

METHOD, APPARATUS AND CONTROL DEVICE FOR MULTI-LOAD SELF-ADAPTIVE GRAVITY COMPENSATION OF MANIPULATOR

[0001] Cross-reference to related applications

[0002] This application requires the priority of the Chinese patent application 202010466099.X that submitted to the Chinese Patent Office on May 28, 2020, titled "a multi-load adaptive gravity compensation method of a manipulator", which The entire contents of this application are incorporated by reference.

Technical field

[0003] The application relates to the field of mechanicals, in particular, to a method, apparatus and control device for gravity compensation of a manipulator.

Background

[0004] With the gradual development of the manipulator manufacturing industry and the sensor industry, manipulators no longer serve only in production lines, but also begin to slowly enter various fields of life. The traditional industrial manipulator needs to set up a safety range, and strictly prohibit personnel from entering its working area during operation to prevent personnel injury. However, most of the application scenarios have many inconveniences when setting the security range, and the efficiency is not high during man-machine collaborative operation. In order to make the work space of man and machine not that separated, and to achieve high-efficiency and high-precision man-machine collaborative operation, people have designed a collaborative manipulator. The collaborative manipulator has the ability to sense contact forces and respond to physical contact between the human body and the manipulator, thus allows the operator and the manipulator to share one workspace. The emergence of collaborative manipulators has greatly expanded the application of manipulators in home care, education and entertainment, health care, high-end manufacturing and other industries, with the characteristics of high efficiency, high precision and high stability of manipulators to improve all aspects of life.

[0005] The zero-force control technology means that in the process of dragging and teaching, the manipulator can move in accordance with the external force, as if it is not affected by the gravity of the manipulator itself. This technology reduces the labor intensity of dragging and teaching, and

increases the fluency in controlling the manipulator. In order to enable the manipulator to achieve zero-force control even when the end tool is clamped, it is necessary to calibrate the parameters of the manipulator body and the tool respectively, and use the reverse engineering to accurately calculate the mass and weight of the manipulator and the tool. Centroid. The technology of parameter calibration of the manipulator is described in the literature “Identifying the dynamic model used by the KUKA LWR:A reverse engineering approach”.(C.Gaz,F.Flacco) and “Gravity compensation of KUKA LBR IIWA Through Fast Robot Interface”.(C.Hou , Y.Zhao) in detail, but there are few calibration data for the end tool parameters. In some complex applications, the manipulator even needs to change the end tool to complete the work. In these cases, how the manipulator can adaptively compensate for the gravity of the tool, to ensure different end tools can obtain zero-force control, becomes the key to the smooth cooperative operation.

[0006] At present, the scheme of the gravity compensation of the manipulator generally needs to use a weighing instrument to measure the mass of the end tool, and then use the suspension method or the support method to measure the centroid of the tool. Then import the measured data into the control system of the manipulator, and let the control system perform gravity compensation according to the parameters of the tool, so that the manipulator can achieve zero-force control. However, when measuring the mass and centroid of the tool, the tool is separated from the system, and the measured parameters tend to ignore the influence of the installation process on the mass and centroid, and gravity compensation can only be performed on the parameters of one tool at a time, and it must be stopped when switching tools. When the program requires frequent switching of multiple tools, the efficiency is low.

[0007] Summary of the invention

[0008] One of the purposes of this application includes providing a manipulator with multi-load adaptive gravity compensation method, apparatus, control device and readable storage medium, reducing operation steps and improving efficiency and gravity compensation performance.

[0009] To achieve the object, the technical scheme adopted in the application is as follows:

[0010] In one aspect, the embodiment of the application provides one manipulator with multi-load self-adaptive gravity compensation method, comprises the following steps,

[0011] S1.1, building a kinematics model for a manipulator;

- [0012] S1.2, reconstructing a gravity item of a dynamics model;
- [0013] S1.3, sampling in a no-load static position;
- [0014] S1.4, sampling in a static position after tools are installed;
- [0015] S1.5, calculating the value of a parameter to be calibrated of each tool respectively;
- [0016] S1.6, calculating the mass and the centroid of each tool respectively;
- [0017] S2.1, calculating a force which is applied to a flange by the tool which is currently installed;
- [0018] S2.2, compensating for the gravity of the tool.
- [0019] In a possible implementation, in step S1.1, a standard D-H method is used to construct a joint coordinate system of the manipulator.
- [0020] In a possible implementation, in step S1.3, under no-load conditions, the manipulator runs to any non-singular position in the workspace, samples joint position and torque readings.
- [0021] In a possible implementation, in step S1.4, each tool is installed at the end of the manipulator, and step S1.3 is repeated to perform static position sampling.
- [0022] In a possible implementation, in step S1.4, for each tool, after the tool is installed at the end of the manipulator, determine the current effective workspace of the manipulator corresponding to the tool according to the size of the tool, and then repeat step S1.3 for static location sampling of the tool based on the effective workspace.
- [0023] In a possible implementation, in step S1.5, the sampling data obtained in step S1.3 and S1.4 are grouped according to tools, and are sequentially substituted into the gravity item in step S1.2.
- [0024] In a possible implementation, in step S1.6, for each tool, the parameter value of calibration when carrying the tool is compared with the parameter value of no-load calibration, and according to the comparison result and the parameter value of the mass, the centroid of the tool, the mass of the end arm in the manipulator, and the centroid of the end arm, to calculate the mass and the centroid of the tool.
- [0025] In the second aspect, the embodiment of the application provides one manipulator with multi-load self-adaptive gravity compensation device, and described embodiment comprises:
- [0026] Model building module, configured to build the kinematics model of manipulator;
- [0027] Gravity reconstruction module, configured to reconstruct the gravity item of the dynamic model;
- [0028] Position sampling module, configured to no-load static position sampling;

[0029] Position sampling module, also configured to carry out static position sampling respectively after installing each tool;

[0030] Parameter calibration module, configured to calculate the parameter value to be calibrated of each tool respectively;

[0031] Mass parameter calculation module, configured to calculate the mass and the centroid of each tool respectively;

[0032] External force calculation module, is configured to calculate the force that the tool of current installation applies to flange;

[0033] Gravity compensation module, configured to compensate for the gravity of the tool.

[0034] In a possible implementation, in the process of building the kinematics model of the manipulator, the model building module uses the standard D-H method to build the manipulator joint coordinate system.

[0035] In a possible implementation, when the manipulator has no load, the position sampling module controls the manipulator to run to any non-singular position in the workspace, and samples the joint position and torque readings.

[0036] In a possible implementation, after each tool is installed at the end of the manipulator, the position sampling module determines the effective workspace of the manipulator currently corresponding to the tool for each tool according to the size of the tool, then based on the effective workspace, the manipulator is repeatedly controlled to run to any non-singular position in the corresponding effective workspace, and the joint position and torque readings are sampled.

[0037] In a possible implementation, the parameter calibration module groups the sampling data obtained by the position sampling module according to the tool, and successively substituted into the gravity item obtained by the gravity reconstruction module for calculation, to obtain the parameter values to be calibrated for each tool.

[0038] In a possible implementation, in the process of calculating the mass and the centroid of each tool, the mass parameter calculation module compares the parameter values calibrated when the tool is carried with the parameter values calibrated without load for each tool respectively, according to the comparison results and the relationship between the mass of the tool, the centroid of the tool, the mass of the end arm in the manipulator and the centroid of the end arm, to calculate the mass and centroid of the tool.

[0039] In a third aspect, an embodiment of the present application provides a control device for a manipulator, comprising a memory and a processor, wherein the memory stores a computer program that can run on the processor, and when the processor executes the computer program, the aforementioned multi-load adaptive gravity compensation method of the manipulator is realized.

[0040] In the fourth aspect, the embodiment of the present application provides a readable storage medium, where a computer program is stored, and when the computer program is run by the processor, the multi-load adaptive gravity compensation method of the aforementioned manipulator is executed .

[0041] One of the beneficial effects of the embodiments of the present application includes: constructing a joint coordinate system of the manipulator by the D-H method, and then establishing a system for the position of the centroid of each segment of the manipulator based on the joint coordinate system. In the original gravity item, the item related to the joint position and the item related to the centroid are split. During the splitting process, the parameters to be calibrated need to be properly combined, and then the split items are put into two matrices, which make it multiplied and still satisfy the original gravity item. Then, the static position of the manipulator in the no-load state is sampled, and then each tool is installed at the end of the manipulator, and the static position is sampled respectively. After grouping different tools of the sampled data into the gravity item, the values of the combined parameters can be solved by using SVD decomposition. Finally the mass and centroid of the tools can be extracted from the combined parameters by using the method of separating the parameters of the combined objects. Based on the calibrated parameters under no load and feedback of real-time joint positions, the force exerted by the currently installed end tool on the flange can be calculated. According to the measured external force on the flange, the system can know which tool is currently installed on the flange, so that it can directly use the calibrated parameter value to measure the external force after compensating the tool gravity, or apply the obtained mass and centroid to into the configuration of the manipulator. The method obtains tool parameters through pre-calculation, which simplifies the operation steps in practical application and greatly enhances the fluency of cooperative operation. In addition, by using joint position and torque sensors to calibrate the tool parameters, the calibrated tool parameters are more in line with the kinematics and dynamic characteristics of the manipulator, thereby improving the performance of zero-force control.

Description of drawings

[0042] FIG. 1 is a flowchart of a manipulator with multi-load adaptive gravity compensation method provided by an embodiment of the present application.

[0043] FIG. 2 is a schematic diagram of a tool and a manipulator end of a multi-load adaptive gravity compensation method for a manipulator provided by an embodiment of the present application.

[0044] Fig. 3 is the multi-tool schematic diagram of manipulator with multi-load self-adaptive gravity compensation method provided by the embodiment of the present application;

[0045] FIG. 4 is a schematic diagram of the composition of a multi-load self-adaptive gravity compensation device of a manipulator provided by an embodiment of the present application.

Embodiment

[0046] Below specific embodiment and description accompanying drawing, the application will be further elaborated and described:

[0047] As shown in Fig. 1-Fig. 3, in the complete manipulator dynamics equation, contains inertial term, centrifugal force and Coriolis force term, gravitational term and frictional force term. The inertia term is related to the joint acceleration, the centrifugal force is related to the Coriolis force term and the joint speed, and the friction force term is also related to the joint speed. The joint acceleration and joint speed are both 0 when the manipulator is in a static state, so for the static position research can be carried out only on the gravity item. The construction of the dynamic equation containing the gravity item requires the joint position and moment of the manipulator as input, so there are certain requirements on the hardware of the manipulator. Taking KUKA LBR Med 7 R800 as an example, the manipulator is a seven-axis cooperative manipulator, and each joint is equipped with high-precision position and torque sensors, which meets the hardware configuration requirements of the manipulator in this application. The actual operation is explained by taking the KUKA LBR Med 7 R800 seven-axis collaborative manipulator as an example.

[0048] S1.1: Build the kinematics model of the manipulator.

[0049] In a possible implementation of the present embodiment, when building the kinematics model of the manipulator, the joint coordinate system of the manipulator is established using the classical D-H method (A Kinematic Notation for Lower-Pair Mechanisms Based on Matrices, J. Denavit, R.S. Hartenberg). For the KUKA LBR Med 7 R800, the D-H parameter table is shown below.

[0050] Table 1: D-H parameter table of KUKA LBR Med 7 R800

[0051]

	α_i	$a_i(\text{mm})$	$d_i(\text{mm})$	θ_i
1	$-\pi/2$	0	540	θ_1
2	$\pi/2$	0	0	θ_2
3	$-\pi/2$	0	400	θ_3
4	$\pi/2$	0	0	θ_4
5	$-\pi/2$	0	400	θ_5
6	$\pi/2$	0	0	θ_6
7	0	0	120	θ_7

[0052] wherein α_i represents the connecting rod rotation angle, a_i represents the connecting rod length, d_i represents the connecting rod offset distance, and θ_i represents the joint angle. After the joint coordinate system is established, the centroid coordinate system is established for the centroid position of each manipulator according to certain rules. When establishing the centroid coordinate system, it is only necessary to ensure that the origin of the coordinate system is located at the centroid of each arm, and the rotation angle can be consistent with the rotation angle of the $i+1$ th joint.

[0053] S1.2: Reconstructing a gravity item of a dynamics model.

[0054] In the present embodiment, for the manipulator of the static state, the gravity item is equal to the joint moment of the manipulator, and the formula is expressed as:

[0055] $G(\theta, m, c) = \tau$

[0056] It can be known from the formula that the gravity item is related to the joint angle θ_i , the mass m_i and the centroid c_i . The mass m_i and the centroid c_i are directly related to the calibration of the tool and need to be extracted. Therefore, the gravity item G should be split as follows:

[0057] $Y(\theta) \cdot A(m, c) = \tau$

[0058] It is easy to find that the mass m_i and the centroid c_i are coupled in the gravitational term and cannot be separated. Therefore, in order to have the matrix A of the parameters to be

calibrated, it is necessary to make the calibrated parameters into the combined m_i and c_i by reasonably combining the parameters while satisfying the equation. When combining parameters, the number of parameters in A should be reduced as much as possible, so as to avoid the solution of the linear equation system falling into the local optimum, so as to obtain a better calibration effect.

[0059] S1.3: Sampling in a no-load static position.

[0060] In this embodiment, it is confirmed that the manipulator is in a no-load state, and the manipulator is moved to a non-singular position in the workspace. After each joint is stationary, the position and moment of the joint are collected. Repeat the sampling step so that the sampling points are spread across the entire workspace as much as possible. During the sampling process, there may be a small number of sampling points that are very close to the singular position. The lack of degrees of freedom of the manipulator at the singular point position will lead to inaccurate torque feedback, these sampling points should be excluded from the sampling set.

[0061] As shown in FIG. 3, S1.4: sampling in a static position after tools are installed.

[0062] In the present embodiment, each tool is installed to the end of the manipulator in turn, and step S1.3 is repeated to carry out a round of motion sampling for each tool, and the data set after the singular position is removed is saved. Since the tool itself has a certain size, the movement range of the manipulator will be limited to a certain extent. During the movement process, there may be accidents that collide with the manipulator body or peripheral obstacles. Therefore, during the process of sampling the static position of the tool's mechanical energy, the effective workspace is re-confirmed, and a reasonable motion trajectory is designed to prevent collisions while filling the workspace as much as possible with sampling points. Therefore, in a possible implementation of this embodiment, for each tool, after the tool is installed at the end of the manipulator, the current effective workspace of the manipulator corresponding to the tool is determined according to the size of the tool, Then repeat step S1.3 for static position sampling of the tool based on the effective workspace.

[0063] S1.5: Calculating the value of a parameter to be calibrated of each tool respectively.

[0064] In the present embodiment, carry out S1.5 step and need to group all data collected according to tool, each group of data is stacked in the equation system obtained in S1.2, as follows:

$$[0065] \quad \bar{Y} \cdot A = \bar{\tau} \Rightarrow \begin{bmatrix} Y_1(\theta_1, \theta_2, \dots, \theta_n) \\ Y_2(\theta_1, \theta_2, \dots, \theta_n) \\ Y_3(\theta_1, \theta_2, \dots, \theta_n) \\ \vdots \end{bmatrix} A(\mathbf{m}, \mathbf{c}) = \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \vdots \end{bmatrix}$$

[0066] wherein the joint position in the data set will be stacked in the matrix $\bar{Y}$, and the joint moment is stacked to $\bar{\tau}$ because the stacking matrix $\bar{Y}$ and $\bar{\tau}$ all have been confirmed, the parameter matrix $A(\mathbf{m}, \mathbf{c})$ to be calibrated can be decomposed by SVD to obtain the linear equations. Matrices can be decomposed into the following forms:

$$[0067] \quad \bar{Y} = U \Sigma V^T \quad (U \in \mathbb{R}^{m \times m}, \Sigma \in \mathbb{R}^{m \times n}, V \in \mathbb{R}^{n \times n})$$

[0068] wherein the left singular matrix U and the right singular matrix V are both orthogonal matrices, so for the overdetermined equation $\bar{Y} \cdot A = \bar{\tau}$, make $X = V^T A$, $B = U^T \bar{\tau}$, then there is a new expression

$$[0069] \quad \Sigma X = B$$

[0070] In the above expression, Σ is a diagonal matrix, and all the diagonal elements are the singular values σ_i of the matrix and $\sigma_1 \geq \sigma_2 \dots \geq \sigma_n > 0$, so X can be obtained. Finally the parameters to be calibrated in the matrix A can be obtained according to $A = VX$.

[0071] S1.6: Calculating the mass and the centroid of each tool respectively.

[0072] In the present embodiment, the process of performing step S1.5 requires that the tool as a rigid body be installed at the end of the manipulator and then calibrate the parameters, therefore, the mass and centroid of the last rigid body in the calibrated parameters are actually the parameters after the last segment of the manipulator is combined with the tool. Thus, the mass and centroid of the tool can be compared by comparing the parameters calibrated with the tool and the parameters calibrated without load, then combined with the multi-body system centroid formula for characterizing the relationship between the mass and centroid of the tool and the mass and centroid of the end arm in the manipulator can be determined. Therefore, in a possible implementation of this embodiment, for each tool, the parameter value calibrated when the tool is carried and the parameter value calibrated without load can be compared, and according to the comparison result and the mass, The relationship between the centroid of the tool, the mass of the end arm in the manipulator, and the centroid of the end arm is calculated to obtain the mass and centroid of the tool.

[0073] wherein, taking the end of KUKA LBR Med 7 R800 as an example, please refer to Fig. 2, the corresponding multi-body system centroid formula of the manipulator system behind the clamping tool has the following physical properties:

$$[0074] \quad c_c = \frac{m_t c_t + m_7 c_7}{m_t + m_7}$$

[0075] wherein c_c is the centroid after the tool and the end arm are combined, m_t and c_t are the mass and centroid of the tool respectively, and m_7 and c_7 are the mass and centroid of the end arm respectively. Combining the above formula with the calibrated parameter expressions, the mass m_t and the centroid c_t of the tool can be obtained.

[0076] At the same time, the present application designs a system for automatically selecting tool parameters and applying gravity compensation. The system uses the output of joint torque and position sensor as the input of the system, and calculates the force exerted by the current tool on the end of the manipulator in the system, so as to determine the type of tool to be clamped, and then applies the parameters calculated in S1 to complete the gravity compensation. The detailed implementation steps are explained below.

[0077] S2.1: Calculate the force that the currently installed tool exerts on the flange (end of the manipulator).

[0078] In this embodiment, The parameters calibrated in the no-load state can be used to calculate the joint torque τ_{robot} caused by the robot body at the current position. The joint moment τ_{measure} measured in real time is subtracted from τ_{robot} , and the joint moment τ_{ext} caused by the external force is obtained. Using the Jacobian matrix, the external force can be mapped from the joint space to the workspace, and the external force on the end of the manipulator (flange) in the workspace can be calculated.

[0079] S2.2: Compensate the tool gravity.

[0080] In this embodiment, the difference between the tools will be reflected in the value of the external force. For example, if the mass difference between tools is large, the value in the XYZ direction of the external force can be used as the basis for distinguishing the tools; if the mass difference of the tools is small and the difference in the centroid is large, the torque in the direction of the external force ABC can be considered as the distinguishing factor; For tools with little difference in mass and centroid, consider it as a tool, and apply the same set of calibrated

parameters to obtain better compensation effects. For a manipulator that allows automatic gravity compensation by inputting tool parameters, the mass and centroid of the tool calculated in step S1.6 can be directly written into the configuration of the manipulator, and the built-in program of the manipulator can calculate the external force exerted on the tool ; For the manipulator without gravity compensation function, the parameters calibrated in step S1.5 can be directly applied to calculate the external force on the current tool. Therefore, the external force felt by the manipulator is the external force after compensating for the gravity of the tool, and the control strategy using the external force as the input will also ignore the influence of the tool, that is, zero-force control is achieved.

[0081] In addition, as shown in Fig. 4, the present application also provides one manipulator with multi-load self-adaptive gravity compensation device 100, to realize the module by various functions included in the multi-load self-adaptive gravity compensation device 100, to the above-mentioned The multi-load adaptive gravity compensation method of the manipulator is performed. The multi-load adaptive gravity compensation device 100 includes a model building module 110 , a gravity reconstruction module 120 , a position sampling module 130 , a parameter calibration module 140 , a mass parameter calculation module 150 , an external force calculation module 160 and a gravity compensation module 170 .

[0082] The model building module 110 is configured to build a kinematic model of the manipulator.

[0083] The gravity reconstruction module 120 is configured to reconstruct the gravity item of the dynamics model.

[0084] The position sampling module 130 is configured to perform no-load static position sampling.

[0085] The position sampling module 130 is also configured to perform static position sampling after installing each tool.

[0086] The parameter calibration module 140 is configured to separately calculate the parameter values to be calibrated for each tool.

[0087] The mass parameter calculation module 150 is configured to calculate the mass and the centroid of each tool respectively.

[0088] The external force calculation module 160 is configured to calculate the force exerted on the flange by the currently installed tool.

[0089] A gravity compensation module 170 is configured to compensate for tool gravity.

[0090] In a possible implementation of this embodiment, the model building module 110 uses the standard D-H method to build a joint coordinate system of the manipulator in the process of building the kinematic model of the manipulator.

[0091] In a possible implementation of this embodiment, the position sampling module 130 controls the manipulator to run to any non-singular position in the workspace, and samples the joint position and torque readings when the manipulator has no load.

[0092] In a possible implementation of this embodiment, after the position sampling module 130 installs each tool on the end of the manipulator, for each tool, it determines the current relationship between the manipulator and the manipulator according to the size of the tool and the effective workspace corresponding to the tool. Then based on the effective workspace, the manipulator is repeatedly controlled to run to any non-singular position in the corresponding effective workspace, and the joint position and torque readings are sampled.

[0093] In a possible implementation of the present embodiment, the parameter calibration module 140 groups the sampled data obtained by the position sampling module according to the tool, and sequentially substitutes it into the data obtained by the gravity reconstruction module. Calculate in the gravity item to obtain the parameter values to be calibrated for each tool.

[0094] It should be noted that the multi-load self-adaptive gravity compensation device 100 provided by the embodiment of the present application has the same basic principle and technical effect as the aforementioned multi-load self-adaptive gravity compensation method. For a brief description, the parts not mentioned in the example section, please refer to the above description of the multi-load adaptive gravity compensation method.

[0095] In addition, the present application also provides a control device for a manipulator, the control device includes a memory and a processor. Wherein, the memory may include one or more computer program products, and the computer program products may include various forms of readable storage media, such as volatile memory and/or non-volatile memory. The volatile memory may include, for example, random access memory and/or cache memory or the like. The non-volatile memory may include, for example, read-only memory, hard disk, flash memory, and

the like. One or more computer programs may be stored on the readable storage medium, and the processor may execute the computer programs to realize the functions represented by the above-mentioned multi-load adaptive gravity compensation method of the manipulator and/or other desired function. Various application programs and various data, such as various data used and/or generated by the application program, may also be stored in the readable storage medium. [0096] The processor can be implemented in at least one hardware form in a digital signal processor, a field programmable gate array, and a programmable logic array, and the processor can be a central processing unit or have data processing capabilities and/or or other forms of processing units with instruction execution capabilities, and may control other components in the control device to perform the desired functions. The processor can accordingly execute the computer program stored in the memory to realize the functions represented by the computer program.

[0097] In a possible implementation of this embodiment, the multi-load adaptive gravity compensation device 100 of the above-mentioned manipulator can be stored in the memory of the control device in the form of software or firmware, the software function modules and computer programs included in the multi-load adaptive gravity compensation device 100 in the memory are executed by the processor of the control device, to realize the function corresponding to the multi-load adaptive gravity compensation method of the above-mentioned manipulator.

[0098] To sum up, the above scheme constructs the joint coordinate system of the manipulator by the D-H method, and then establishes the position of the centroid of each segment of the manipulator based on the joint coordinate system. In the original gravity item, the item related to the joint position and the item related to the centroid are split. During the splitting process, the parameters to be calibrated need to be properly combined, and then the split items are put into two matrices, multiplying them still satisfies the original gravity item. Then, the static position of the manipulator in the no-load state is sampled, and then each tool is installed at the end of the manipulator, and the static position is sampled separately. After grouping different tools of the sampled data into the gravity item, the values of the combined parameters can be solved by using SVD decomposition. Finally, the mass and centroid of the tools can be extracted from the combined parameters by using the method of separating the parameters of the combined objects. Based on the calibrated parameters under no load and feedback of real-time joint positions, the

force exerted by the currently installed end tool on the flange can be calculated. According to the measured external force on the flange, the system can know which tool is currently installed on the flange, so that it can directly use the calibrated parameter value to measure the external force after compensating the tool gravity, or apply the obtained mass and centroid to into the configuration of the manipulator. The method obtains tool parameters through pre-calculation, which simplifies the operation steps in practical application and greatly enhances the fluency of cooperative operation. In addition, by using joint position and torque sensors to calibrate the tool parameters, the calibrated tool parameters are more in line with the kinematics and dynamic characteristics of the manipulator, thereby improving the performance of zero-force control.

[0099] Finally it should be noted that above embodiment is only in order to illustrate the technical scheme of the application, rather than the restriction to the protection scope of the application, although the application has been described in detail with reference to the optional implementation, the common skilled person should understand that the technical solutions of the present application may be modified or equivalently replaced without departing from the spirit and scope of the technical solutions of the present application.

Industrial Applicability

[0100] The embodiment of the present application provides a manipulator with multi-load adaptive gravity compensation method, apparatus, control device and readable storage medium, constructs a manipulator joint coordinate system by the D-H method, and then compares each segment based on the joint coordinate system, the position of the centroid of the manipulator is established. In the original gravity item, the item related to the joint position and the item related to the centroid are split. During the splitting process, the parameters to be calibrated need to be properly combined, and then the split items are put into two matrices, multiplying them still satisfies the original gravity item. Then, the static position of the manipulator in the no-load state is sampled, and then each tool is installed at the end of the manipulator, and the static position is sampled separately. After grouping different tools of the sampled data into the gravity item, the values of the combined parameters can be solved by using SVD decomposition. Finally, the mass and centroid of the tools can be extracted from the combined parameters by using the method of separating the parameters of the combined objects. Based on the calibrated parameters under no

load and feedback from real-time joint positions, the force exerted on the flange by the currently installed end tool can be calculated. According to the measured external force on the flange, the system can know which tool is currently installed on the flange, so that it can directly use the calibrated parameter value to measure the external force after compensating the tool gravity, or apply the obtained mass and centroid to into the configuration of the manipulator. The method obtains tool parameters through pre-calculation, which simplifies the operation steps in practical application and greatly enhances the fluency of cooperative operation. In addition, by using joint position and torque sensors to calibrate the tool parameters, the calibrated tool parameters are more in line with the kinematics and dynamic characteristics of the manipulator, thereby improving the performance of zero-force control.

Claims

1. A manipulator with multi-load adaptive gravity compensation method, characterized in that, comprising the following steps,
 - S1.1, building a kinematics model for a manipulator;
 - S1.2, reconstructing a gravity item of a dynamics model;
 - S1.3, sampling in a no-load static position;
 - S1.4, sampling in a static position after tools are installed;
 - S1.5, calculating the value of a parameter to be calibrated of each tool respectively;
 - S1.6, calculating the mass and the centroid of each tool respectively;
 - S2.1, calculating a force which is applied to a flange by the tool which is currently installed;
 - S2.2, compensating for the gravity of the tool.
2. The manipulator with multi-load adaptive gravity compensation method according to claim 1, characterized in that, in step S1.1, a standard D-H method is used to construct a joint coordinate system of the manipulator.
3. The manipulator with multi-load adaptive gravity compensation method according to claim 1 or 2, characterized in that, in step S1.3, under no-load conditions, the manipulator runs to any non-singular position in the workspace, samples joint position and torque readings.
4. The manipulator with multi-load adaptive gravity compensation method according to claim 3, characterized in that, in step S1.4, each tool is installed at the end of the manipulator, and step S1.3 is repeated to perform static position sampling.
5. The manipulator with multi-load adaptive gravity compensation method according to claim 4, characterized in that, in step S1.4, for each tool, after the tool is installed at the end of the manipulator, determine the current effective workspace of the manipulator corresponding to the tool according to the size of the tool, and then repeat step S1.3 for static location sampling of the tool based on the effective workspace.
6. The manipulator with multi-load adaptive gravity compensation method according to any claim 1~5, characterized in that, in step S1.5, the sampling data obtained in step S1.3 and S1.4 are grouped according to tools, and are sequentially substituted into the gravity item in step S1.2.

7. The manipulator with multi-load adaptive gravity compensation method according to any claim 1~6, characterized in that, in step S1.6, for each tool, the parameter value of calibration when carrying the tool is compared with the parameter value of no-load calibration, and according to the comparison result and the parameter value of the mass, the centroid of the tool, the mass of the end arm in the manipulator, and the centroid of the end arm, to calculate the mass and the centroid of the tool.

8. A multi-load adaptive gravity compensation device for a manipulator, characterized in that, the device comprises:

Model building module, configured to build the kinematics model of manipulator;

Gravity reconstruction module, configured to reconstruct the gravity item of the dynamic model;

Position sampling module, configured to no-load static position sampling;

Position sampling module, also configured to carry out static position sampling respectively after installing each tool;

Parameter calibration module, configured to calculate the parameter value to be calibrated of each tool respectively;

Mass parameter calculation module, configured to calculate the mass and the centroid of each tool respectively;

External force calculation module, is configured to calculate the force that the tool of current installation applies to flange;

Gravity compensation module, configured to compensate for the gravity of the tool.

9. The multi-load adaptive gravity compensation device according to claim 8, characterized in that, in the process of building the kinematics model of the manipulator, the model building module uses the standard D-H method to build the manipulator joint coordinate system.

10. The multi-load adaptive gravity compensation device according to claim 8 or 9, characterized in that, when the manipulator has no load, the position sampling module controls the manipulator to run to any non-singular position in the workspace, and samples the joint position and torque readings.

11. The multi-load adaptive gravity compensation device according to claim 10, characterized in that, after each tool is installed at the end of the manipulator, the position sampling module determines the effective workspace of the manipulator currently corresponding to the tool for each

tool according to the size of the tool, then based on the effective workspace, the manipulator is repeatedly controlled to run to any non-singular position in the corresponding effective workspace, and the joint position and torque readings are sampled.

12. The multi-load adaptive gravity compensation device according to claim 8~11, characterized in that, the parameter calibration module groups the sampling data obtained by the position sampling module according to the tool, and successively substituted into the gravity item obtained by the gravity reconstruction module for calculation, to obtain the parameter values to be calibrated for each tool.

13. The multi-load adaptive gravity compensation device according to claim 8~12, characterized in that, in the process of calculating the mass and centroid of each tool, the mass parameter calculation module compares the parameter values calibrated when the tool is carried with the parameter values calibrated without load for each tool, and compares the results according to the comparison results and the mass of the tool, the relationship between the mass of the tool, the centroid of the tool, the mass of the end arm in the manipulator and the centroid of the end arm, to calculate the mass and centroid of the tool.

14. A control device of a manipulator, comprising a memory and a processor, wherein the memory stores a computer program that can run on the processor, characterized in that, when the processor executes the computer program, the multi-load adaptive gravity compensation method of the manipulator described in any claim 1~7 is realized.

15. A readable storage medium where a computer program is stored, characterized in that, when the computer program is run by the processor, the multi-load adaptive gravity compensation method of the manipulator described in any claim 1~7 is executed.