

Coordination of Paths of Two Robot Manipulators

The invention relates to a method for teaching and executing mutually coordinated paths
5 of a first robot manipulator and a second robot manipulator and a system for teaching and
executing mutually coordinated paths of a first robot manipulator and a second robot
manipulator.

In particular, when a first robot manipulator and a second robot manipulator are supposed
10 to perform a task cooperatively together, the question of the coordination of the first robot
manipulator relative to the second robot manipulator arises. For example, if a load is to
be lifted and transported by the first robot manipulator and the second robot manipulator
together, it is crucial that the first and the second robot manipulator work together in a
coordinated manner. Also in other tasks that are to be carried out in a coordinated manner
15 by a first and a second robot manipulator, their corresponding movement paths have to be
precisely coordinated.

The object of the invention is to specify a movement path for a first robot manipulator
and a second movement path of a second robot manipulator coordinated to the first
20 movement path by means of a teaching process (also known as “teach-in”).

The invention results from the features of the independent claims. Advantageous
refinements and embodiments are the subject matter of the dependent claims.

25 A first aspect of the invention relates to a method for teaching, in mutually coordinated
paths, a first robot manipulator and a second robot manipulator, comprising the steps:

- manually guiding a first reference point of the first robot manipulator over a desired first path,
- acquiring the first path or acquiring a first set of poses for the first path and storing the
30 first path or the first set of poses in a first data set,
- automatically traveling along the first path,
- during the automatic travel along the first path: manual guiding of a second reference
point of the second robot manipulator over a desired second path,
- acquiring the second path or acquiring a second set of poses for the second path and

storing the second path or the second set of poses in a second data set, wherein the second data set is assigned to the first data set so that each location of the second path is at least approximately assigned to a location of the first path, and

- synchronized traveling along the first path by the first robot manipulator according to the first data set and traveling along the second path by the second robot manipulator according to the second data set.

Manual guiding is preferably understood to mean a process in which the user places his hand in particular on one of the links of a respective robot manipulator and accelerates it in a desired direction by applying a force to it.

The first robot manipulator and the second robot manipulator are in particular two independent robot manipulators, i.e., each of the robot manipulators could also perform tasks independently and is controlled by its own control unit. Alternatively, the first robot manipulator and the second robot manipulator are preferably arranged on a common platform and are controlled by a common control unit. The invention relates to both alternatives.

The term “set of poses” is advantageously understood to mean a time series of poses of the respective robot manipulator. Accordingly, a pose of the respective robot manipulator is acquired and stored in particular in each individual time step of a plurality of time steps. A pose is stored in particular by means of a vector of joint angles, so that a stored pose can be uniquely reproduced at any point in time. While in the first alternative a path of the respective reference point is explicitly acquired, for example by an optical detection system, when a set of poses is acquired, in particular a complete set of joint angles of the respective robot manipulator is thus acquired. If the set of poses is traveled along in accordance with the respective data set, the respective path of the respective reference point thus results automatically.

When assigning the second data set to the first data set, so that a location on the first path is at least approximately assigned to each location on the second path, it is not necessary for any location on the second path to be assigned to a location on the first path with complete mathematical correctness, but only approximately, so that the locations are also assignable to one another, for example, by means of interpolation of support points or

other approximation methods.

In contrast to a trajectory, a respective path of a respective robot manipulator merely describes the geometric pathway of the respective reference point without containing an item of time information of a respective location on the pathway. In contrast, a trajectory contains the geometric pathway of the path, wherein each location is also assigned an item of time information as to the point in time at which the location is to be traversed.

The first path and also the second path are preferably acquired by position sensors, in particular on the joints of the respective robot manipulator.

For the manual guidance of a respective reference point, the guiding user can guide any links of the robot manipulator. It is not necessary for the user to start directly at the reference point of the respective robot manipulator.

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The automatic traveling along the first path and the synchronized travel along the first path and the second path each take place in particular by a corresponding control of actuators, using which the respective robot manipulator is movable.

20 In the case of the synchronized traveling, in particular the first data set and the second data set are coordinated with one another in such a way that at a respective point in time, a location of the first path and a location of the second path have their respective relative position specified by the teaching process.

25 It is an advantageous effect of the invention that a first path of a first robot manipulator and a second path of a second robot manipulator are determinable in relation to one another very easily by a user. In particular, because the user only has to manually guide a single robot manipulator at a time, and in particular can observe the first robot manipulator while it is automatically traveling along the first path, a very precise teaching process is possible, in particular of the second path of the second robot manipulator relative to the first path of the first robot manipulator.

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According to an advantageous embodiment, the first data set stores the first path and the second data set stores the second path in each case by means of a discrete number of path

points, wherein a length of the second data set is matched to the length of the first data set in order to assign the second data set to the first data set, so that the first data set and the second data set have an equal number of discrete path points.

- 5 Only when the first data set and the second data set have the equal number of discrete path points can the path points be assigned to one another directly. This is particularly advantageous in the case of discretely running control programs, according to which in particular the joint angles are regulated in discretized time steps. The matching of the respective lengths of the respective data set, which corresponds to the matching of the
- 10 number of the respective discrete path points per data set, is preferably carried out by omitting a certain number of discrete stand points in the initially longer data set, or also by interpolation and generation of originally non-existent discrete path points in the initially shorter data set.
- 15 According to a further advantageous embodiment, the first data set stores the first path and the second data set stores the second path in a vectorized manner in each case.

In this context, vectorized means that the first path and the second path are in the form of an analytical expression, preferably by a polynomial function, Bézier curve, or another

20 algebraic function that can be parameterized within its order. In this way, the first path and/or the second path are each advantageously stored in a very memory-efficient manner.

According to a further advantageous embodiment, the first reference point is and/or the second reference point is a specified point on a respective end effector of the respective

25 robot manipulator. The respective end effector of the respective robot manipulator is arranged in particular on the respective distal link of the respective robot manipulator.

According to a further advantageous embodiment, the first robot manipulator is controlled in a gravity-compensated manner while the first robot manipulator is being manually

30 guided and/or the second robot manipulator is controlled in a gravity-compensated manner while the second robot manipulator is being manually guided.

In the case of gravity-compensated control, in particular the actuators of a respective robot manipulator are controlled in such a way that gravity does not result in any acceleration

of the respective robot manipulator. Apart from this control of the actuators, the respective robot manipulator can preferably be moved as required by manual guidance. This advantageously facilitates the manual guidance of the respective robot manipulator by a user.

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According to a further advantageous embodiment, the first robot manipulator and/or the second robot manipulator each has links connected to one another by joints with degrees of freedom at least partially redundant to one another, so that at least a subset of the links of the first robot manipulator and/or of the second robot manipulator are each movable in
10 a null space, wherein the first data set and/or the second data set has, in addition to the respective path of the respective reference point, items of information about a respective pose of the respective robot manipulator in its null space.

The pose of a respective robot manipulator generally describes both an orientation and a
15 position of the entirety of the links of a respective robot manipulator or an end effector of a respective robot manipulator. Since a subset of the joints has degrees of freedom that are redundant to one another, some of the links of the respective robot manipulator in particular are movable in space without the position and/or the orientation of the end effector at the distal end of the respective robot manipulator or the position of the
20 reference point changing at the same time. The movement of the links at the joints with redundant degrees of freedom is therefore also called movement in the null space. If this movement is understood as algebraic linear mapping, then the movement in the null space is also called the core of the mapping. The movement of these links via joints with redundant degrees of freedom takes place in particular without changing the position of
25 the respective reference point at the same time.

Another aspect of the invention relates to a system for teaching mutually coordinated paths of a first robot manipulator and a second robot manipulator, having a first robot manipulator with a first control unit and a second robot manipulator with a second control
30 unit, wherein the first robot manipulator has a first path acquisition unit and wherein the second robot manipulator has a second path acquisition unit, wherein the first path acquisition unit is designed to acquire a desired first path of a first reference point of the first robot manipulator or a first set of poses for the first path during manual guidance of the first robot manipulator and store it in a first data set, wherein the first control unit is

designed to control the first robot manipulator to travel along the first path according to the first data set, and wherein the second path acquisition unit is designed to acquire a desired second path of a second reference point of the second robot manipulator or a second set of poses for the second path during manual guidance of the second robot
5 manipulator while the first robot manipulator travels along the first path and store it in a second data set, wherein the second data set is assigned to the first data set in such a way that a location of the first path is at least approximately assigned to each location of the second path.

10 According to one advantageous embodiment, the first control unit and/or the second control unit are each designed to control the first robot manipulator to travel along the first path according to the first data set and, synchronized thereto, to control the second robot manipulator to travel along the second path according to the second data set.

15 Advantages and preferred refinements of the proposed system result from an analogous and corresponding transfer of the statements made above in conjunction with the proposed method.

Further advantages, features, and details will be apparent from the following description,
20 in which – possibly with reference to the drawing – at least one exemplary embodiment is described in detail. Identical, similar, and/or functionally identical parts are provided with the same reference numerals.

In the drawings:

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Fig. 1 shows a method for teaching and executing mutually coordinated paths of a first robot manipulator and a second manipulator robot according to one exemplary embodiment of the invention, and

30 Fig. 2 shows a system for teaching mutually coordinated paths of a first robot manipulator and a second manipulator robot according to a further exemplary embodiment of the invention.

The illustrations in the figures are schematic and not to scale.

Fig. 1 shows a method for teaching and executing mutually coordinated paths 11, 22 of a first robot manipulator 10 and a second robot manipulator 20, comprising the steps:

- manually S1 guiding a first reference point of the first robot manipulator 10 over a
5 desired first path 11,
- acquiring S2 the first path 11 and storing the first path 11 in a first data set,
- automatically traveling S3 along the first path 11,
- during the automatic travel along the first path 11: manual guiding S4 of a second
reference point of the second robot manipulator 20 over a desired second path 22,
- 10 - acquiring S5 the second path 22 and storing the second path 22 in a second data set,
wherein the second data set is assigned to the first data set such that a location of the first
path 11 is at least approximately assigned to each location of the second path 22, and
- synchronized traveling S6 along the first path 11 by the first robot manipulator 10
according to the first data set and traveling along the second path 22 by the second robot
15 manipulator 20 according to the second data set.

Fig. 2 shows a system 100 for teaching mutually coordinated paths 11, 22 of a first robot manipulator 10 and a second robot manipulator 20, having a first robot manipulator 10 with a first control unit 14 and a second robot manipulator 20 with a second control unit
20 24,

- wherein the first robot manipulator 10 has a first path acquisition unit 15 and wherein the second robot manipulator 20 has a second path acquisition unit 25, wherein the first path acquisition unit 15 is designed to acquire a desired first path 11 of a first reference point of the first robot manipulator 10 during manual guidance of the first robot manipulator 10
25 and store it in a first data set, wherein the first control unit 14 is designed to control the first robot manipulator 10 to travel along the first path 11 according to the first data set, and wherein the second path acquisition unit 25 is designed to acquire a desired second path 22 of a second reference point of the second robot manipulator 20 during manual guidance of the second robot manipulator 20 while the first robot manipulator 10 travels
30 along the first path 11 and store it in a second data set, wherein the second data set is assigned to the first data set in such a way that a location of the first path 11 is at least approximately assigned to each location of the second path 22.

Although the invention has been further illustrated and described in detail by way of

preferred exemplary embodiments, the invention is not limited by the disclosed examples, and other variations can be derived therefrom by a person skilled in the art without departing from the scope of the invention. It is therefore clear that a multitude of possible variations exists. It is also clear that embodiments mentioned as examples really only
5 represent examples, which are not to be construed in any way as limiting the scope of protection, the possible applications, or the configuration of the invention. Rather, the preceding description and description of the figures enable a person skilled in the art to implement the exemplary embodiments, wherein a person skilled in the art aware of the disclosed inventive concept may make various changes, for example as to the function or
10 arrangement of individual elements cited in an exemplary embodiment, without departing from the scope as defined by the claims and their legal equivalents, such as more extensive explanations in the description.

List of reference numerals

	10	first robot manipulator
5	11	first path
	13	first end effector
	14	first control unit
	15	first path acquisition unit
	20	second robot manipulator
10	22	second path
	23	second end effector
	24	second control unit
	25	second path acquisition unit
	100	system
15	S1	manual guidance
	S2	acquisition
	S3	automatic travel along
	S4	manual guidance
	S5	acquisition
20	S6	synchronized travel along

Claims

1. A method for learning and executing mutually coordinated paths (11, 22) of a first
5 robot manipulator (10) and a second robot manipulator (20), comprising the steps:
 - manual guiding (S1) a first reference point of the first robot manipulator (10) over a desired first path (11),
 - acquiring (S2) the first path (11) or acquiring a first set of poses for the first path (11) and storing the first path (11) or the first set of poses in a first data set,
 - 10 - automatic traveling (S3) along the first path (11) according to the first data set,
 - during the automatic travel along the first path (11): manual guiding (S4) a second reference point of the second robot manipulator (20) over a desired second path (22),
 - acquiring (S5) the second path (22) or acquiring a second set of poses for the
 - 15 second path (22) and storing the second path (22) or the second set of poses in a second data set, wherein the second data set is assigned to the first data set so that a location of the first path (11) is at least approximately assigned to each location of the second path (22), and
 - synchronized traveling along the first path (11) by the first robot manipulator (10)
 - 20 according to the first data set and traveling along the second path (22) by the second robot manipulator (20) according to the second data set.
2. The method according to claim 1,
wherein the first data set stores the first path (11) and the second data set stores the
25 second path (22) in each case by means of a discrete number of path points, and
wherein a length of the second data set is matched to the length of the first data set in order to assign the second data set to the first data set, so that the first data set and the second data set have an equal number of discrete path points.
- 30 3. The method according to claim 1,
wherein the first data set stores the first path (11) and the second data set stores the second path (22) in vectorized fashion, respectively.
4. The method according to any one of the preceding claims,

where the first reference point and/or the second reference point is in each case a specified point on a respective end effector (13, 23) of the respective robot manipulator (10, 20).

- 5 5. The method according to any one of the preceding claims,
 wherein the first robot manipulator (10) is controlled in a gravity-compensated
 manner during the manual guidance of the first robot manipulator (10) and/or
 wherein the second robot manipulator (20) is controlled in a gravity-compensated
 manner during the manual guidance of the second robot manipulator (20).
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6. The method according to any one of the preceding claims,
 wherein the first robot manipulator (10) and/or the second robot manipulator (20)
 each has links connected to one another by joints with degrees of freedom at least
 partially redundant to one another, so that at least a subset of the links of the first
15 robot manipulator (10) and/or the second robot manipulator (20) are each movable
 in a null space, and wherein the first data set and/or the second data set has, in
 addition to the respective path (11, 22) of the respective reference point, items of
 information about a respective pose of the respective robot manipulator (10, 20) in
 its null space.
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7. A system (100) for teaching and executing mutually coordinated paths (11, 22) of a
 first robot manipulator (10) and a second robot manipulator (20), comprising a first
 robot manipulator (10) with a first control unit (14) and a second robot manipulator
 (20) with a second control unit (24), wherein the first robot manipulator (10) has a
25 first path acquisition unit (15) and wherein the second robot manipulator (20) has a
 second path acquisition unit (25), wherein the first path acquisition unit (15) is
 designed to acquire a desired first path (11) of a first reference point of the first
 robot manipulator (10) or a first set of poses for the first path (11) during manual
 guidance of the first robot manipulator (10) and to store it in a first data set, wherein
30 the first control unit (14) is designed to control the first robot manipulator (10) to
 travel along the first path (11) according to the first data set, and wherein the second
 path acquisition unit (25) is designed to acquire a desired second path (22) of a
 second reference point of the second robot manipulator (20) or a second set of poses
 for the second path (22) during manual guidance of the second robot manipulator

(20) during the travel along the first path (11) by the first robot manipulator (10) and to store it in a second data set, wherein the second data set is assigned to the first data set in such a way that a location of the first path (11) is at least approximately assigned to each location of the second path (22).

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8. The system (100) according to claim 7,
wherein the first control unit (14) and/or the second control unit (24) are each designed to control the first robot manipulator (10) to travel along the first path (11) according to the first data set and, synchronized thereto, to control the second robot
10 manipulator (20) to travel along the second path (22) according to the second data set.