

METHOD FOR JOINING AN OBJECT INTO AN OBJECT-RECEIVING AREA USING A ROBOT MANIPULATOR

5 The invention relates to a method for joining an object into an object-receiving area using a robot manipulator. The invention further relates to a robot manipulator.

10 The task of the invention is to provide an easy and robust method for joining an object into an object-receiving area using a robot manipulator. An additional task is to provide a robot manipulator designed and adapted to join an object into an object-receiving area by means of a robot manipulator.

The invention follows from the features of the independent claims. Advantageous further developments and embodiments are the subject of the dependent claims. Additional features, application options, and advantages of the invention follow from the following description
15 and from the explanations of exemplary embodiments of the invention shown in the Figure.

A first aspect of the invention pertains to a method for joining an object into an object-receiving area by means of an actuator-driven robot manipulator of a robot and for controlling the robot manipulator of a robot, wherein the robot manipulator has an effector at its distal
20 end, designed to receive and/or grip the object, and wherein a joining trajectory T is defined for the object-receiving area and the object to be joined, and a target orientation $T_{soil}(\vec{R}_T)$ of the object to be joined is defined along the joining trajectory T for locations $\vec{R}_T$ of the joining trajectory T .

25 The proposed method comprises the following steps. In a first step, the effector is used to receive/grip the object. The effector features a mechanical interface that is required for these purposes, and it is advantageously formed as a gripper, as an artificial hand, a tool, etc.

In a second step, the object is moved using the robot manipulator along the joining trajectory
30 T into the object-receiving area while rotating and/or tilting the object relative to the target orientation in a force-regulated and/or impedance-regulated manner $O_{soil}(\vec{R}_T)$ until a specific threshold condition G1 for a torque acting on the effector and/or a force acting on the effector is reached or exceeded, and/or until a provided force/torque signature and/or a position/speed

signature on the effector is reached or exceeded, which indicate(s) that the object has been completely successfully joined into the object-receiving area within specified tolerances.

5 The robot manipulator is advantageously designed and adapted to move an assigned point of the effector (for instance, the so-called “tool center point”, or TCP) or an assigned point of the object (for instance, its center of gravity or its geometric center) along a specified trajectory.

10 The joining trajectory T is advantageously defined depending on the relative point of departure of the object arranged on the effector towards the object-receiving area, on the geometry of the object, and on the geometry of the object-receiving area.

The joining trajectory T is typically a three-dimensional curve with one or multiple arches. Naturally, a joining trajectory T in the form of a straight line is possible as well.

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In a third step, the effector is used to release the object. Alternatively, the effect may simply release the object. Advantageously, the release involves force-regulated and/or impedance-regulated rotating and/or tilting motions.

20 In a fourth step, the effector is moved away from the object-receiving area by the robot manipulator, along an exit trajectory A .

25 The success rate of the joining process is significantly increased by the force-regulated and/or impedance-regulated rotating and/or tilting motions according to the invention of joining the object into the object-receiving area of the effector.

30 An advantageous further development of the proposed method is characterized in that in addition to the rotating and/or tilting motions, the effector also makes translational lateral movements with the subject of the second and third steps of the method along the joining trajectory T / exit trajectory A . Through this measure, the aforementioned success rate of the joining process or of the end form process is further increased.

In an advantageous variation of the method, the joining trajectory T and the exit trajectory A are identical. In the typical general case, the joining trajectory T and the exit trajectory A are advantageously selected to be different, which allows for the shortening of clock times by means of a time-optimized exit trajectory A .

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An advantageous further development of the proposed method is characterized in that the rotating and/or tilting motions in the second and/or third step rotate or tilt the subject around one, two, or three rotational or tilting axes relative to the target orientation $O_{soil}(\vec{R}_T)$, such that the rotation or tilting of the object around the respective rotational or tilting axis is by an angle in the range of up to $\pm 1^\circ, \pm 2^\circ, \pm 5^\circ, \pm 7^\circ, \pm 10^\circ, \pm 12^\circ, \pm 15^\circ$ to the target orientation $O_{soil}(\vec{R}_T)$.

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The joining of the object into the object-receiving area is advantageously accomplished by means of snapping, clicking, screwing, pressing, locking, sticking, soldering, or shrinking it into place.

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The object-receiving area has at least one opening that is accessible from the outside. Furthermore, this opening is dimensioned such that the object can be joined through the opening into the object-receiving area. The method is therefore suitable in principle for joining objects into an object-receiving area that meet the aforementioned conditions and that can be manipulated by a robot manipulator or its effects .

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A further development of the method is characterized in that if during the receiving/ gripping of the object by the effector an errors should occur, the receiving/gripping of the object by the effector is repeated with different parameters for receiving/gripping the object. Such an error during the receiving/gripping of the object may be detected, for instance, by an effector and/or by force and/ position sensors, optical sensors, ultrasound sensors, etc. that are arranged on the robot manipulator.

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The modified parameters for receiving/gripping the object may be determined either in a trajectories plan for the robot manipulator or in a control and regulation unit of the robot or of the robot manipulator. An adjustment of a target trajectory for receiving/gripping the object

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may be made based on forces or moments sensed at the effector. Alternatively or in addition, relaxing an impedance regulator used for controlling the robot manipulator for the receiving/gripping of the object may reduce undesirable high process forces.

- 5 An advantageous further development of the method is characterized in that to the extent that an error should occur during the movement of the object using the robot manipulator along the joining trajectory T into the object-receiving area, the movement of the object using the robot manipulator into the object-receiving area along a modified joining trajectory T^* and/or with modified parameters for the force-regulated and/or impedance-regulated rotation/tilting
- 10 of the object relative to the target orientation $O_{sol}(\vec{R}_T)$ is repeated. Such an error occurring while moving the object may be detected, for instance, by an effector and/or by force and/position sensors, optical sensors, ultrasound sensors, etc. that are arranged on the robot manipulator. The modified parameters for the force-regulated and/or impedance-regulated rotation/tilting of the object relative to the target orientation $O_{sol}(\vec{R}_T)$ may be determined
- 15 either in a trajectories plan for the robot manipulator or in a control and regulation unit of the robot or of the robot manipulator.

- An advantageous further development of the method is characterized in that to the extent that errors, or errors other than the errors described above, should occur while the process takes
- 20 place, a warning is issued and/or the process is aborted.

- An advantageous further development of the method is characterized in that the rotating and/or tilting motions correspond to closed cyclical movements, in particular or non-closed Lissajous figures in two to six dimensions or Fourier series or rectangular movements or
- 25 Gaussian transformations, etc.

- An advantageous further development of the method is characterized in that the translational movements of the object around the joining trajectory T correspond to closed or nob-closed cyclical movements, in particular Lissajous figures in two to six dimensions or Fourier series
- 30 or rectangular movements or Gaussian transformations, etc.

An additional aspect of the invention pertains to a computer system with a data processing device, in which the data processing device is designed such that a method such as described above is executed on the data processing device.

- 5 An additional aspect of the invention pertains to a digital storage medium with electronically readable control signals, in which the control signals can interact with a programmable computer system such that a method such as described above is executed.

- 10 An additional aspect of the invention pertains to a computer program product with program code, stored on a machine-readable medium, for the execution of the aforementioned method when the program code is executed on a data processing device.

An additional aspect of the invention pertains to a computer program with program codes for executing the aforementioned method when the program runs on a data processing device.

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An additional aspect of the invention relates to a robot with a actuator-driven robot manipulator, wherein the robot manipulator has an effector at its distal end, designed to receive and/or grip the object, and wherein a joining trajectory T is defined for an object-receiving area and an object to be joined into the object-receiving area, and target orientations $O_{sol}(\vec{R}_T)$ of the object to be joined is defined along the joining trajectory T for locations $\vec{R}_T$ of the joining trajectory T , featuring a control unit, designed and adapted such that a method aforementioned can be executed.

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- Additional advantages, features and details follow from the following description, in which – possibly with reference to the drawing – at least one exemplary embodiment is described in detail. Identical, similar and/or analog parts were given the same reference numbers.

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In the drawings:

- 30 **Fig. 1** shows a flow chart of a proposed method.

Fig. 1 shows a flow chart of a proposed method for joining an object into an object-receiving area by means of an actuator-driven robot manipulator of a robot and for controlling the robot

manipulator, wherein the robot manipulator has an effector at its distal end, designed to receive and/or grip the object, and wherein a joining trajectory T is defined for the object-receiving area and the object to be joined, and a target orientation $O_{sol}(\vec{R}_T)$ of the object to be joined is defined along the joining trajectory T for locations $\vec{R}_T$ of the joining trajectory T

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The method comprises the following steps. In a first step **101**, the effector is used to receive/grip the object.

- 10 In a second step **102**, the object is moved using the robot manipulator along the joining trajectory $\vec{T}$ into the object-receiving area while rotating and/or tilting the object relative to the target orientation $O_{sol}(\vec{R}_T)$ in a force-regulated and/or impedance-regulated manner until a specific threshold condition G1 for a torque acting on the effector and/or a force acting on the effector is reached or exceeded, and/or until a provided force/torque signature and/or a
- 15 position/speed signature on the effector is reached or exceeded, which indicate(s) that the object has been completely successfully joined into the object-receiving area within specified tolerances.

- After the successful completion of step **102**, a release of the object by the effector by way of force-regulated and/or impedance-regulated rotating and/or tilting motions follows in step
- 20 **103**.

Step **104** involves the moving away of the effector by the robot manipulator along a specified exit trajectory A .

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Reference list

101- 104 Steps of the method

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CLAIMS

1. A method for inserting an object into an object-receiving area by means of an actuator-driven robot manipulator of a robot and for the controlling the actuator-driven robot manipulator, wherein the actuator-driven robot manipulator has an effector at its distal end, designed to receive and/or grip the object, and wherein a joining trajectory T is defined for the object-receiving area and the object to be joined, and a target orientation $O_{sol}(\vec{R}_T)$ of the object to be inserted is defined along the joining trajectory T for locations $\vec{R}_T$ of the joining trajectory T , the method comprising the following steps:
- 1.1 receiving/gripping (101) the object using the effector;
- 1.2 moving (202) the object using the actuator-driven robot manipulator along the joining trajectory $\vec{T}$ into the object-receiving area while continuously performing predetermined rotating and tilting movements of the object relative to the target orientation $O_{sol}(\vec{R}_T)$ in a force-regulated and/or impedance-regulated manner, until
- a specific threshold condition G1 for a torque acting on the effector and/or a force acting on the effector is reached or exceeded, and/or
 - a provided force/torque signature and/or a position/speed signature on the effector is reached or exceeded, which indicate(s) that the object has been completely successfully joined into the object-receiving area within specified tolerances;
- 1.3 release (103) of the object by the effector;
- 1.4 moving (104) effector away from the object-receiving area using the actuator-driven robot manipulator along a specified exit trajectory A .
2. Method according to Claim 1,
- in which the release (103) takes place by means of continuously performed force-regulated and/or impedance-regulated rotating and/or tilting motions.
3. Method according to Claim 1 or 2,

in which the effector also makes translational lateral movements with the object in step 1.2 and/or step 1.3 around the joining trajectory T / exit trajectory A .

4. Method according to one of the Claims 1 through 3,
5 in which the rotating and tilting motions in step 1.2 and/or in step 1.3 rotate or tilt the object around one, two, or three rotational or tilting axes relative to the target orientation $O_{sol}(\vec{R}_T)$, such that the rotation or tilting of the object around the respective rotational or tilting axis is by an angle in the range of up to $\pm 1^\circ, \pm 2^\circ, \pm 5^\circ, \pm 7^\circ, \pm 10^\circ, \pm 12^\circ, \pm 15^\circ$ to the target orientation $O_{sol}(\vec{R}_T)$.
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5. Method according to one of the Claims 1 through 4,
in which, if during the receiving/gripping of the object by the effector an error should occur, the receiving/gripping of the object by the effector is repeated with different parameters for receiving/gripping the object.
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6. Method according to one of the Claims 1 through 5,
in which, to the extent that an error should occur when the object is moved by the actuator-driven robot manipulator along the joining trajectory T in the joining direction into the object-receiving area, the movement of the object using the actuator-driven robot manipulator into the object-receiving area along a modified joining trajectory T^* and/or with modified parameters for the force-regulated and/or impedance-regulated rotation/tilting of the object relative to the target orientation $O_{sol}(\vec{R}_T)$ is repeated.
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- 25 7. A computer system with a data processing device, in which the data processing device is designed such that a method according to one of the previous Claims 1 through 6 is executed on the data processing device.
8. A digital storage medium with electronically readable control signals, in which the control signals can interact with a programmable computer system in such a manner that a method according to one of the previous Claims 1 through 6 is executed.
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9. A computer program product with a program code stored on a machine-readable medium for executing the method according to one of the previous Claims 1 through 6, when the program code is executed on a data processing device.
- 5 10. A computer program with program codes for the execution of the method according to one of the previous Claims 1 through 6, when the program runs on a data processing device.
- 10 11. A robot with an actuator-driven robot manipulator, wherein the actuator-driven robot manipulator has an effector at its distal end, designed to receive and/or grip the object, and wherein a joining trajectory T is defined for an object-receiving area and an object to be joined into the object-receiving area, and target orientations $O_{sol}(\vec{R}_T)$ of the object to be joined is defined along the joining trajectory T for locations $\vec{R}_T$ of the joining trajectory T , featuring a control unit, designed and adapted such that a method according to one of the Claims 1 through 5 can be executed.
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