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(54) Benævnelse: **Indretning og fremgangsmåde til computerassisteret generering af en manipulatorbane**

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Device and method for the computer-assisted generation of a manipulator track

Description

[0001] The present invention relates to a device and a method for computer-assisted generation of a manipulator path and, in particular, for computer-assisted generation of a manipulator process.

[0002] A manipulator process generally comprises a path of one or more manipulators, in particular robots and combinations of robots and additional axes such as, for example, linear axes, rotary or rotary/tilt tables, as well as a sequence of actions of one or more tools, in particular of manipulator tools such as a gripper, welding tongs or the like. For example, a manipulator process for automatically assembling a seal to a motor vehicle door can comprise, amongst other things, the delivery of the door to an assembly cell by a first tool in the form of a conveyor belt or of a first industrial robot, positioning on an external axis of a rotary table, application of an adhesive along an edge of the door by a second industrial robot with a second tool in the form of an adhesive gun, as well as insertion of the door by a third robot whose gripper represents a third tool. The second industrial robot moves for this purpose along a manipulator path in such a way that the adhesive gun that it guides travels along the edges of the door on a tool path and applies adhesive to certain sections, i.e. activates or deactivates the adhesive gun in a predetermined sequence of actions along the tool path.

[0003] A predetermined sequence of one or a plurality of positions is here generally referred to as a path, wherein a position defines the location and/or orientation. A tool path therefore comprises one or a plurality of locations and/or orientations of the tool, for example the location and orientation of a gripper, an outlet opening of an adhesive gun, or the like. In a corresponding manner, a manipulator path comprises one or a plurality of poses of the manipulator, described for example in coordinate or joint space by its joint positions, or in Cartesian working space, described for example by the location and orientation of its TCP ("Tool Centre Point"), which emerge uniquely from the joint positions and, in the case of redundant manipulators or of singular poses, can be represented, taking additional boundary conditions into account if appropriate, through reverse transformation of the kinematics or by resolving the reverse kinematics to the joint positions.

[0004] One or a plurality of process values of the tool can be changed in at least one position of a tool path, in order to initiate actions or to execute sequences of actions. For example, changes can be made to the quantity of adhesive discharged by an adhesive gun through variation of the pressure, the magnitude of the current and/or the volume of welding wire being supplied to welding tongs, the opening angle or times of the gripper tongs of a gripper and so forth as process values.

[0005] The process values of a manipulator-controlled tool along a path of a manipulator, together with this path of the manipulator, thus describe a manipulator process, in which a manipulator brings a tool into at least one position where at least one process value of the tool is changed. If a plurality of manipulator tools works together in, for example, a fabrication or assembly cell, the combination of the different manipulator paths and process value sequences can also constitute a manipulator process.

[0006] Until now such manipulator processes were input step-by-step into a manipulator control through a process known as teaching, usually performed in situ, for example in the assembly cell, in that an operator manually brings the manipulator to approach poses on the desired manipulator path, and these are then connected by a path generator in the manipulator control to form a manipulator path. Problems such as singular poses or those that cannot be reached, collisions and the like are only detected late in this process, which requires time-consuming reteaching. An optimization of the manipulator process by means of a mathematical process is scarcely possible, nor is a transfer to other manipulators.

[0007] In addition to this teaching, what is known as off-line programming is also known. Here, a control instruction is generated from a sequence of individual control commands that are entered by the operator at a computer or at the manipulator control; its execution by the manipulator control guides the manipulator along the desired path. However, due to the complex control commands, which vary for different manipulator controls, this method requires a highly qualified operator, and is not very intuitive, which stands in the way of widespread application in practice. Modifying the manipulator process by changing the abstract control commands is complex.

[0008] What both these approaches have in common is an early focus on the manipulator path when planning a manipulator process, so that the manipulator being used in particular must be specified at the beginning of the manipulator process planning, and therefore the manipulator path must be generated again when the manipulator being used is changed. In addition, the programming of manipulator paths by teaching or by off-line programming is usually not very self-explanatory, which hinders the wider use of manipulators in, for example, workshops in which the user is primarily interested in solving the process task, for example the application of adhesive along the edge of a workpiece.

[0009] US 2006/0025890 A1 describes a device for off-line generation of a program for a process that is to be carried out by robots. CAD data is used here to describe the shape of the workpiece. The position and orientation of the workpiece are determined by means of a visual sensor.

[0010] US 2004/0213915 A1 describes a method for segmenting the surface of the workpiece into virtual partial surfaces from which the path planning for a painting tool is derived.

[0011] US 5,645,884 describes a method for coating a workpiece. A trajectory is generated here on the basis of a digitized model of the workpiece, and process magnitudes are also defined.

[0012] WO 00/25185 A1 describes a method for generating a process plan for a robot. A process template is here selected on the basis of workpiece information, and the process defined by specifying the parameters of this template.

[0013] The object of the present invention is therefore to improve the generation of a manipulator path.

[0014] This object is achieved by a method with the features of Claim 1. Claim 10 protects a device, Claims 11 and 12 respectively protect a computer program and a computer program product for carrying out a method according to Claim 1. The subsidiary claims relate to advantageous developments.

[0015] The present invention is based on the idea that the generation of a manipulator path is oriented to the process task to be achieved, such as the handling and/or processing of a workpiece, and to use that as the basis for generating the manipulator path. Whereas in the past an attempt was made to complete a process task with a previously specified manipulator, according to the invention the process task now stands in the foreground, from which it is possible successively to generate a manipulator path optimized for this, and in a preferred development the complete manipulator process, which, in addition to one or a plurality of manipulator paths, also comprises process value sequences of one or a plurality of tools relative to the manipulator path or paths.

[0016] This procedure is on the one hand more intuitive, since, in particular, an operator who is not skilled in dealing with manipulators is interested primarily in the solution of the process task, thus for example wants to process a workpiece in a specific manner, and according to the invention is supported in the generation of a manipulator path that is optimum for this purpose. On the other hand, the solution according to the invention leads to a more efficient generation of manipulator paths, since, working deductively from the desired effect, which is the solution of the process task, the causes required for this, in particular a manipulator path, are determined step-by-step. A computer-assisted method permits the partially automated implementation of this principle.

[0017] A method according to the invention for computer-assisted generation of a manipulator process creates a saveable, virtual manipulator path or, preferably, a saveable, virtual manipulator process, preferably in the form of an object-oriented process data model, and for this purpose comprises firstly the positioning of one or a plurality of virtual workpieces relative to a reference system by means of a positioning device.

[0018] The reference system can, for example, be a world coordinate system, a coordinate system of an assembly cell, a manipulator or the like. Positions, i.e. locations and/or orientations of points, lines, surfaces, coordinate systems and the like can be entered into this coordinate system. Preferably, a user of a computer-assisted method can select a suitable reference system from a catalogue. Various stored reference systems can, for example, represent different cells with their boundary conditions such as existing working and safety spaces, obstacles and the like. If, in a particularly preferred embodiment, the computer-assisted generation is performed in an object-oriented manner, the reference system can be an object with corresponding properties.

[0019] One or a plurality of virtual workpieces is positioned by means of the positioning device relative to this reference system. A variety of properties, such as geometrical dimensions, material data such as weight, elasticity, moment of inertia and the like, can be assigned to a virtual workpiece. The virtual workpiece can also, preferably, be selected from a library. Preferably, virtual components with their properties are generated from numerical data, such as manufacturing dimensions, CAD data, FEM data or the like, and imported into such a library or directly into the virtual manipulator process. In an object-oriented process data model they can be linked to the reference system in order to define their position relative to it. Virtual workpieces can equally well be at rest here relative to the reference system if they represent something like an assembly table in an assembly cell, or can move relative to the reference system, if they represent something like a workpiece on a transport belt. If a plurality of virtual components is present, their position can preferably be defined relative to the reference system or to another virtual workpiece whose position relative to the reference system is defined directly or indirectly, i.e. by way of further virtual workpieces.

[0020] Particularly preferably, the positioning of the virtual components, as well as further method steps, is performed by means of a two or three-dimensional editor (2D, 3D editor) that displays a two or three-dimensional view of the reference system, in that an operator can place or edit objects by means of an input device such as a keyboard, a two-dimensional mouse, a trackball, a three-or multi-dimensional mouse (known as a "spacemouse"), a joystick, a virtual reality input device such as a VR glove or the like. The selection and positioning of a virtual workpiece can then preferably be performed by means of a drag-and-drop functionality.

[0021] To process a virtual workpiece, the operator selects one or a plurality of virtual tools which, according to the invention, is provided and loaded by a tool loading device. These too can preferably be selected from a library of saved, virtual tools that is made available to the operator by, for example, the manufacturer of the real tools, or which can be generated by the operator by means of a suitable editor. A reference point of a manipulator, what is known as the TCP, can also represent a virtual tool in order, for example, to generate pure transfer movements of a manipulator.

[0022] Specific properties can be assigned to a virtual tool, which can form an object in an object-oriented process data model. Thus, in addition to physical properties such as, for example, the mass and/or inertia, process values in particular, for example the activation or deactivation of welding tongs or an adhesive gun, the opening or closing of a gripper, the application of a torque to a drilling or milling head or the like can be assigned to a virtual tool.

[0023] Additionally or alternatively, specific geometrical data, for example tool dimensions such as the external dimensions of an adhesive gun or welding tongs, or the changeable location of gripper tongs, can be assigned to a virtual tool.

[0024] Additionally or alternatively, specific tool path conditions can also be assigned to a virtual tool. For example, an adhesive gun is usually moved along an edge or in a movement pattern over a two or three-dimensional surface in order to apply adhesive there. A drill is usually advanced along a straight line. Thus, for example, the tool path condition that a path runs along an edge or over a surface can be assigned to a virtual adhesive gun, whereas the tool path condition that a tool path passes through a start and end point of a hole or an application point on a workpiece, along a hole direction as far as a hole depth, can be assigned to a virtual drill.

[0025] Degrees of freedom and/or constraints of a tool can in particular be taken into account through such tool path conditions. A degree of freedom of a tool here in general describes a permissible position or change in position, for example a shift or rotation, while a constraint bars a position or change in position, or only permits it depending on one or a plurality of degrees of freedom. Degrees of freedom and constraints can, for example, be defined relative to the virtual workpiece that is to be processed by the virtual tool, or relative to Cartesian space.

[0026] For example, in the case of certain adhesives and types of application, an adhesive gun must always be located above the gluing location in order to prevent the adhesive gun being soiled by drips of glue, and when moving along an adhesive path must be tilted more sharply in the direction of travel as the adhesive gun moves faster relative to the component. The first can be implemented through a constraint on a Cartesian basis that bars an orientation of the adhesive gun with its outlet opening upwards; while the latter can be implemented by a workpiece-based constraint that specifies an angle of inclination of the adhesive gun depending on its speed of travel. Conversely, a degree of freedom can be assigned to a drill around its axis of rotation, since the rotation of the tool about this axis does not have any significant effect on the process. Preferably such degrees of freedom and constraints or other tool path conditions can be taken into account automatically in the generation of the tool path by the tool path generation device.

[0027] On the basis of the virtual tool and of the virtual workpiece that is to be processed with it, a virtual tool path is now generated by the tool path generation device. In a preferred embodiment, contour features of the virtual workpiece that is to be processed, such as corner points, edges, surfaces, curve extremes or the like are registered for this purpose. Preferably the contour features that are to be registered depend on the tool path conditions assigned to the selected virtual tool. If, for example, an adhesive gun, to which the tool path condition that a tool path passes along the edge or over a surface is assigned, is selected as the virtual tool, edges or surfaces of the virtual workpiece are registered as contour features. If, on the other hand, a vacuum gripper to which the tool path condition that the gripper can adhere to sufficiently large, flat surfaces is selected as the virtual tool, surfaces that can be used effectively by this gripper can, for example, be registered as contour features. In the preferred embodiment of a 3D editor, a snap-functionality can be provided for this purpose which, when activated by means of an input device by the operator, registers those contours, i.e. points, edges, surfaces or the like that are located at any one time closest to a visual display of the virtual tool.

[0028] Additionally or alternatively, tool positions can be input, independently of a workpiece contour, to generate the virtual tool path. To cool a tool it can, for example, be advantageous to move it to a position remote from the workpiece between two contacts with a workpiece. Such tool positions can, for example, be input into a 3D editor by clicking a position of the virtual tool displayed three-dimensionally relative to the reference system. In this way, similarly to conventional teaching, a TCP position can, for example, be approached, which improves the intuitive operability and simplifies the modification of automatically generated tool paths.

[0029] The virtual tool path is generated, preferably by means of a path generator, on the basis of tool positions for the virtual tool which may be input in particular as described above through registering contour features and/or inputting tool positions independently of a workpiece contour. Preferably a path generator that is also the basis of a manipulator control is used for this purpose. A path generator can, for example, interpolate between individual tool positions, in a manner known per se, linearly, circularly, through splines or blending. One advantage of the use of a path generator that is implemented in a manipulator control is that, in addition to its availability, in particular the real manipulator can implement a tool path generated in this way very precisely.

[0030] The tool path generated in such a manner is preferably stored as an object of the object-oriented process data model that represents the virtual manipulator process.

[0031] If a virtual tool path is generated, the operator, or a manipulator selection device, selects a virtual manipulator kinematic which, according to the invention, is provided and loaded by a kinematic loading device. A manipulator kinematic here describes the kinematic of a manipulator; it can, for example, comprise the forwards and/or reverse transformation, in particular the mathematical description of the kinematic chain that maps the axis values of a manipulator onto a position, i.e. a location and/or orientation of a reference coordinate system, in particular of the TCP or of a tool (forward transformation or forward kinematic), or, conversely, provides the axis positions required to approach a predetermined tool position (reverse transformation or reverse kinematic). Accessibilities, i.e. a maximum possible working region of the manipulator, constrained positions, in particular singular poses and the like, can also be obtained from the manipulator kinematic. A manipulator selection device can here select a suitable virtual manipulator kinematic automatically, for example on the basis of predetermined boundary conditions and quality criteria, such as the availability, the costs, the suitability or the like.

[0032] Since the manipulator kinematic emerges from the dimensions and joint positions, a virtual manipulator kinematic can be assigned to any real manipulator. In this way a virtual manipulator kinematic can be selected from a library of possible manipulator kinematics which, for example, is made available by a robot manufacturer, and linked to the virtual tool. This can be done by the user or by the program. For example a reference coordinate system, in particular a TCP of the virtual manipulator kinematic, can be positioned for this purpose in a predetermined and preferably constant relative position with respect to the virtual tool, by means of which a synchronization between the tool and the manipulator is realized - a virtual manipulator, "grasps", so to speak, the virtual tool.

[0033] A base position can be determined in the reference system for the virtual manipulator kinematic, where said position defines, relative to the reference system, for example the position, i.e. the location and/or orientation of a fixed coordinate system of a manipulator basis, what is known as the kinematic root. For this purpose the user can position a base coordinate system of the virtual manipulator kinematic in the reference system by means of the 3D editor, so for example virtually placing the manipulator in an assembly cell. From this then emerge its poses, the axis settings that position the reference coordinate system of the virtual manipulator kinematic in the predetermined relative position to the virtual tool, for example bringing together the TCP of the virtual manipulator with a TCP of the virtual tool. The determination of the base position can, however, also be performed automatically, in that, for example, the virtual manipulator kinematic with mean values for the various joints or axes is linked with a tool position of the virtual tool path, such as the start, end or middle point. It is as if, so to speak, a virtual manipulator, whose joints are all in their middle setting, is suspended with its TCP at the virtual tool which is located in the centre of the tool path - in this way a virtual manipulator can first be positioned in the reference system in such a way that it has a high probability of being able to implement the entire tool path. Mixed forms are also possible in order, for example, to place a redundant manipulator optimally.

[0034] It is possible as early as this stage to detect unsuitable manipulator kinematics or base positions, with which, for example, the planned tool path cannot be realized or in which the manipulator kinematic adopts an unfavourable pose, such as a singular pose or one that collides with the workpiece or the cell.

[0035] If the base position of the virtual manipulator kinematic and its connection to the virtual tool is established, a virtual manipulator path can be found on the basis of the virtual tool path and of the virtual manipulator kinematic in particular through resolving the reverse kinematic, which maps the tool positions of the virtual tool path to poses of the virtual manipulator kinematic. Inasmuch as the virtual manipulator kinematic is redundant with respect to the virtual tool path, which is to say that it has more degrees of freedom than are required for the movement of the tool along the virtual tool path, appropriate supplementary conditions can be used to generate an optimal, unique virtual tool path, in that, for example, a distance from singular poses is maximized, deviations from joint middle positions are minimized, or the like.

[0036] The manipulator path generated automatically by a manipulator path generation device in such a manner is preferably also stored as an object of the object-oriented process data model that represents the virtual manipulator process.

[0037] According to a preferred embodiment of the present invention, process values can be edited after the virtual tool path has been generated, i.e. equally either before or after generation of the manipulator path. As described above, process values describe the actions of the tool, i.e. for example the activation or deactivation of welding tongs or an adhesive gun, the opening or closing of a gripper, the application of a torque to a drilling or milling head or the like. If, for example, the path of an adhesive gun is generated, the user can specify the discharge of adhesive along this path, for example increasing the adhesive volume in certain sections of the path, or travelling sections of the path without the application of adhesive. A two and/or three-dimensional process value editor is preferably provided for this purpose. For this purpose a two-dimensional process value editor displays, for example, one or more process values, such as the volume of adhesive applied, the torque of a drill or the like, as the ordinate against time or against the tool path coordinate as abscissa. In this view, the user can specify the sequence of actions of the tools in the manipulator process in a simple and intuitive manner by editing the progression, for example setting new process values or shifting existing process values using a mouse or other input device. A three-dimensional process value editor for example displays one or more process values, for example the volume of adhesive applied, by means of points along the virtual tool path at which a process value changes, by means of a coloured display of the path depending on the process value, and/or by means of a roller-coaster display of a process value over the virtual tool path or the like.

[0038] An editing of process values here refers just as much to the initialization or creation as it does to the change of specification of specific quantitative values of defined process values. Thus for example, in the case of welding tongs, an operator can define whether the quantity of welding wire supplied is represented as a process value, and then specify this process value along the manipulator path or tool path, for example specifying specific quantitative values section-by-section.

[0039] In a preferred embodiment of the present invention, the virtual tool path, the virtual manipulator path, or the complete virtual manipulator process can be simulated, in particular displayed graphically or as an animation. The virtual tool path, including the change of the process values, can here advantageously be simulated independently of the selected manipulator kinematic, after the virtual tool path has been generated.

[0040] If, in order to generate the virtual tool path, a path generator that is also the basis of a manipulator control is used, the virtual manipulator path yielded by this advantageously corresponds very closely to the path that a real manipulator will travel in a realization of the manipulator process.

[0041] A further advantage lies in the faster reaction to changes of the virtual tool or manipulator path: whereas in previous methods, the complete manipulator program is first generated, depending on the manipulator type, by a programming environment, supplied to the manipulator control which must process it, and only then, on the basis of the results obtained from this, can the manipulator path or tool path be visually displayed by the programming environment, a virtual tool or manipulator path that has been generated by a path generator on which a manipulator control is based can be sampled significantly faster. The reason for this is that it is not necessary to generate and process the whole of the program code; rather, a path can be generated and displayed by the integrated path generator, so that it is possible to react quickly to input from the user that changes the tool path or the manipulator path, for example the input of additional tool positions, and the changed virtual tool path or manipulator path that results can be displayed visually. This again increases the intuitive operability.

[0042] The simulation makes it possible to check the manipulator process generated according to the invention. As a result, the occurrence in particular of kinematic conditions such as, for example, kinematic constrained positions, non-achievable poses or the like can be recognized at an early stage of the planning process. Additionally or alternatively, a visual or automatic collision check can be made. In addition to such purely kinematic conditions, it is possible additionally or alternatively for dynamic conditions also to be checked, such as whether supported load limits are observed in all positions, whether drive or braking powers are sufficient to realize the manipulator path, and the like. Preferably a warning is issued if kinematic or dynamic conditions are not satisfied. For this purpose it is possible for example for a corresponding area of the virtual tool path or manipulator path, in which the virtual manipulator is at or close to a kinematic constrained position, a collision, exceeding a supportable load or the like, to be coloured or marked in some other manner in the 3D editor.

[0043] A simulation of the entire manipulator process or of the manipulator path or tool path advantageously also offers the possibility of optimizing it or them by means of mathematical methods, such as determining an optimum speed profile along the virtual tool path, determining optimum tool positions or manipulator poses for processing the workpiece, or the like.

[0044] With the method according to the invention explained above, a virtual manipulator process can be planned with computer assistance and, if appropriate, checked or optimized. In a particularly preferred embodiment of the present invention, such a manipulator process can also be realized simply and efficiently with one or more real manipulators.

[0045] In a preferred embodiment, a control instruction for a manipulator is generated for this purpose on the basis of the virtual manipulator process. A plurality of mutually independent real manipulators, such as industrial robots, and manipulator controls, control cabinets for example, is frequently available. For that reason it is possible in particular for different virtual manipulator controls to be provided which are made available to the operator, for example in a library, from which they can be loaded. The reality of the different manipulators and manipulator controls is, so to speak, simulated through the provision of different virtual manipulator kinematics and controllers. On the basis of the virtual manipulator control selected by the operator and of the virtual manipulator paths to be implemented, or of the virtual manipulator process to be implemented, a control instruction is then generated automatically, i.e. a sequence of commands is generated that implements the virtual manipulator process, in particular the virtual manipulator paths and the sequence of actions of the tool. Like the platform-dependent transformation of a computer program from a higher programming language into machine-readable code for different platforms, it is possible for a control instruction for different manipulator controls to be generated from the virtual manipulator process in an easy manner. The control instruction is then transferred to a real manipulator control.

[0046] It is particularly advantageous for a consistent sequence to be maintained in the control instruction in the real manipulator control and the virtual manipulator process. It can thus, for example, happen that a local operator changes the control instruction of the manipulator, for example manually re-teaching a robot path in an assembly cell. On the other hand, after the transfer of the control instruction to the manipulator control, changes to the planned manipulator process such as additional working tasks or a change to the process value progression can occur.

[0047] For that reason, in a preferred embodiment of the present invention, an alignment of the control instruction of the manipulator and of the virtual manipulator process is carried out when the control instruction or the virtual manipulator process is changed, in that when, for example, there is a change in the virtual manipulator process, the control instruction is generated again on the basis of the new virtual manipulator process, and transferred to the real manipulator control. Conversely a change of the control instruction in the real manipulator control can be uniquely represented in the virtual manipulator process.

[0048] The implementation of manipulator tasks is markedly simplified in that the virtual manipulator process, preferably in the form of an object-oriented process data model, is stored and kept consistent with the control instruction in the real manipulator control. Thus for example an operator with a portable computer, on which a computer program for carrying out the method according to the invention is implemented and in which the virtual manipulator process is stored, can directly, in situ and in an easy manner, carry out a re-planning of the manipulator process or can transfer it to other manipulators. The ability to edit stored virtual manipulator processes that are preferably kept consistent with real control instructions and thereby further improved in practice, also allows the development of a process library which makes the generation of new, similar manipulator processes easier on the basis of manipulator processes that have already been stored. The saving as an object-oriented process data model makes the checking and modification of the manipulator process that is generated faster and more reliable.

[0049] Through the computer-assisted generation of a virtual manipulator process, this can advantageously be implemented with different real manipulators and manipulator controls. In an improved embodiment of the present invention, therefore, the manipulator control to which the control instruction is transferred is selected from a plurality of available manipulator controls. If, for example, a plurality of free robots with the same kinematic and their own manipulator controls is available in a real assembly cell, the control instruction is transferred to the manipulator control of a robot selectable from this group. The selection and/or transfer preferably takes place over a network.

[0050] It is advantageous, due to the difference between reality and a virtual model, to first appropriately calibrate the real manipulator in order to implement a virtual manipulator process with a real manipulator. For this purpose, the operator brings the tool of the manipulator to one or more calibration positions, such as corner points of a workpiece, assembly table or the like. The control instruction is then calibrated in the manipulator control on the basis of these calibration positions, for example adding a constant offset in individual joints or the like, so that the real manipulator travels the correct manipulator path relative to the workpiece, assembly table or the like.

[0051] In a preferred embodiment of the present invention, one or more virtual calibration positions are already defined for this purpose when the virtual manipulator process is generated. Contour features of a virtual workpiece can be registered for this purpose. In addition, information on the calibration positions is stored, for example generating and storing tables of the axis angle or two-dimensional or three-dimensional images of the calibration positions, for example displaying a plan view of the points to be approached for the calibration or of surfaces from a perspective that may be selectable or have a fixed specification, for example from the point of view along a final manipulator member, from the point of view of a manipulator basis or from the point of view of a selected position in the reference system.

[0052] The calibration positions are then transferred to the manipulator control. This information, for example images on a display of the manipulator control, is then shown to the operator during the calibration of the manipulator. In this way the operator knows intuitively which positions he must approach for calibration, and only has to approach the positions displayed in the images, preferably marked through a coordinate system or the like, with the manipulator in order to calibrate them.

[0053] A device according to the invention for carrying out a method according to the present invention comprises a positioning device, a tool loading device, a tool path generation device, a kinematic loading device and a manipulator path generation device, along with, preferably, a contour feature registration device, a tool position input device, a path generator, a path simulation and/or checking device, a process value editing device, a control instruction generation device, a storage device and/or further devices for implementing method steps described above. These devices can, for example, be implemented together in a computer with an input device, for example a keyboard, mouse, joystick or similar, and an output device, a screen for example, or may also be distributed over various computers.

[0054] Additional advantages and features emerge from the subsidiary claims and the exemplary embodiments. In this respect, partially in schematic form;

Fig. 1: shows a 3D editor according to an embodiment of the present inven-

tion;

Fig. 2: shows a 2D process value editor according to an embodiment of the present invention and the 3D editor according to Fig. 1;

Fig. 3: shows an industrial robot and a device according to an embodiment of the present invention; and

Fig. 4: shows the procedure of the method according to an embodiment of the present invention.

[0055] Figs. 1, 2 respectively show views of the display of a 3D editor 10 and a 2D process value editor 20, with which a method according to an embodiment of the present invention, as is illustrated schematically in Fig. 4, is executed on a computer 60 that is illustrated in Fig. 3, and forms a device for computer-assisted generation of the manipulator process, which is adapted to carry out the method according to Fig. 4, and which in particular comprises a positioning device, a tool loading device, a tool path generation device, a kinematic loading device and a manipulator path generation device (not illustrated).

[0056] For the computer-assisted generation of a manipulator process according to a method according to an embodiment of the present invention, as is illustrated schematically in Fig. 4, a reference system 1 is first selected in a step S10 from a library 6 (cf. Fig. 1), for example an assembly cell or a world coordinate system. This is displayed in the 3D editor 10 (cf. Fig. 1), and stored as an object of an object-oriented process model. In a preferred embodiment, a world coordinate system is here always specified as the reference system 1.

[0057] In a step S20, virtual workpieces 2 are then positioned relative to the selected reference system 1. For this purpose, an assembly table 2.1 is, for example, selected from the library 6, and by means of a positioning device, such as a mouse of the computer 60 in combination with suitable software, is positioned in the reference system 1. A further workpiece in the form of a workpiece 2.2 that is to be machined and which, for ease of identification, has a fish-like contour, is positioned in the reference system 1 on the assembly table 2.1. Objects are introduced for this purpose into the object-oriented process model, and are appropriately linked kinematically to the reference system object. The virtual workpiece 2.2 is here generated from CAD data of the workpiece that is to be machined, and is also made available in the library 6 from which it can then be loaded.

[0058] A virtual tool in the form of an adhesive gun 3 is now selected in a step S30, in that an appropriate object is loaded from the library 6 of the 3D editor 10 into the object-oriented process model.

[0059] A virtual tool path 4 is then generated in a step S40. After the search region has been specified, suitable contour features such as edges, points, surfaces and/or polygons are then registered in the 3D editor 10 on the virtual workpiece 2.2 as initial values for a virtual tool path 4 by the computer 60. These can now be modified in that tool positions on this path are removed, or additional tool positions are added, and/or the orientations of the tool positions are adapted so that the virtual tool path 4 illustrated in Fig. 2 results. After any supporting points on the virtual tool path 4 that may be necessary have been input, these are linked by means of a path interpolater, as is also implemented in a robot controller, and the virtual tool path 4 is thus generated. Path conditions, such as a constraint that blocks orientations of the adhesive gun 3 with its outlet opening upwards, are taken into account here. At this point, the tool path can already be simulated, in particular can be displayed graphically.

[0060] A virtual manipulator kinematic 5 is selected in a step S50. For this purpose, virtual manipulator kinematics of various real manipulators that may be used, including the industrial robot 50 (Fig. 3), are stored in the library 6. The user virtually "places" the robot 50, which virtually "grasps" the adhesive gun 3, in the assembly cell in that he selects this virtual manipulator kinematic, specifies a position for its base coordinate system in the reference system 1 and links the TCP of the virtual manipulator kinematic 5 to a reference coordinate system of the virtual tool 3. The virtual manipulator kinematic that has been selected from those made available is loaded for this purpose into the program, and linked with the object-oriented process model.

[0061] On the basis of the virtual tool path 4 that has been generated, the manipulator path generation device generates, in a step S60, a virtual manipulator path, in that joint angle progressions for the individual axis of the virtual manipulator kinematic 5 are determined from the reverse transformation of the virtual manipulator kinematic.

[0062] Process values 7 for the virtual tool 3 are now edited in a step S70 by means of the 2D process value editor 20. Values for adhesive pressure 7.1 and adhesive volume 7.2 are input in the exemplary embodiment for this purpose along the tool path coordinate (abscissa).

[0063] In a step S80, the entire virtual manipulator process, that is the path 4 of the virtual adhesive gun 3, the path of the virtual manipulator 5, and the sequence of actions of the tool, i.e. the progression of the process values 7, are now simulated. In particular, kinematic conditions such as singular poses, constrained positions, accessibilities, collisions and dynamic conditions, in particular carrying capacities and motor load limits, are checked here, and the paths or process value sequences are corrected if necessary. A mathematical optimization of the virtual manipulator process is additionally performed in respect of appropriate quality criteria, such as the process time.

[0064] In step S80, a control instruction for a manipulator is generated on the basis of the virtual manipulator process, in that the stored manipulator path is translated into appropriate control commands for a real manipulator control. A corresponding virtual manipulator control can be selected for this purpose from the library 6, so that advantageously the same manipulator process can be implemented on a large number of different manipulators or manipulator controls, each of which use different programming languages or control commands. This control instruction is then transferred to a manipulator control of a real robot 50 in a step S90.

[0065] While the manipulator process is being executed by this robot 50, an alignment of the control instruction of the manipulator and of the virtual manipulator process is carried out when there are changes to the control instruction in the manipulator control, for example made by an in situ operator who matches the process better to real boundary conditions, or changes to the virtual manipulator process, for example to supplement further process tasks such as the application of an additional adhesive seam. The computer 60 on which the virtual manipulator process is stored as an object-oriented, and correspondingly easily modified, process data model and the manipulator control of the real robot 50 exchange data in a step S100 or S90 for this purpose when there is a change to the virtual manipulator process or to the control instructions.

[0066] If a plurality of manipulators or manipulator controls is available in an assembly cell, each of which is suitable for implementation of the virtual manipulator process, an available manipulator or an available manipulator control is selected from this plurality in a step S90 prior to transmitting the control instruction.

[0067] The robot 50 should be calibrated before it is commissioned, so that it performs the planned manipulator process as exactly as possible. For this purpose, virtual calibration positions, for example noticeable corner points of the fish-shaped workpiece 2.2, of the manipulator are generated in the 3D editor 10. Images of the calibration positions are here generated, for example in a three-dimensional view as is shown in Fig. 1 or 2, each illustrating a selected calibration position, i.e. the position of the tool 3 that touches the noticeable corner point of the fish-shaped component 2.2. These calibration positions and images are transferred to the manipulator control of the robot 50.

[0068] During the calibration of the robot 50 by an in situ operator, these images are then displayed, so that help is provided to the operator as to which position he must approach next with the robot 50 when calibrating. This significantly shortens the calibration time.

<u>List of reference signs</u>

[0069]

1	Reference system
2	Virtual workpiece
3	Virtual tool
4	Virtual tool path
5	Virtual manipulator kinematic
6	Catalogue
7	Process values
10	3D editor
20	2D process value editor
50	Industrial robot
60	Computer

Patentkrav

1. Fremgangsmåde til computerassisteret generering af en manipulatorbane, omfattende trinene:
- tilvejebringelse og indlæsning (S30) af et virtuelt værktøj (3),
- generering (S40) af en virtuel værktøjsbane (4) baseret på et virtuelt arbejdsemne (2) og den indlæste virtuelle værktøj (3),
- tilvejebringelse og indlæsning (S50) af en virtuel manipulatorkinematik (5),
- tilvejebringelse og indlæsning (S50) af en virtuel manipulatorstyring,
- generering (S60) af en virtuel manipulatorbane baseret på den virtuelle værktøjsbane og den virtuelle manipulatorkinematik,
- redigering (S70) af procesværdier (7) af en virtuel manipulatorproces efter at den virtuelle manipulatorbane er blevet genereret,
- generering (S80) af en styreinstruks til en manipulator baseret på den virtuelle manipulatorstyring og på den virtuelle manipulatorproces,
- overførsel (S90) af styreinstruksen til en manipulatorstyring, og
- afstemning (S90, S100) af styreinstruksen i manipulatorstyringen og den virtuelle manipulatorproces ved ændringer af styreinstruksen i manipulatorstyringen eller ved ændring af den virtuelle manipulatorproces, hvori den virtuelle manipulatorstyring tilvejebringes i et bibliotek (6) og indlæses fra dette bibliotek.

2. Fremgangsmåde ifølge krav 1, **kendetegnet ved, at**
- til generering af den virtuelle værktøjsbane bestemmes det virtuelle arbejdsemnes konturkendetegn,
- til generering af den virtuelle værktøjsbane bestemmes det virtuelle værktøjs positioner, som er indgivet af en bruger,
- til generering af den virtuelle værktøjsbane tages der højde for det virtuelle værktøjs frihedsgrader og/eller restriktioner, og/eller
- den virtuelle værktøjsbane og/eller den virtuelle manipulatorbane genereres ved hjælp af en banegenerator.

3. Fremgangsmåde ifølge ethvert af de foregående krav, **kendetegnet ved** trinet:
- simulering af den virtuelle værktøjsbane og/eller den virtuelle manipulatorbane (S80).

4. Fremgangsmåde ifølge ethvert af de foregående krav, **kendetegnet ved** trinet:

- kontrol (S80) af den virtuelle værktøjsbane og/eller den virtuelle manipulatorbane.

5. Fremgangsmåde ifølge krav 4, **kendetegnet ved, at** kontrollen af den virtuelle manipulatorbane omfatter:
- kontrol af kinematiske betingelser,
- kontrol af kollision, og/eller
- kontrol a dynamiske betingelser.

6. Fremgangsmåde ifølge ethvert af de foregående krav, **kendetegnet ved, at**
- manipulatorstyringen, til hvilken styreinstruksen overføres, kan vælges som en tilgængelig manipulatorstyring fra en flerhed af manipulatorstyringer.

7. Fremgangsmåde ifølge ethvert af de foregående krav, **kendetegnet ved** trinene:
- generering af manipulatorens virtuelle kalibreringspositioner,
- generering af information, især billeder af kalibreringspositionerne,
- overførsel af kalibreringspositionerne til manipulatorstyringen, og
- visning af informationen under en kalibrering af manipulatoren.

8. Fremgangsmåde ifølge ethvert af de foregående krav, **kendetegnet ved, at** det virtuelle arbejdsemne, det virtuelle værktøj og/eller den virtuelle manipulatorkinematik tilvejebringes i et bibliotek (6) og indlæses fra biblioteket.

9. Fremgangsmåde ifølge ethvert af de foregående krav, **kendetegnet ved** trinet:
- lagring af den virtuelle værktøjsbane, den virtuelle manipulatorbane og/eller den virtuelle manipulatorproces.

10. Indretning til computerassisteret generering af en manipulatorproces, omfattende:
- en positioneringsindretning til positionering (S20) af et virtuelt arbejdsemne (2) i forhold til et referencesystem,
- en værktøjsindlæsningsindretning til indlæsning (S30) af et udvalgt virtuelt værktøj (3),
- en værktøjsbaneindlæsningsindretning til indlæsning (S40) af en virtuel værktøjsbane (40),

- en kinematisk indlæsningsindretning til indlæsning (S50) af en udvalgt virtuel manipulatorkinematik (5), og
- en manipulatorbanegenereringsindretning til generering (S60) af en virtuel manipulatorbane baseret på den virtuelle manipulatorbane og den virtuelle manipulatorkinematik, hvori indretningen er indrettet til at udføre en fremgangsmåde ifølge et af de foregående krav.

11. Computerprogram, som udfører en fremgangsmåde ifølge et af krav 1 til 9, når det afvikles på en indretning ifølge krav 10.

12. Computerprogramprodukt med programkode, som er lagret på en maskinlæsbar bærer og som udfører et computerprogram ifølge krav 11.

Fig. 1

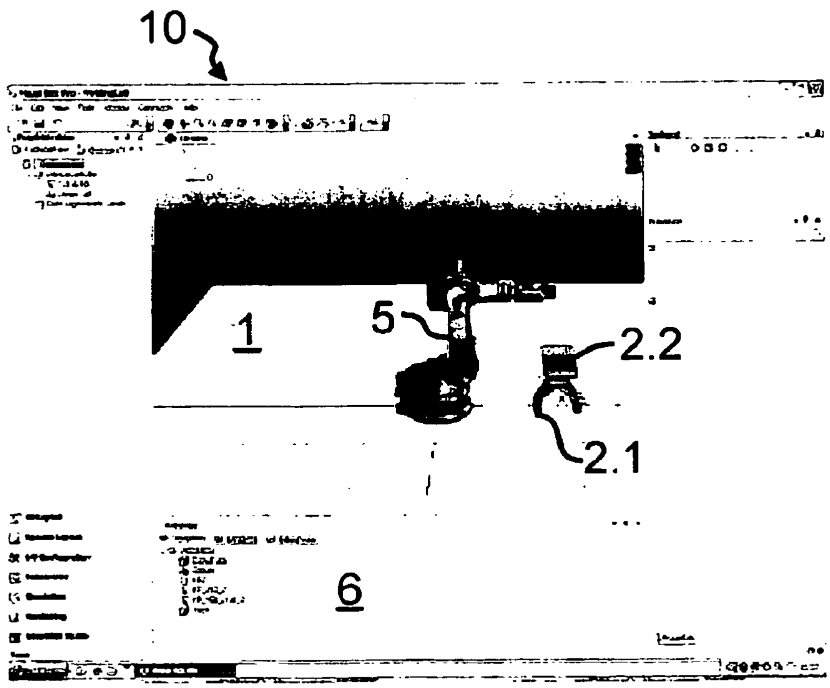

Fig. 2

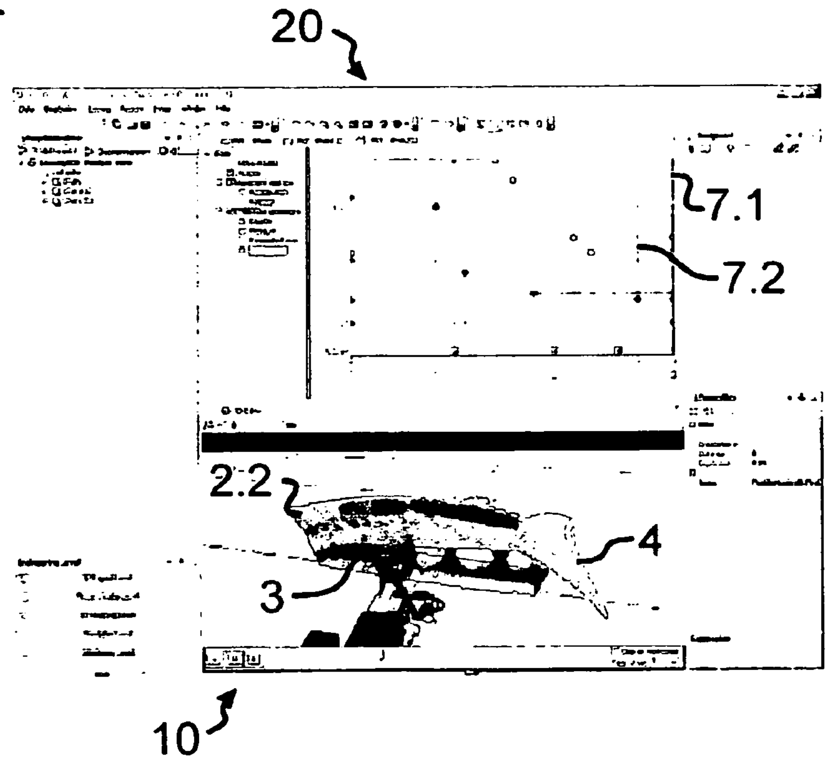

Fig. 3

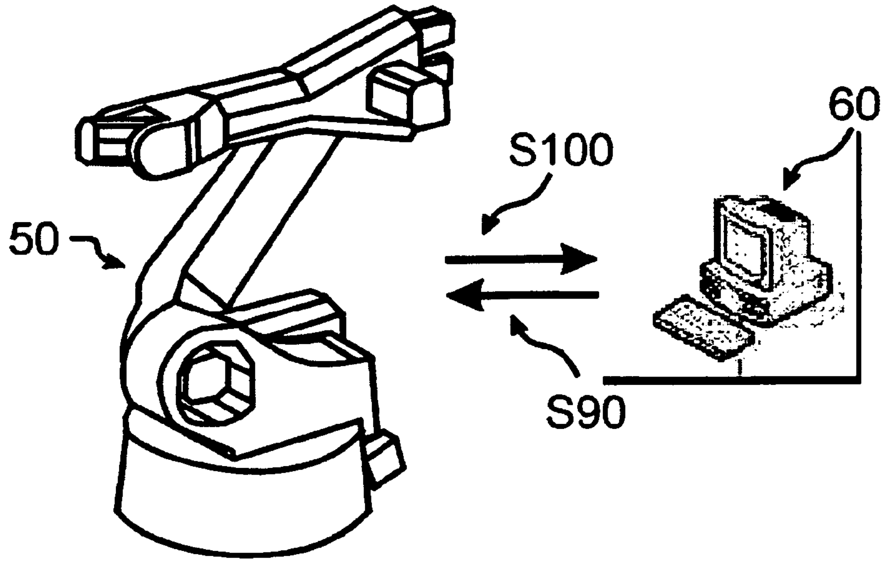

Fig. 4