Claims

1. A method for operating a robot, wherein the robot comprises movable elements ELE_m which can be driven by actuators AKT_n, and is designed to carry out a movement B with the elements ELE_m, where n = 1, 2, …, N, m = 1, 2 …, M, N = 1, 2, …, M = 1, 2, …, and wherein the robot comprises a detection system for determining signals $W_{G_k^B}(t)$ of a group of measurement variables G_k^B, where k = 1, 2, …, K and K ≥ 1, characterizing the movement B of the elements ELE_m and the interactions thereof with an environment, comprising the following steps

- determining (101), by means of the detection system, reference signals $W_{G_k^B}^R(t)$ of the measurement variables G_k^B during at least one execution of the movement B of the elements ELE_m, which is in the form of a reference movement B, wherein the reference signals $W_{G_k^B}^R(t)$ include reference interactions of the elements ELE_m with the environment, in particular external forces and/or torques acting on the elements ELE_m,
- based on the reference signals $W_{G_k^B}^R(t)$, using an adaptive method, automatically determining (102) a mathematical model $M_{G_k^B}$ for describing the reference movement B including the reference interactions, by the measurement variables G_k^B,
- during a normal execution of the movement B:
  - o using the model $M_{G_k^B}$, predicting (103) signals $W_{G_k^B}^P(t)$ for describing the reference movement B, including the reference interactions, by the measurement variables G_k^B,
  - o comparing (104) the signals $W_{G_k^B}(t)$ determined currently during a normal execution of the movement B with the predicted signals $W_{G_k^B}^P(t)$ for determining a deviation $\Delta_{G_k^B}(t)$ between $W_{G_k^B}^P(t)$ and $W_{G_k^B}(t)$, where k = 1, 2, …, K and K ≥ 1,
  - o in so far as the deviation $\Delta_{G_k^B}(t)$ does not meet a predefined condition $BED_{G_k^B}$, based on the deviation $\Delta_{G_k^B}(t)$, classifying (105) the current deviation $\Delta_{G_k^B}(t)$ in one of a number I of predefined error categories $F_{i,G_k^B}(\Delta_{G_k^B}(t))$, where i = 1, 2, …, I, wherein predefined control information and/or automatically predictable control

information $S_{F_i,G_k^B}(t)$ for the actuator AKT_k are produced for each of the error categories $F_{i,G_k^B}(\Delta_{G_k^B}(t))$ and

o controlling (106) the actuators AKT_k taking into account the control information $S_{F_i,G_k^B}(t)$.

2. The method according to Claim 1,

in which the group of measurement variables G_k^B comprises one or more of the following variables: force acting on the movable robot components, torque and/or position, speed, or acceleration of the robot components, and/or pressure, temperature, energy and/or contact points, and/or estimated contact points with an environment.

3. The method according to Claim 1 or 2,

in which the movable elements ELE_m form arm members of a robot arm, wherein at least some of the elements ELE_m are driven by the actuators AKT_k, and wherein the detection system in each case acquires the measurement variables G_k^B for some or all of the arm members.

4. The method according to any one of Claims 1 to 3,

wherein the adaptive method for determining a mathematical model $M_{G_k^B}$ is carried out based on one or more Gaussian processes.

5. The method according to any one of Claims 1 to 4,

wherein the model $M_{G_k^B}$ is a statistical model which is trained based on the signals $W_{G_k^B}^R(t)$.

6. The method according to Claim 5,

wherein the statistical model comprises a hidden Markov model HMM and/or a support vector machine SVM and/or a neuronal network.

7. The method according to any one of Claims 1 to 6,

wherein the signals $W_{G_k^B}(t)$ are determined based on the raw data $R_{G_k^B}(t)$ acquired by the sensors of the detection system and/or wherein the signals $W_{G_k^B}(t)$ are determined based on estimation signals.

8. The method according to any one of Claims 1 to 7,

wherein the condition $BED_{G_k^B}$ predetermines, for at least one of the measurement variables G_k^B, that the deviation $\Delta_{G_k^B}(t)$ between $W_{G_k^B}^P(t)$ and $W_{G_k^B}(t)$ is smaller than/equal to a predefined limit value $LIMIT_{G_k^B}$: $\Delta_{G_k^B}(t) \leq LIMIT_{G_k^B}$.

9. The method according to any one of Claims 1 to 8,

wherein the control information $S_{F_i,G_k^B}(t)$ defines a completed reaction movement of the robot components and/or a change of at least one condition $BED_{G_k^B}$ and/or a change of the model $M_{G_k^B}$.

10. A robot designed and implemented to carry out a method according to any one of Claims 1 to 9.