CLAIMS

1. A method of calibrating robots, the method comprising the steps of:
(a) providing at least two robots (R_1 and R_2), each robot (R_1, R_2) having joints and/or links connecting two flanges: a base flange and a tool flange,
(b) forming a closed chain from the at least two robots (R_1, R_2), wherein the connecting flanges of the at least two robots (R_1, R_2) do not share a same rotational axis,
(c) manipulating at least one of the links or joints in the chain, thereby inducing manipulations of some of the other links or joints in the chain, and then
(d) estimating kinematic models (M_1, M_2) for each robot (R_1, R_2) based on sensor information associated with the joints of each of the at least two robots (R_1, R_2).

2. The method according to claim 1, where the sensor information is obtained from the same sensors, which are used to drive the robot joints and/or links.

~~3. The method according to claim 2, where the sensor information is only obtained from the same sensors, which are used to drive the robot joints and/or links.~~

4~~3~~. The method according to claim 1~~, 2~~ or 3~~2~~, wherein step (c) comprises the sub steps of
- changing the joint positions, and thereby the position (Q) of the joints of each of the at least two robots (R_1, R_2), and
- collecting the corresponding position pairs ($<R_1Q, R_2Q>_m$).

5~~4~~. The method according to claim 4~~3~~, wherein the sensor information is information about the position (Q) of the joints, and wherein step (d) comprises estimating the kinematic models (M_1, M_2) based on the collected position pairs ($<R_1Q, R_2Q>_m$).

6~~5~~. The method according to any of the preceding claims, wherein the sensor information comprises any of the following and/or changes in any of the following: angles, position coordinates, or their derivatives, and/or

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~~7. The method according to any of the preceding claims, wherein the sensor information comprises any of the following and/or changes in any of the following:~~ force, torque, or their derivatives.

~~8~~6. The method according to any of the preceding claims, wherein step (b) of forming a closed chain from the at least two robots (R_1, R_2) is performed by physically connecting said at least two robots (R_1, R_2) at least at their base flanges, and/or at their tool flanges.

~~9~~7. The method according to any of the preceding claims, wherein step (b) of forming the closed chain from the at least two robots (R_1, R_2) further comprises a step of fixing at least one distance between the at least two robots (R_1, R_2).

~~10~~8. The method according to any of the preceding claims, wherein step (b) of forming a closed chain from the at least two robots (R_1, R_2) further comprises a step of fixing at least one direction of the connection between the at least two robots (R_1, R_2).

~~11~~9. The method according to any of the preceding claims, wherein step (b) of forming a closed chain from the at least two robots (R_1, R_2) comprises the step of using measurement equipment to measure the relative positions between the at least two robots (R_1, R_2).

~~12. The method according to claim 11, wherein the measurement equipment is configured for measuring the distance between parts of the at least two robots (R_1, R_2).~~

~~13. The method according to claim 11 or 12, wherein the measurement equipment is configured for determining the direction between parts of the at least two robots (R_1, R_2)~~

~~14. The method according to claim 13, wherein the measurement equipment is at least one ball bar connecting the at least two robots (R_1, R_2).~~

~~10~~5. The method according to any of the preceding claims, wherein the step (d) of estimating the kinematic models (M_1, M_2) is furthermore based on an estimation or measurement of the offset between the at least two robots (R_1, R_2) at their base flange, and at their tool flange.

~~11~~6. The method according to any of the preceding claims, wherein the step (d) of estimating the kinematic models (M_1, M_2) is furthermore based on statistical information about at least one part of the chain.

127. The method according to claim 117, wherein the statistical information is used to estimate the models (M_1, M_2) based on sensor information which exceeds the number of equations, without statistical information, to be solved.

138. The method according to any of the preceding claims, further comprising the step of evaluating whether sufficient sensor information associated with the joints of each of the at least two robots (R_1, R_2) is obtained after step (c), but before step (d).

149. The method according to any of the claims 43-138, further comprising the step of evaluating whether sufficient position pair data ($<R_1Q, R_2Q>_m$) are obtained after step (d), but before step (e), and then

- repeat step (d) if not sufficient position pair data ($<R_1Q, R_2Q>_m$) are obtained in order to update the kinematic models (M_1, M_2), or
- perform step (e) if sufficient position pair data ($<R_1Q, R_2Q>_m$) are obtained in order to update the kinematic models (M_1, M_2).

2015. The method according to claim 138, wherein sufficient sensor information corresponds to a number of unknowns, which does not exceed the number of equations to be solved in order to estimate the kinematic models (M_1, M_2).

216. The method according to claim 2015, comprising the step of collecting an overhead percentage (OPI) of sensor information, in addition to what is necessary for solving the equations in order to estimate the kinematic models (M_1, M_2).

2217. The method according to claim 216, further comprising the steps of

- retaining at least a fraction of said overhead percentage (OPI) of sensor information from being used to update the kinematic models (M_1, M_2),
- saving said fraction of said overhead percentage (OPI) of sensor information on a data storage device, and
- verifying the calibration using said fraction of overhead percentage of sensor information.

2318. The method according to claim 2217, wherein the step of verifying the calibration comprises the steps of comparing said fraction of the collected overhead percentage

of sensor information with corresponding values predicted by the estimated kinematic models (M_1, M_2) for the robots.

~~24. The method according to claim 23, wherein said comparison is performed by calculating a difference between every one of said fraction of the collected overhead percentage of sensor information and corresponding values predicted by the estimated kinematic models (M_1, M_2) for the robots, and comparing said difference or its numerical value with a threshold value.~~

~~25. The method according to claims 21-24, wherein said overhead percentage of sensor information (OPI) is in the range between 10% and 200%, preferably between 20% and 80%, even more preferably between 20% and 60% or alternatively in the range between 10% and 20%, or in the range between 20% and 40%, or in the range between 40% and 60%, or in the range between 60% and 80%, or in the range between 80% and 100%, or in the range between 100% and 120%, or in the range between 120% and 140%, or in the range between 140% and 160%, or in the range between 160% and 200%.~~

~~26. The method according to any of the preceding claims, further comprising the step of saving the estimated kinematic models (M_1, M_2) on a data storage device.~~

~~27~~19. The method according to any of the preceding claims, wherein the step (c) of manipulating at least one of the joints and or links of the at least one robot (R_1, R_2) in the chain is performed by turning off at least one of the position regulators of the joints of one of said two robots (R_1, R_2), and let it be led around by the other robot.

20~~8~~. The method according to any of the claims 1-~~26~~19, wherein the step (c) of manipulating at least one of the joints of the at least one robot (R_1, R_2) in the chain is performed by turning off at least one of the position regulators of the joints of each of said two robots (R_1, R_2), and change the joint position externally.

21~~9~~. The method according claim 20~~8~~, wherein the step (c) of manipulating at least one of the joints of the at least one robot (R_1, R_2) in the chain is performed by turning off at least one of the position regulators of the joints of each of said two robots (R_1, R_2), and change the joint position manually.

~~30. The method according to any of the preceding claims, wherein the kinematic models (M_1, M_2) are determined by parameters defining transformations.~~

~~31. The method according to claim 30, wherein the parameters are two types of Denavit-Hartenberg parameters.~~

~~32. The method according to claim 31, wherein the two types of Denavit-Hartenberg parameters are represented by the Schilling parameters, and the parallel variant parameters, respectively.~~

~~33~~22. The method according to any of the preceding claims, further comprising the step of adjusting the force by which the at least two robots (R_1, R_2) operate.

~~34. The method according to any of the preceding claims, wherein each of the models (M_1, M_2) comprises a transformation for each joint.~~

2~~35~~. The method according to any of the preceding claims, further comprising the steps of connecting N additional robots in parallel or in series with the at least two robots (R_1, R_2), N being a natural number, and performing the steps of claim 1 for each additional N robots.

~~36~~24. The method according to any of the preceding claims, wherein said at least two robots (R_1, R_2) are two robot arms of a single robot.

~~37. The method according to claim 36, wherein at least one of said arms are an articulated robot arm.~~

~~38. The method according to claim 36 or 37, wherein at least one of said arms comprises a prismatic joint.~~

~~39. The method according to claim 36, 37 or 38, wherein said single robot has one base flange and at least two tool flanges.~~

~~40. A method of converting a working program from a first robot R_1 to a second robot R_2, each robot (R_1, R_2) having joints connecting two flanges: a base flange and a tool flange, the method comprising the steps of:~~

(a) replacing the first robot R_1 with the second robot R_2,

(b) providing a working program R_1P associated with the first robot R_1,

(c) choosing a number of positions or angles in accordance with the working program R_1P and moving the second robot R_2 to those positions, thereby providing a position or angle pair data set $<R_1Q, R_2Q>$, and then

(d) estimating kinematic models (M_1, M_2) of said at least two robots, base flange offset (T_{base}) and tool center point offset (T_{tcp}) using the position pair data set $<R_1Q, R_2Q>$ of the first robot R_1 and the second, replacing robot R_2, by creating and employing a virtual closed chain system and then

(e) performing a working program conversion on the basis of said estimated kinematic models (M_1, M_2).

41. The method according to claim 40, further comprising the step of evaluating whether the program can run on the second robot within suitably chosen tolerances.

42. The method according to claim 41, further comprising the step of choosing an additional number of positions in accordance with the working program R_1P and moving the second robot R_2 to those additional positions, thereby providing an extended position pair data set, and then performing steps (d) and (e), using this extended position pair data set, if the program cannot run on the second robot within the suitably chosen tolerances.

43. The method according to claim 40, 41 or 42, further comprising the steps of converting another working program on the basis of the estimated kinematic models (M_1, M_2).

44. The method according to any of the claims 40-43, wherein step (e) of performing the working program conversion on the basis of said estimated kinematic models, comprises the sub steps of:

- applying forward kinematics on all R_1Q in R_1P with the estimated kinematic model M_1 associated with the first robot R_1 resulting in the program R_1K,
- applying inverse kinematics on R_1K with the estimated kinematic model M_2 for the second robot R_2, thereby giving the positions R_2Q, and then
- replacing R_1Q in the program R_1P with the corresponding R_2Q, thereby giving a working program R_2P associated with the second robot R_2, whereby the program conversion is completed.

~~45. The method according to any of the claims 40-44, wherein the kinematic models (M_1, M_2) are determined by parameters defining transformations.~~

~~46. The method according to claim 45, wherein the kinematic models (M_1, M_2) are determined by three types of Denavit-Hartenberg parameters.~~

~~47. The method according to claim 46, wherein the three types of Denavit-Hartenberg parameters are represented by the Schilling parameters, the Parallel variant parameters, and RPY parameters.~~

~~48. The method according to claim 45, 46 or 47, wherein RPY parameters are used to modulate the last joint of the robot.~~

~~49~~25. The method according to any of the preceding claims, wherein the kinematic models (M_1, M_2) are estimated by using predetermined models as a starting point.