means for determining additional information that associates with at least one further degree of freedom; and processor means for generating a second set of instructions based on said first set of instructions and the additional information for use in the control of the operation of the actuator apparatus for processing the object with the processing device provided with the first number of degrees of freedom.

The embodiments of the invention may enable provision of instructions for *actuators (such as control programs) such that rapid changes in the orientation of* the components of the actuator apparatus and/or non-optimal orientation said components may be avoided. The embodiments may enable smoother movements of a processing device relative to the object to be processed, thus enabling better quality of the processed surfaces. The embodiments may also enable a pre-check of the instructions in order to verify that the processing device may reach all parts of the object to be processed and/or that none of the components will overrun its working area during the actual processing of the object. The instruction correcting procedure may be automatic.

Brief Description of Drawings

For better understanding of the present invention, reference will now be made by way of example to the accompanying drawings in which:

Figure 1 shows a system that may employ an embodiment of the present invention;

Figure 2 shows a schematic presentation of the paths of movement in an embodiment of the present invention;

Figure 3 illustrates an orientation of a processing device resulting from use of a conventional technique for generation of a machining program for the Figure 1 object;

Figure 4 illustrates the orientation of the processing device holder obtainable by means of the principles of the present invention;

Figures 5a to 5c illustrate the processing device orientation in various locations on relative to the object;

Figure 6 is a flowchart illustrating the operation of one embodiment of the present invention;

Figures 7a and 7b illustrate a further embodiment of the invention;

Figure 8 shows an instruction generation apparatus; and

Figure 9 is a flowchart illustrating the operation of a further embodiment of the present invention.

Description of Preferred Embodiments of the Invention

Reference is first made to Figure 1 which shows a machining system employing an industrial robot 1 mounted on tracks 10 for actuating a tool holder assembly 3. The basic structure and operation of a six axis industrial robot is known by the skilled person, and will thus not be explained in detail. It is sufficient to note that a robot typically comprises a frame portion and one or several swivelling and/or rotational arms so that it is capable of providing different movements of the tool in the working area thereof.

The various possibilities for rotational and/or pivotal movement of the six axis robot 1 of Figure 1 are indicated by the two-headed arrows A1 to A6. In addition to the "normal" six axis, the robot 1 is arranged to move along a seventh axis, as is indicated by arrow A7.

More particularly, the frame portion 6 can be rotated as indicated by double-headed arrow A1. A first arm 5 is pivotally attached to the frame portion 6, and can be pivoted as indicated by double-headed arrow A2. A second or outer arm 4 is pivotally attached to the first arm 5. The pivoting between the first and second arms is actuated by the bar 15, and occurs as indicated by arrow A3. A pivoting point 7 is arranged at the end of the outer arm 4 to enable movement as indicated by double-headed arrow A4. A short mounting arm or fixture 8 projects from the pivoting point 7 and provides an attachment point for the tool holder assembly 3. The mounting arm of a robot is typically referred to as a wrist. The mounting arm 8 may revolve around an axis that is illustrated by the two-headed arrow A5. In a typical construction the frame and arm components provides axis 1 to 5.

A rotating tool 11 is mounted on the tool holder 3. The tool 11 is adapted revolve around axis A6. The rotational and/or swivelling movements of the various components of the robot may be provided by suitable actuators, such as by servomotors and/or pneumatic or hydraulic cylinders. A tool centre point TCP is shown to be located at the outer end of the tool 11 on the rotational axis thereof.

It should be appreciated that the actuator apparatus may be adapted to provide other number of possible axis than what is illustrated by Figure 1. For example, axis A7 (i.e. the tracks 10) may not be necessary in all applications or the robot may be provided with an additional pivoting point, thereby enabling a greater number of degrees of freedom for the processing apparatus.

The operation of the various components of the robot 1 is controlled by a controller unit 2. The control unit 2 is arranged to follow a set of instructions i.e. to process a reprogrammed processing program that has been prepared for an object 9 so that the object may be processed by means of the robot 1 in a desired manner. The program may have been prepared by means of an appropriate programming tool, such as by a CAD/CAM tool modified in accordance with the embodiments of the invention. A part of the information on which the processing may be based on may be fetched/received from an internal or external database or from an imaging apparatus of a machine vision system (not shown in Figure 1) via an appropriate communication media.

The controller 2 typically includes required data processing and storage capability, such as an appropriate central processing unit (CPU) and necessary software for running the control applications in the processing unit. The central processing unit may be based on microprocessor technology. As a more practical example, the controller unit may be based on a Pentium™ processor, even thoug a less or more powerfull processor may also be employed depending on the requirements of the system and the objects to be handled. Depending on the application, the controller 2 may be provided with appropriate memory devices, drives, display means, a keyboard, a mouse or other pointing device and any adapters and interfaces that may be required. In addition, if the processing of the object 9 is based on information received from e.g. a camera of a machine vision system, an appropriate imaging software is typically required. The controller may also be provided with a network card for installations where the machining system is connected to a data network, such as to a network that is based on use of Internet Protocol (IP) for data transporation. A data communication connection 12 is provided between the controller 2 and the robot 1 for transmission of data between the robot and the controller.

The exemplifying workpiece 9 of Figure 1 comprises a hull frame for a boat. As is well known, the hull of a boat may have a curved surface, and especially the front end thereof may be of double curved contour. The workpiece 9 may be supported by any appropriate supporting means, such as by an appropriate fixed support or by a support apparatus providing movement thereof, such as a rotating table or a conveyor.

The tool 11 is used for providing the desired shape of the boat. Some applications may require use of several different tools during the processing, e.g. one for the rough machining, one for the machining and one for the finishing stages. The tool holder assembly 3 may comprise a spindle for rotating the tool 11. The skilled person is familiar with the operation and structure of the various spindle arrangements, and thus the internal parts within the spindle housing are not shown or explained in more detail. It is sufficient to note that if a rotating tool is to be used, a suitable spindle apparatus may be used to provide the drive force for the rotating tool 11. The spindle may be driven by an appropriate motor. The most commonly used alternatives for the motor are at the present electric, pneumatic and hydraulic motors, although other possibilities are not excluded. Although it is not necessary in all applications, the rotation of the tool around the rotational axis thereof may be provided in two directions. The rotating tool 11 may be attached to the spindle by means of a chuck, a mandrel or other appropriate clamping device (not shown).

The rotating machining tool 11 is arranged to rotate around a so called tool centre line TCL. When rotating tools are concerned, it may be preferred to define that the tool centre point (TCP) is located on the TCL, and more particularly that the TCP is located on the TCL at the tip of the tool. However, the TCP may also be defined in the edge of the tool (e.g. in grinding wheels). As explained above, the controller 2 is instructed to control the operation of the various components of the robot 1 based on the orientation and location of the control point of the processing device, i.e. the TCP of the tool 11.

Figure 2 shows schematically a top view of the subsequent paths of movement 20 of the tip of the tool 11 on the surface of the other half of the boat 9 of Figure 1. The boat surface is machined by moving the tool in subsequent movements 20 in the direction form the rear of the boat to the front of the boats, i.e., in direction from point A to point B. As can be seen, the subsequent paths join at the tip of the boat, i.e. at point B. Each of the paths 20 consists of a plurality of successive points 21 (for clarity reasons, only a part of the points is shown). During the programming work the orientation of the tool centre point is defined in the used coordinate system at each of these points. In addition to the TCP parameters, it may also be necessary to determine any parameters that associate with possible external axis at each point. The computation is accomplished by an appropriate programming tool (for a possible tool, see Figure 8). The controller will then control the operation of the actuator apparatus based on this program.

Figure 3 illustrates a situation that may occur with curved surfaces. As can be seen, due to the mathematically problematic situation caused by the double curved contours of the boat 9, the arm 4 of the robot 1 may become driven outside (i.e. "overrun") the working area. In order to still be able to reach the surface of the boat 9 at the end point B of the machining path, the controller has turned the wrist 8 of the robot into an extremely angled (and thus undesired) position shown in Figure 3.

Figure 4 illustrates the orientation of the wrist close to the point B when the wrist 8 has a "correct" or an optimal orientation. The procedure for obtaining the desired i.e. optimal orientation of the tool holder 3 and the wrist 8 will now be described in more detail with reference to Figures 4 to 8 and the flowchart of Figure 6. It should be appreciated that in this specification the definition orientation of the processing device refers to the orientation of the tool holder (and thus the tool) or similar processing device and/or also to the orientation of the wrist or similar apparatus supporting the processing device, where appropriate and not especially excluded.

In the beginning of the program generation process it is typically necessary to define some predefined information of the object. That is, the contour of the surface of the object 9 may need to be defined so that it is possible to generate a set of instructions for the actuator apparatus 1 so that the surface of the object may be processed by the tool 11. It should be appreciated that the initial surface of a workpiece for an object may be different in dimensions and/or contour than the finished i.e. final surface of the object. The term "surface" refers in this specification to the finished surface of the object if nothing else is indicated. The information may be obtained e.g. based on the drawings for the object or other information prepared for the manufacture of the object, by means of a machine vision system or other system capable of producing the required object information and so on.

During the programming stage the required parameters for the internal and possible external axis may be computed by means of a conventional programming procedure, such as by means of a CAD/CAM programming tool. That is, during the programming work, required orientation vectors and other necessary parameters at different locations i.e. points within a defined working area may be initially computed at each of the points 21 between the first and last points A, B in each of the paths 20 in any appropriate manner.

According to an embodiment, the point B at the front end of the boat frame 9 is selected to form a reference point (RP). It should be appreciated that the reference point does not necessarily need to be located at the end point of the machining path or in the common point of two or more machining paths. An optimal orientation of the TCP is defined for the reference point. In applications which include use of an external axis, optimal external axis parameters may be defined in the reference point. The parameters defined for the reference point RP may then be used to change one or several of the parameters used at the other points. That is, the user, e.g. the person installing the program into the controller may tell or teach to the controller good orientation parameters at the reference point RP. The orientation parameters are then modified at the other points based on the information of the desired orientation at the reference point RP. However, the correction of the parameters may also be accomplished during the generation of the program, that is before the program is input in the controller.

The correction is preferably made within a defined (limited) distance or range from the reference point RP. In the Figure 1 example the dashed line 16 indicated the area within which the control parameters are to be corrected based on the reference point RP. A possibility is to limit the correction area such that the correction applies throughout the front end area of the boat frame 9. As shown by Figure 2, the machining paths 20 converge at the front end area i.e. the front end forms an area where the frame 9 has a double curved contour and where a correction of the orientation parameters may be required. The size of the area 16 may be defined beforehand or it may be defined individually for each reference point based on other information of the object. The area sizing may be a dynamic process.

According to a preferred embodiment the program generation tool monitors for any overrun situations that could occur if no correction is provided. Whenever a possible overrun is detected at a location on the object, this location is selected to form a reference point. The position of the processing device is corrected, and the corrected parameters are used as a base for correction within a range from the selected reference point. The programming tool may be adapted to accomplish this automatically. The range may be defined based on information of the object, and may vary between different reference points on the object.

It is noted that in some applications it is possible to define the optimal parameters for the external axis only, and to use the original TCP parameters for the axis of the robot 1. For example, in order to straighten the wrist 8 it may be enough if the entire robot 1 is moved sideways on the tracks 10, i.e. along the external axis A7.

The modification of the orientation vectors is accomplished preferably such that the change is linear between the starting point of the correction (i.e. at the edge of the defined area) and the reference point RP. This provides a smooth correction of the vectors between the two points. As can be seen from Figures 4 to 8, the position of the wrist 8 remains substantially constant relative to the arm 4 in various locations relative to the object.

Since the orientation information is corrected in all such points that are close to the reference point B and that may require correction, a proper orientation of the wrist may be provided such that the position of the wrist is not changed too rapidly in zones with complicated surfaces and/or changing contours. It may also be possible to more effectively avoid overrun situations since the use of the reference point may enable a localised control of the various components of the robot so that any overrun is prevented. By means of the proposed automatic correction of the parameters based on a reference point it may also be possible to improve the quality of the resulting surface, as all sudden movements in the position of the components of the robot may affect the final result. Although a manual correction of the parameters in one or few points may be a possibility, at least in theory, the skilled person understands that an area to be processed may comprise hundreds or thousands of points. This may make the manual correction of the parameters in practise impossible and in any case time consuming and/or too expensive. In addition, when all points within a defined area are corrected at once and based on a similar rule of correction, it may be possible to avoid a situation in which two neighbouring points have substantially different orientation information and thus rapid movements of the components of the actuator when moving from a point to another point.

According to a possibility all points in the path 20 between the starting and ending point of the machining path 20 or in the vicinity of the reference point are corrected.

According to a further embodiment, at least one additional reference point is selected. The additional reference point may be used e.g. when there is a discontinuity in the contour of the surface to be processed. Figures 7A and 10B illustrate a curved surface with a recess 25 on the top portion thereof. Three reference points RP1, RP2 and RP3 are assigned for the object 9. The point RP1 is for the overall correction of the machining parameters whereas the points RP2 and RP3 are applied only for the area of the recess 25, and more particularly, at the respective ends of the recess 25.

Each of the reference points may be used as a base for a local correction in the vicinity of the reference points. The correction may be applied based on a single reference point, that is such that only one reference point is taken into account. According to an alternative two or more reference points (such as RP2 and RP3 or RP1 to RP3) are taken into account when correcting the TCP orientation parameters and/or the external axis parameters.

It is also possible to arrange the workpiece to be supported by another actuator device or by a conveyor arrangement so that the workpiece 9 may be moved in a controlled manner relative to the tool 11. Therefore it should be understood that while in the exemplifying embodiments the tool 11 is moved relative to the object 9, the relative movement between the tool and the object may also be provided by moving the object or by moving both the object and the tool. The provision of the external axis may increase the importance of the correction of the control parameters, especially those parameters that associate with the external axis.

Figure 8 shows a schematic presentation of an apparatus for the generation of the instructions. The apparatus 30 is shown to comprise an input 32 for data that associates with the object. The may define the shape and/or size and/or further characteristics of the object so that it is possible to generate processing instructions for the object. A processor 31 is adapted to generate the control parameters based on the input data, to determine a desired orientation of the processing device at a reference point, to determine at least one reference parameter that associates with the desired orientation of the processing device, and to modify the control parameters. It should be appreciated that the apparatus 30 may comprise a processor entity for accomplishing all the required data processing or that the processor functions may be distributed for several processor units. This is an implementation issue.

The apparatus 30 is shown to interface the controller 2 of a robot via a data communication connection 36. The apparatus 30 may also include a database 33 for storing any information that may be required for the program generation. Additional input means, such as a keyboard 34 and a display 35 may also be provided.

In accordance with an embodiment shown by Figure 9, a CAD/CAM system or similar per se conventional arrangement may be employed for the generation of a first set of instructions, said first set of instructions being for controlling movements of an actuator that is capable of providing the processing device with a number of degrees of freedom that is less than what is actually required by a robot or similar device providing at least six degrees of freedom for a processing device. For example, the first set of instruction may be suitable for controlling a five axis machine tool. The input for the process of generation of the first set of instructions comprises information of the contour of the object to be processed. During the process additional information is determined, said additional information being associated with at least one further degree of freedom. The additional information preferably comprises information of the orientation of the processing device. A second set of instructions is then generated based on said first set of instructions and the additional information. The second set of instructions is adapted to be suitable for controlling operation of the robot. The additional information may also comprise information that associates with an axis that is external to the kinetic system of the robot. The orientation information of the second set of information may be modified as described above with reference to Figures 1 to 7. The method may be implemented by means of an apparatus similar to the data processing apparatus 30 of Figure 8.

It should be appreciated that whilst embodiments of the present invention have been described in relation to an industrial robot, embodiments of the present invention are applicable to any other suitable type of actuators. It is also noted herein that while the above describes exemplifying embodiments of the invention, there are several variations and modifications which may be made to the disclosed solution without departing from the scope of the present invention as defined in the appended claims.

Claims

1. A method of generating instructions for actuator apparatus, said actuator apparatus being adapted to process an object by means of a thereto attached processing device based on said instructions, comprising:

generating control parameters based on data of the object, said control parameters associating with the orientation of the processing device during the processing of the object and being generated for a plurality of locations on the object so that each of the locations is assigned with at least one control parameter;

selecting a reference point;

determining a desired orientation of the processing device at the reference point;

determining at least one reference parameter that associates with the desired orientation of the processing device at the reference point; and

based on said at least one reference parameter, modifying those of the control parameters that associate with locations on the object within a predefined area.

2. A method as claimed in claim 1, wherein the at least one parameter is changed in all locations within a predefined distance from the reference point.

3. A method as claimed in claim 1 or 2, wherein the at least one parameter is changed linearly throughout a path of movement of the processing device relative to the surface of the object between the reference point and a point substantially on the edge of the predefined area.

4. A method as claimed in any preceding claim, wherein the control parameters to be generated and corrected comprise orientation vectors.

5. A method as claimed in any of claims 1 to 3, wherein the control parameters to be generated and corrected comprise Euler angles.

6. A method as claimed in any preceding claim, wherein the processing device is provided with at least six degrees of freedom for the movement thereof.

7. A method as claimed in any preceding claim, wherein the processing device is assigned with a control point, said control parameters defining the orientation of the control point at the respective locations.

8. A method as claimed in claim 7, wherein the control point comprises a tool centre point.

9. A method as claimed in any preceding claim, comprising:

determining during the generation of the control instructions that an undesired orientation of the processing device will occur in a location on the object;

selecting said location to form a reference point; and

modifying the control parameters within a distance from said selected reference point.

10. A method as claimed in any preceding claim, wherein at least one of the control parameters assigned for a location on the object associates with an axis that is external for the kinetic system of the actuator apparatus.

11. A method as claimed in claim 10, wherein the external axis is provided by means of moving the object relative to the actuator apparatus or moving the entire actuator apparatus relative to the object.

12. A method as claimed in any preceding claim, comprising selection of more than one reference point.

13. A method as claimed in claim 12, wherein the modification of said least one control parameter is based on different reference parameters in different areas of the object.

14. A method as claimed in claim 12, wherein the modification of said at least parameter within the predefined area is based on more than one reference point.

15. A method as claimed in any preceding claim, wherein the generation of the control parameters is accomplished by a programming tool.

16. A method as claimed in any preceding claim, wherein the surface or boundary of the object to be processed has at least some curved portions.

17. A method as claimed in claim 16, wherein at least a part of the surface has a double-curved shape or spherical shape.

18. A method as claimed in any preceding claim, wherein the actuator apparatus to be controlled based on the instructions comprises a robot.

19. A method of processing an object by means of a processing device attached to actuator apparatus, said actuator apparatus being arranged to move the processing device relative to the object, comprising:

generating data regarding the contour of the object to be processed;

generating control parameters based on said data for controlling orientation of the processing device when processing the object, the control parameters associating with a plurality of locations on the object so that each location is assigned with at least one control parameter;

selecting a reference point that associates with the object;

determining at least one reference parameter that associates with a desired orientation of the processing device at the reference point; and

based on said at least one reference parameter, modifying said control parameters at locations that are within a predefined area; and

processing the object based on the modified control parameters.

20. A method as claimed in claim 19, wherein the actuator apparatus comprises a robot.

21. A method as claimed in claim 20, wherein the robot is moved relative to the object to be processed.

22. A method as claimed in any of claims 19 to 21, wherein the object to be processed is moved relative to the actuator apparatus.

23. A method as claimed in any of claims 19 to 22, wherein the actuator apparatus provides the processing device with at least six degrees of freedom for the movement thereof.

24. A method as claimed in any of claims 19 to 23, wherein the processing device is assigned with a control point, said control parameters defining the orientation of the control point at each of the locations on the object.

25. A method as claimed in claim 24, wherein the control point comprises a tool centre point.

26. A method as claimed in any of claims 19 to 25, wherein the processing comprises one of: deburring; grinding; milling; tooling; reaming; boring; cutting; polishing; finishing; brushing; spraying.

27. A method of generating instructions for actuator apparatus for processing an object by means of a processing device attached to the actuator apparatus, said actuator apparatus providing the processing device with a first number of degrees of freedom in a three dimensional space, comprising the steps of:

defining information of the contour of the object to be processed;

generating a first set of instructions by means of an instruction generation tool based on said information of the contour, said first set of instructions being for controlling movements of an actuator capable of providing the processing device with a second number of degrees of freedom, said second number being less than said first number;

determining additional information that associates with at least one further degree of freedom; and

generating a second set of instructions based on said first set of instructions and the additional information for use in the control of the operation of the actuator apparatus for processing the object with the processing device provided with the first number of degrees of freedom.

28. A method as claimed in claim 27, wherein the first set of instructions is generated by means of a computer aided design and manufacture programming technique and provides the processing device with five degrees of freedom.

29. A method as claimed in claim 27 or 28, wherein the actuator apparatus comprises an industrial robot enabled to provide the processing device with at least six degrees of freedom.

30. A method as claimed in any of claims 27 to 29, wherein the additional information comprises orientation of the processing device.

31. A method as claimed in any of claims 27 to 30, wherein the additional information comprises information that associates with an axis that is external to the kinetic system of the actuator apparatus.

32. A method as claimed in any of claims 27 to 31, wherein the first set of instructions is generated for controlling a machine tool.

33. An apparatus for generation of instructions for actuator apparatus adapted for processing an object by means of a processing device attached to the actuator apparatus based on said instructions, comprising:

a data input for input of data defining the shape of the object;

processor means for generating control parameters based on the input data for the control of the orientation of the processing device during the processing of the object, the processor means being adapted to generate said control parameters for a plurality of locations on the object so that each of the locations becomes assigned with at least one control parameter;

processor means for determining a desired orientation of the processing device at a reference point that associates with the object;

processor means for determining at least one reference parameter that associates with the desired orientation of the processing device at the reference point; and

processor means for modifying, based on said at least one reference parameter, control parameters that associate with locations on the object within a predefined area.

34. A system for processing objects, comprising:

actuator apparatus adapted to move a processing device attached to the actuator apparatus relative to an object to be processed;

a controller for controlling the operation of the actuator apparatus; and

an apparatus for generating instructions for the controller, said instructions defining control parameters for the control of the orientation of the processing device during the processing of the object for a plurality of locations on the object so that each of the locations becomes assigned with at least one control parameter, wherein the apparatus for generating the instruction is adapted to modify the control parameters that associate with locations on the object within a predefined area based on information of at least one parameter that associates with a desired orientation of the processing device at a selected reference point.

35. An apparatus as claimed in claim 33 or a system as claimed in claim 34, wherein at least one of the control parameters associates with an axis that is external for the kinetic system of the actuator apparatus.

36. A system as claimed in claim 34 or 35, comprising means for moving the object relative to the actuator apparatus or means for moving the actuator apparatus entity relative to the object.

37. An apparatus as claimed in claim 33 or a system as claimed in any of claims 34 to 36, wherein the apparatus is adapted to modify the control parameters based on more than one reference point.

38. An arrangement for generating instructions for actuator apparatus for processing an object by means of a processing device attached to the actuator apparatus, said actuator apparatus providing the processing device with a first number of degrees of freedom in a three dimensional space, the arrangement comprising:

means for defining information of the contour of the object to be processed;

processor means for generating a first set of instructions by means of an instruction generation tool based on said information of the contour, said first set of instructions being for controlling movements of an actuator capable of providing the processing device with a second number of degrees of freedom, said second number being less than said first number;

processor means for determining additional information that associates with at least one further degree of freedom; and

processor means for generating a second set of instructions based on said first set of instructions and the additional information for use in the control of the operation of the actuator apparatus for processing the object with the processing device provided with the first number of degrees of freedom.

39. An arrangement as claimed in claim 38, wherein the first set of instructions is generated by means of a computer aided design and manufacture programming tool and provides control for movement of a processing device with five degrees of freedom.

40. An arrangement as claimed in claim 38 or 39, wherein the actuator apparatus is adapted to provide the processing device with at least six degrees of freedom.

41. An arrangement as claimed in any of claims 38 to 40, wherein the additional information comprises information that associates with an axis that is external to the kinetic system of the actuator apparatus.

42. An arrangement as claimed in any of claims 38 to 41, wherein the first set of instructions is generated for controlling a machine tool.

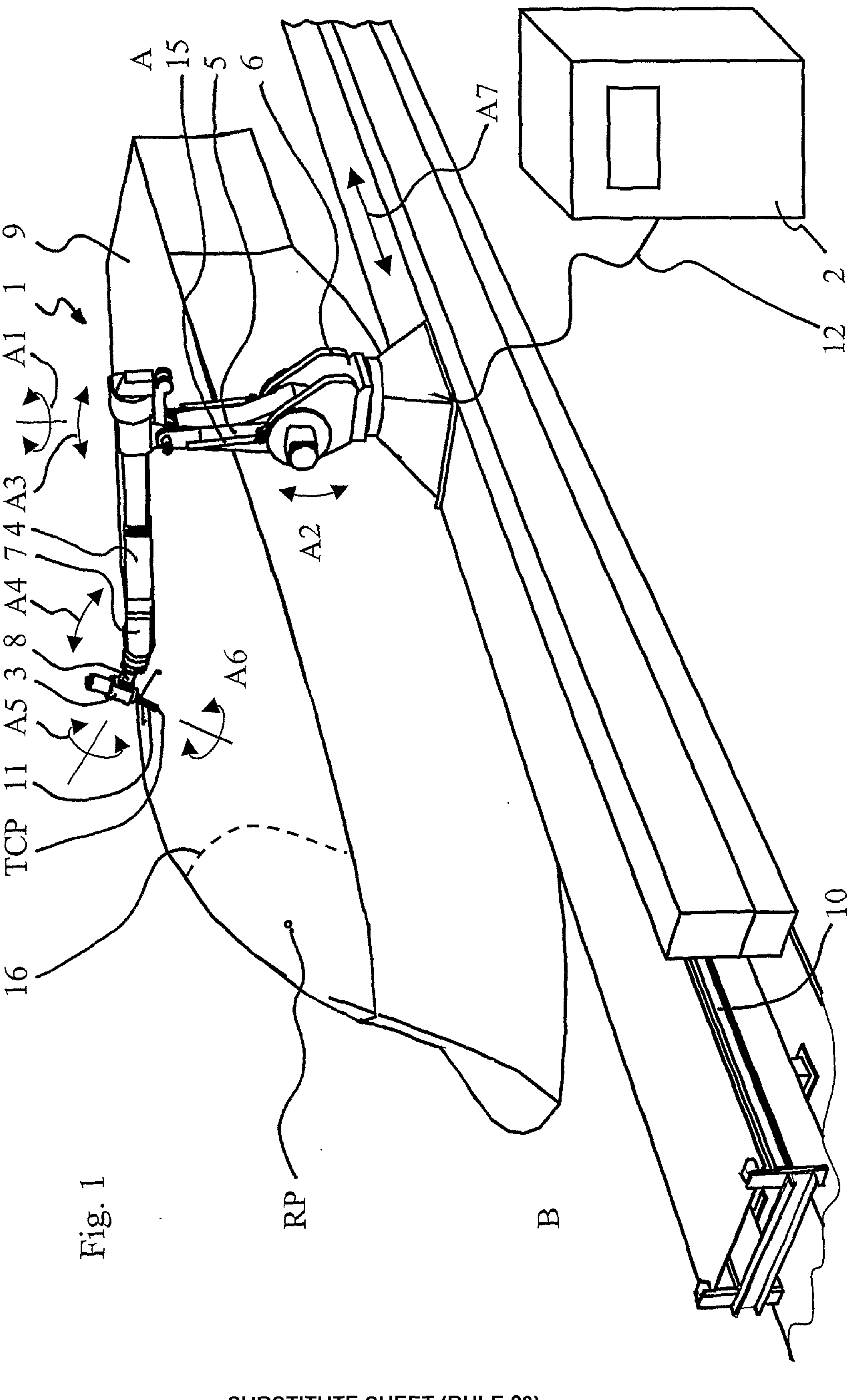

Fig. 1

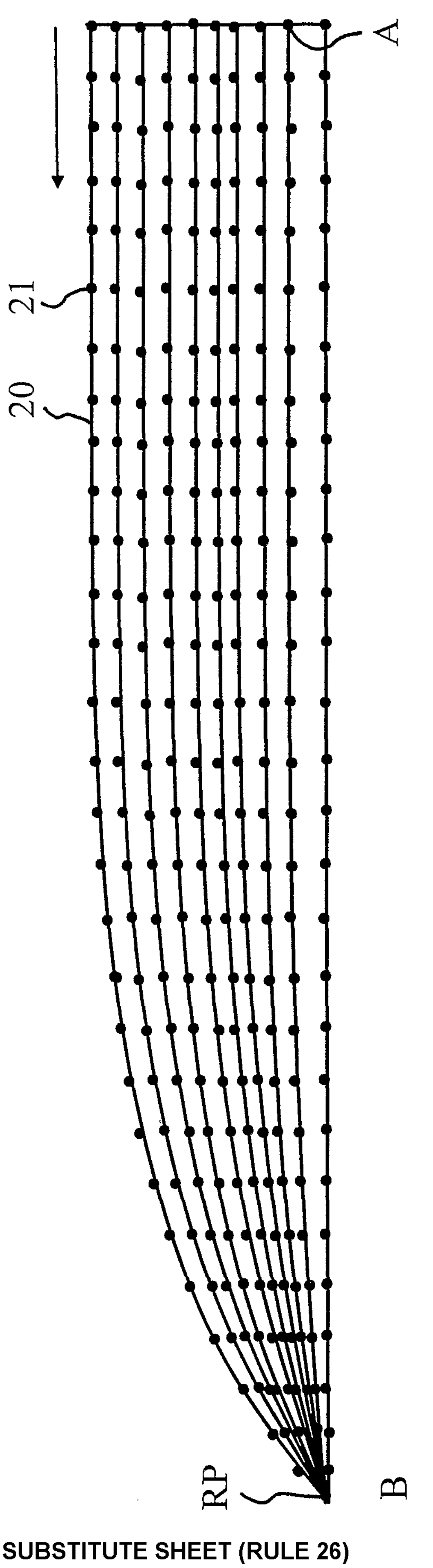

Fig. 2

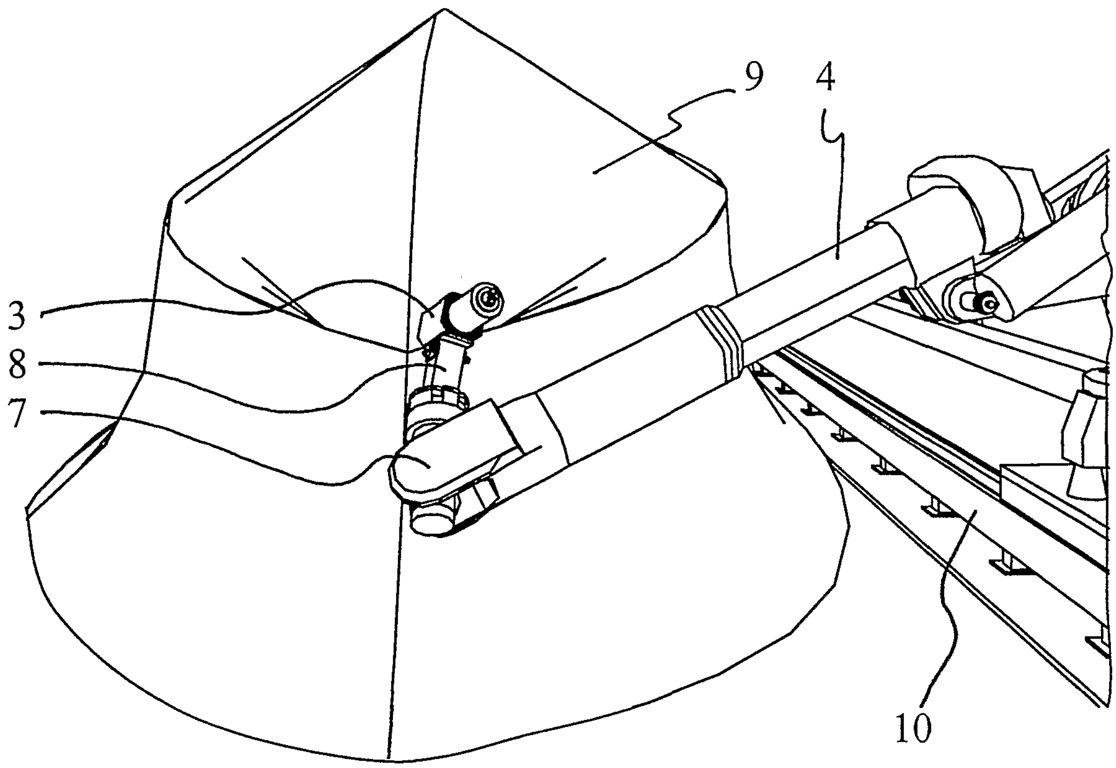

Fig. 3

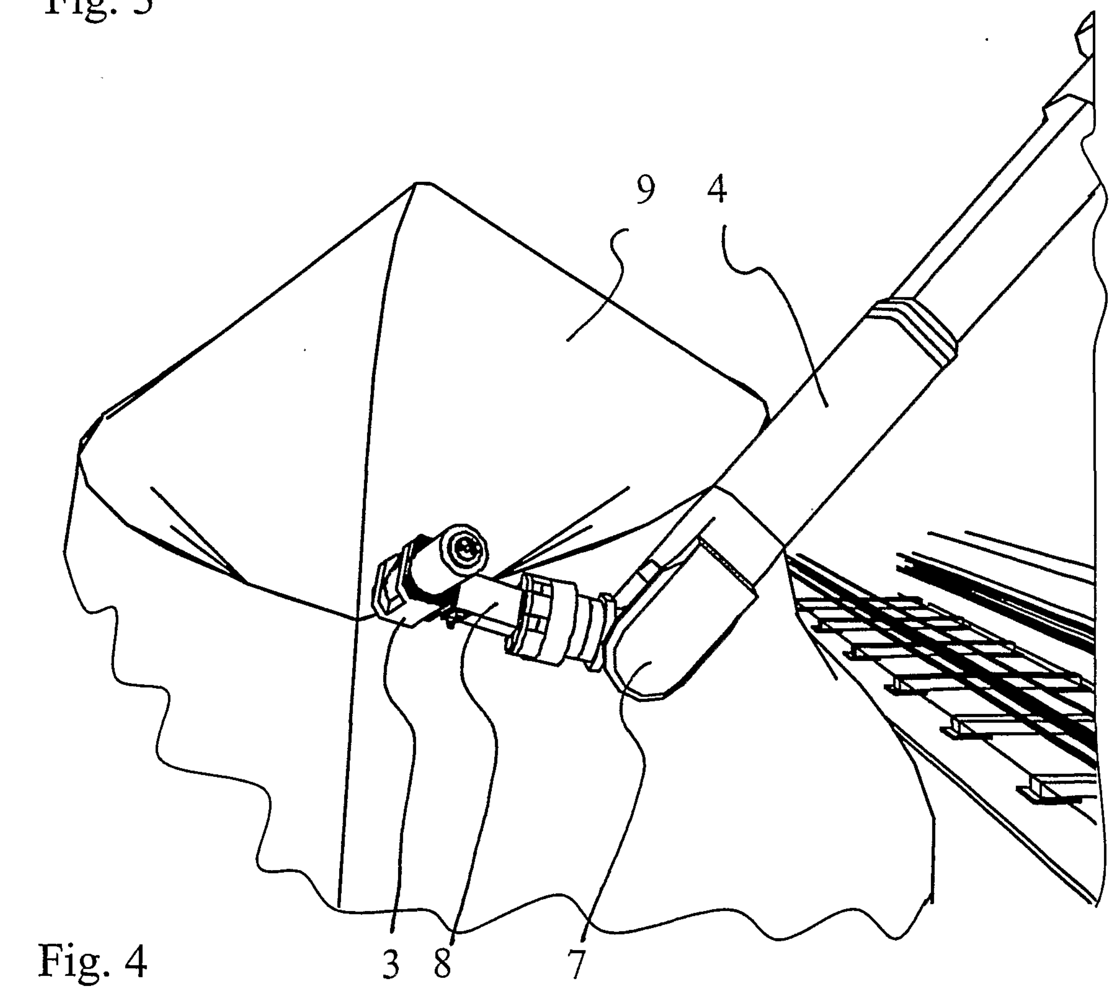

Fig. 4

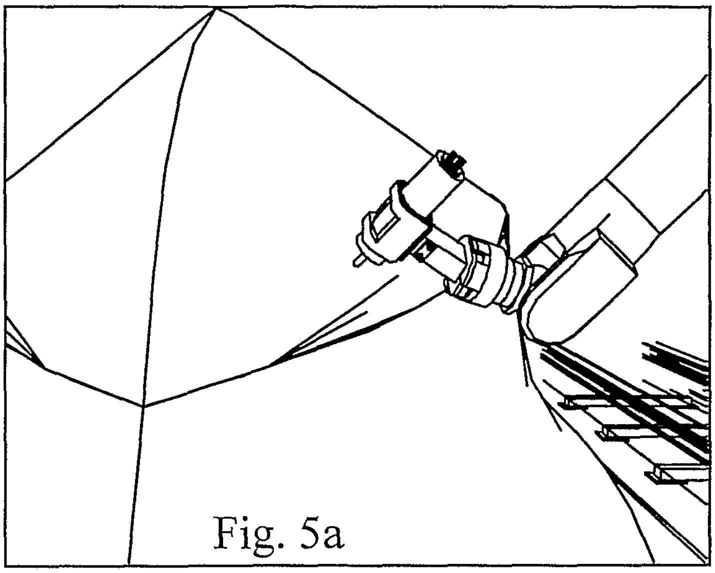

Fig. 5a

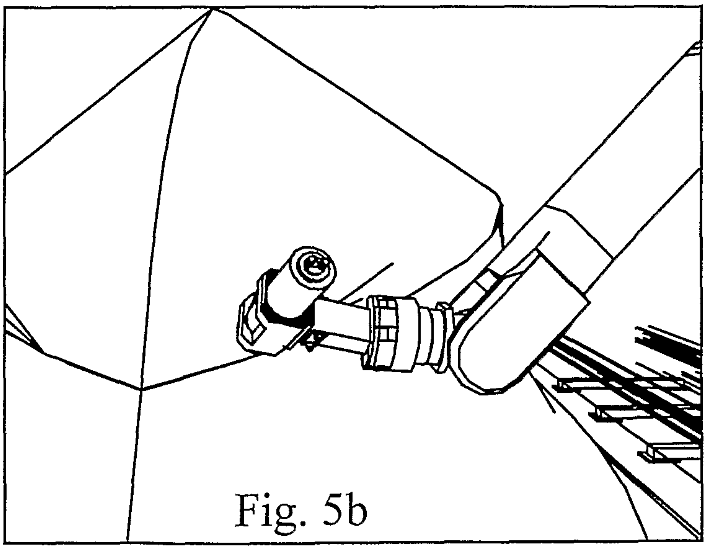

Fig. 5b

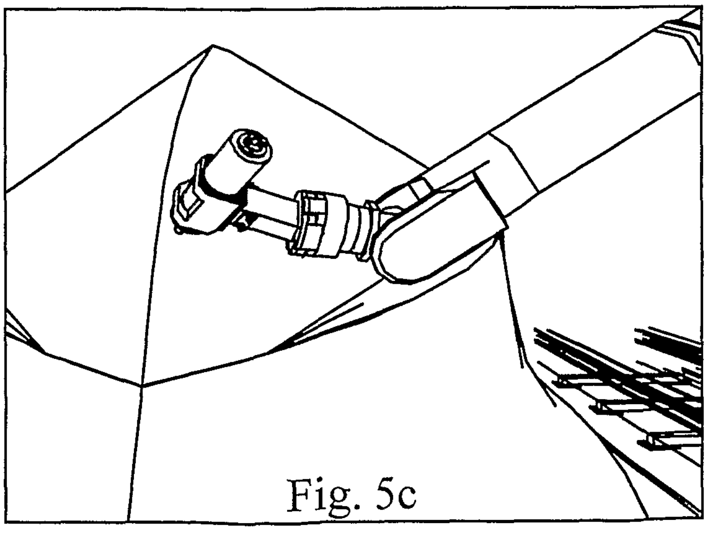

Fig. 5c

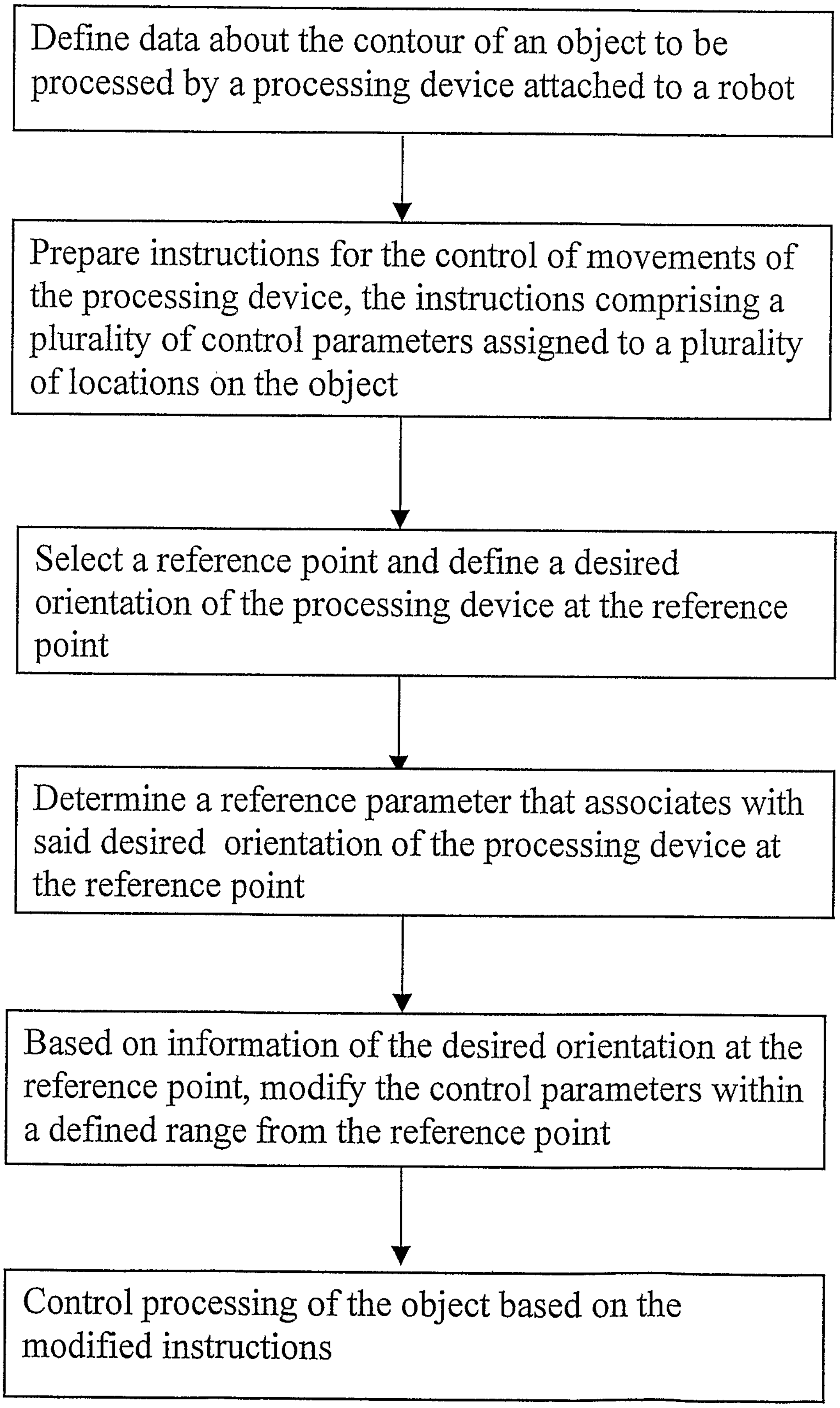
Define data about the contour of an object to be processed by a processing device attached to a robot
Prepare instructions for the control of movements of the processing device, the instructions comprising a plurality of control parameters assigned to a plurality of locations on the object
Select a reference point and define a desired orientation of the processing device at the reference point
Determine a reference parameter that associates with said desired orientation of the processing device at the reference point
Based on information of the desired orientation at the reference point, modify the control parameters within a defined range from the reference point
Control processing of the object based on the modified instructions

Fig. 6

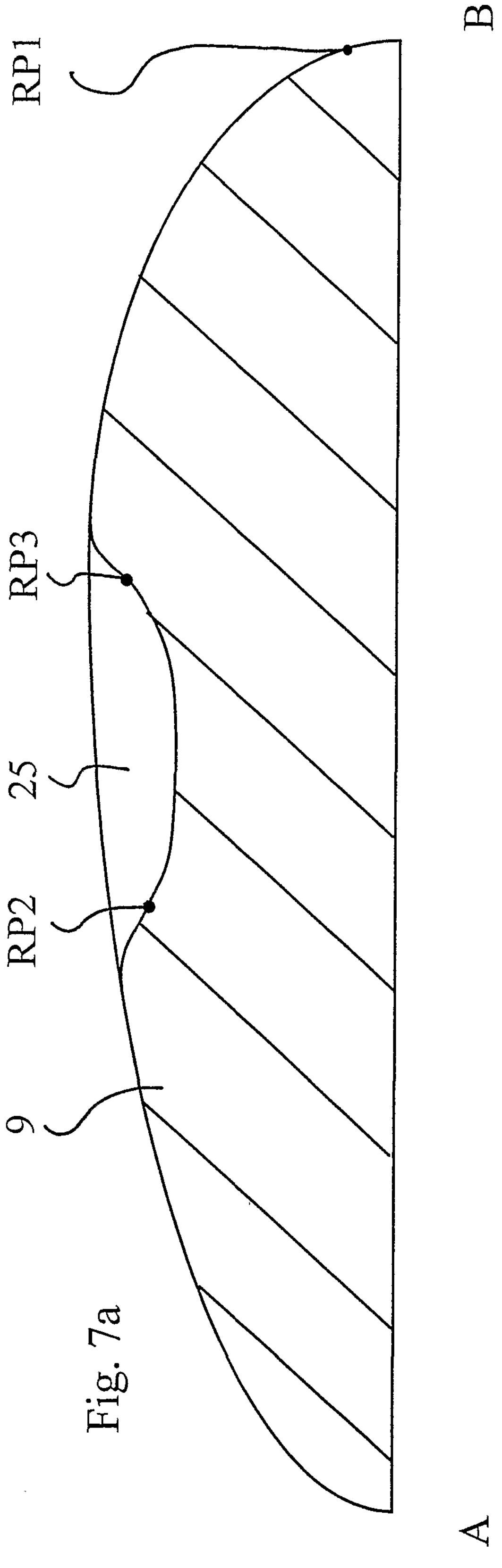

Fig. 7a

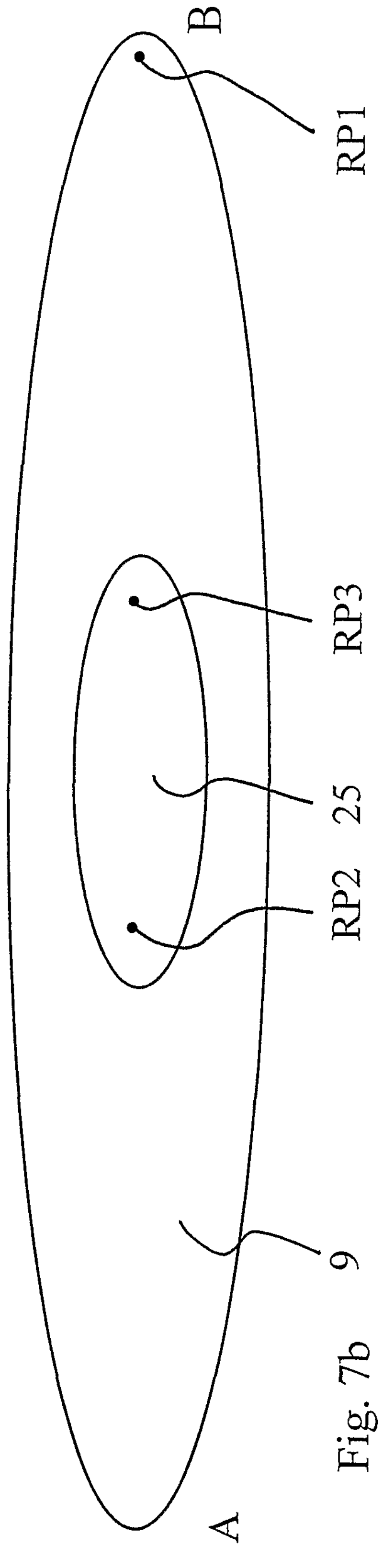

Fig. 7b

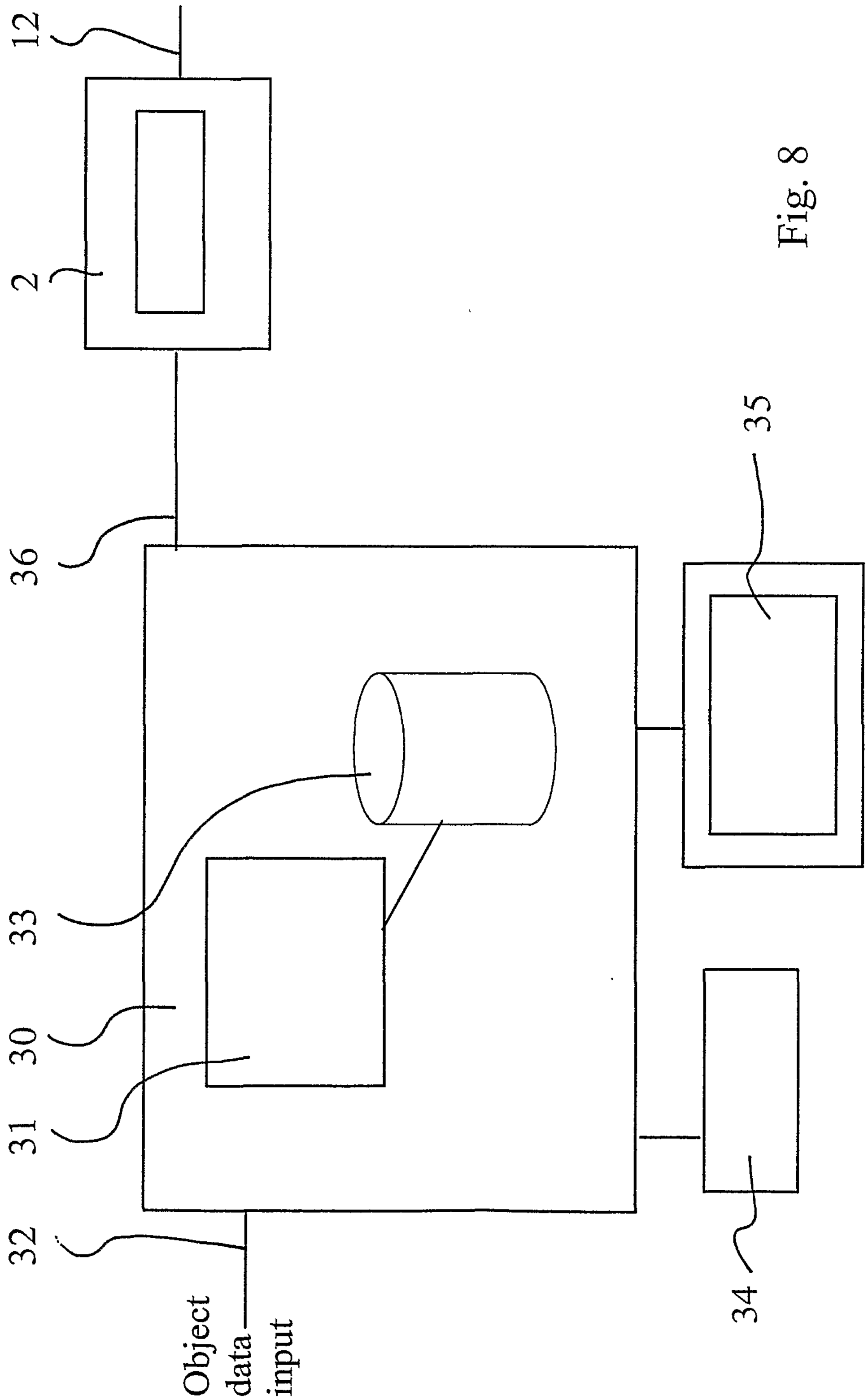

Fig. 8

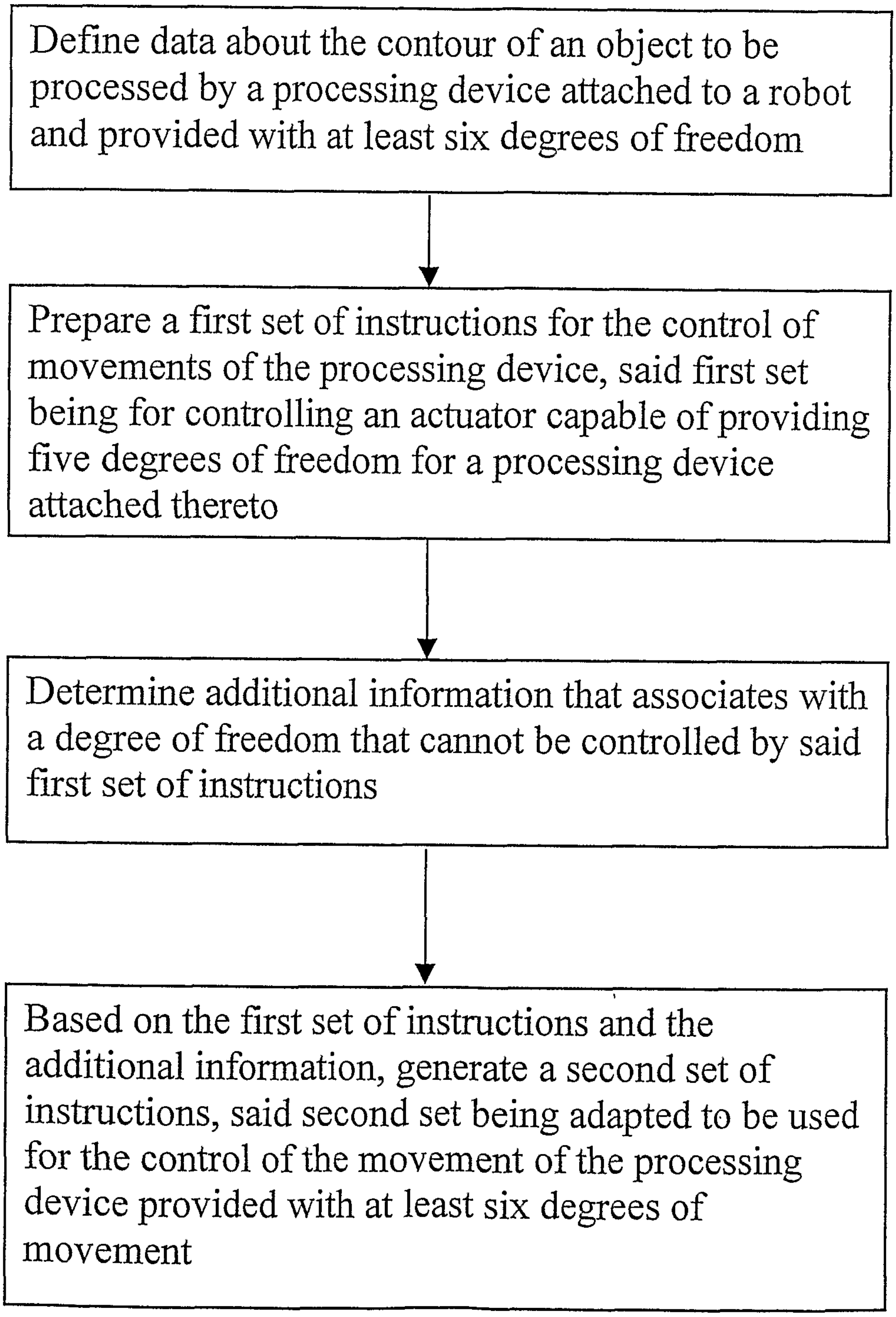
Define data about the contour of an object to be processed by a processing device attached to a robot and provided with at least six degrees of freedom
Prepare a first set of instructions for the control of movements of the processing device, said first set being for controlling an actuator capable of providing five degrees of freedom for a processing device attached thereto
Determine additional information that associates with a degree of freedom that cannot be controlled by said first set of instructions
Based on the first set of instructions and the additional information, generate a second set of instructions, said second set being adapted to be used for the control of the movement of the processing device provided with at least six degrees of movement

Fig. 9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/02865

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B25J9/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B25J

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

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

WPI Data, EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	"OPTIMAL MANIPULATOR POSITION AND ORIENTATION DETERMINATION SCHEME SUBJECT TO JOINT CONSTRAINTS" IBM TECHNICAL DISCLOSURE BULLETIN, IBM CORP. NEW YORK, US, vol. 31, no. 6, 1 November 1988 (1988-11-01), pages 217-218, XP000023774 ISSN: 0018-8689 the whole document	1,7-9, 16-21, 24-27, 30, 32-34, 36,38,42
Y		2-4,6, 12-15, 23,28, 29,37, 39,40

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 November 2001	15/11/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Nettesheim, J

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/02865

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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A	YONG K HWANG ET AL: "A GLOBAL MOTION PLANNER FOR CURVE-TRACING ROBOTS" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION SAN DIEGO, MAY 8 - 13, 1994, LOS ALAMITOS, IEEE COMP. SOC. PRESS, US, vol. 1 CONF. 11, 8 May 1994 (1994-05-08), pages 662-667, XP000478926 ISBN: 0-8186-5332-9 page 663, right-hand column, paragraph 1 -page 665, right-hand column, last paragraph	1-42
A	US 5 241 249 A (DETRICHE JEAN-MARIE) 31 August 1993 (1993-08-31) column 2, line 54 -column 5, line 34; figures 1-5	1-42
A	SHIBATA T ET AL: "MOTION PLANNING BY GENETIC ALGORITHM FOR A REDUNDANT MANIPULATOR USING AN EVALUATION FUNCTION BASED ON CRITERIA OF SKILLED OPERATORS" PROCEEDINGS OF THE 1995 IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION. NAGOYA,JAPAN, MAY 21 - 27. 1995, PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION, NEW YORK, IEEE, US, vol. 3, 21 May 1995 (1995-05-21), pages 2476-2481, XP000731606 ISBN: 0-7803-1966-4 the whole document	1-42

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 01/02865

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