Design and Research of Novel Industry Robot Wrist Force Multidimensional Sensor

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Abstract: The main function of the wrist force sensor in robot remote operation is to realize the force feedback, one as a necessary part of the contact force of the process itself; another is the contact force as a robot gripper with respect to the environment the exact location of the information source, wrist force sensor provides information can reduce the robot to peripheral equipment precision requirement. Remote sensing operation environment, the manipulator and the environment from the direct effect of the information, the wrist force sensor detection, conversion, transmission to the master, for the establishment of virtual environment and the main basis and real-time interactive environment. The sensor circuit system design, designed the bridge circuit is applicable, overall on the measurement system is designed, and for sensor data acquisition software programming theory.

Keywords: Wrist force sensor, Virtual instrument, Robot, Feedback.

1. Introduction

At present, the development of robots has entered the era of intelligent robot. One of the most important features of intelligent robot is equipped with the surrounding environment information timely feedback sensor more complete to the robot control system [1], robot wrist force sensor is one kind of the important robot sensors. With the wide application of industrial robots and robot sensors, will need a lot of, but the robot wrist force sensor is the robot contact tasks is security, robot remote task security. Through contact force sensor to detect the manipulator and the environment and feedback on the robot's hand, enable the operator to produce be personally on the scene of force effect, so as to control the robot with the feeling [2].

Wrist force sensor is one of the most important in intelligent robot, as a force feedback control system in detecting element, can rapidly reflect the change of force and moment, should have good dynamic characteristics [3]. Dynamic characteristics of wrist force sensor is greatly affects the overall performance of the robot system, because if the dynamic performance of the wrist force sensor is poor, cannot be fast, accurately reflect the variation of the measured force and moment, so that the whole robot system can’t work normally [4].

The structure determines the sensor performance in a certain extent. The six dimension wrist force sensor is mounted on the robot wrist (away from the end effect recent), full information can also provide three bit space, has the widespread application of zero force on the robot teaching, contour tracking, the bullet burr and grinding, matched with a shaft
hole, bimanual coordination and automatic assembly operations, is a robot force control and force/position the most important hybrid control of sensor [5].

In this paper, on the basis of existing research results at home and abroad on the basic principle of force transformation, sensor, six dimensional sensing force Jacobi matrix elements, structure design, structure optimization design of additional elastic, dynamic performance analysis of elastic body, sensor system design of several key basic theory and its application are studied systematically. To force conversion principle of the sensor is analyzed, providing theoretical basis for design and force sensor. Analysis of additional elastic component of the strain amplification principle, we derive the analytical relationship between structural parameters of strain amplification and additional elastic component, finds the factors affecting the additional elastic component strain amplification, provides the theoretical basis for structure design and optimization of the additional elastic component. The sensor circuit system design, designed the bridge circuit is applicable, overall on the measurement system is designed, and for sensor data acquisition software programming theory.

2. The Structure Design of a New Type of Wrist Force Sensor

2.1. Finite Element Analysis of Elastic Wrist Force Sensor

The elastic body structure of robot wrist force sensor is generally more complicated, because of the influence of the principle of design and the manufacture error and other factors, makes the coupling exists in each of the sensor output channel. Classical analytic method is difficult to accurately analyze and describe this kind of coupling relation, usually using the method of experiment for calibration [6-8]. The experimental equipment calibration results are often not accurate enough.

\[ D^f = \begin{bmatrix} A_1 \cdot B_1 & A_2 \cdot B_2 & \cdots & A_{11} \cdot B_{11} \\ A_1 \cdot B_1 & A_2 \cdot B_2 & \cdots & A_{12} \cdot B_{12} \\ \vdots & \vdots & \ddots & \vdots \\ A_1 \cdot B_1 & A_2 \cdot B_2 & \cdots & A_{16} \cdot B_{16} \end{bmatrix} \]

(1)

\[ F + dF = G_f \cdot (f + df) \]

(2)

2.2. The Basic Theory of the Wrist Force Sensor

This paper study on a new type of wrist force sensor, which belongs to the parallel wrist force sensor, is the six dimension wrist force sensor, a novel parallel decoupling and isotropic robot, its structure is a variant of the traditional Stewart platform, and the general Stewart platform structure is different. 6 ball hinges on the platform of the new structure of the center is not distributed on the same circumference, 6 ball joints under platform of the center is not distributed in the same circle, the force sensing element is composed of an upper platform, the 6 elastic connecting rod, the lower platform and 12 spherical hinges connected [9].

Its characteristics are: 6 rigid rods are divided into 3 groups, each group of two separately along three mutually perpendicular to the direction of arrangement, plane and each rigid rod axis perpendicular to each other, to realize six axis force and torque decoupling from the structure; each additional elastic component of relative two side are respectively pasted 2 strain gauge [10]. The full bridge circuit, corresponding to 6 rigid rods consist of six strain bridge, when acting on a platform of measured force makes the 6 rigid rod micro strain, additional elastic component corresponding to the rigid rod on the producing strain was amplified, thus can obtain six road detection signal measurement, so as to realize the six axis force and moment. Its basic structure was shown in Fig. 1.

![Fig. 1. Schematic diagram of mechanism and structure parameters of the sensor.](image)

2.3. The Definition of Jacobi Matrix Condition Number

If the connecting rod force error dF, then the moving platform stress also has certain error dF, the above formula can be written as:

\[ \|df\| = \|G_f \cdot df\| \leq \|G_f\| \cdot \|df\| \]

(3)

Then:

\[ \|F\| = \|P_f^{-1} \cdot F\| \leq \|P_f^{-1}\| \cdot \|F\| \]

(4)
In the formula, \( \| \cdot \| \) said the norm of vector or matrix, have the following relationship between relative deviation of \( F \) and \( f \):

\[
\frac{\|dF\|}{\|F\|} \leq \| G_F^f \| \| G_F^f \|^{-1} \|df\| \| f \|
\]

(5)

The vector into the formulation to obtain the Jacobi matrix of six dimension wrist force sensor, the model of parallel

\[
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & e_1 \\
0 & 1 & 0 & 0 & 0 & e_2 \\
0 & 0 & 1 & -d & 0 & e_3 \\
0 & 0 & 0 & 0 & 1 & e_4 \\
0 & 0 & -d & 1 & 0 & e_5 \\
-d & d & 0 & 0 & 0 & e_6 \\
\end{bmatrix}
\]

(6)

2.4. Establishment and Simulation Analysis of Sensor Model in ADAMS

Automatic Dynamic Analysis Mechanical Systems is currently the world's most widely used mechanical system dynamics simulation and the most authoritative analysis software. Using ADAMS software, the geometric model of mechanical system users can quickly, easily create fully parameterized, then the simulation analysis and add the corresponding conditions, can help improve the design of various mechanical systems, from the simple to the connecting rod mechanism of vehicle, aircraft, satellites and even complex body.

The vector and the reading component:

\[
\begin{bmatrix}
D_x \\
D_y \\
D_z \\
F_x \\
F_y \\
F_z \\
\end{bmatrix} = \begin{bmatrix}
a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\
a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\
a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \\
a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} \\
a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} \\
a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \\
\end{bmatrix} \begin{bmatrix}
F_1 \\
F_2 \\
F_3 \\
F_4 \\
F_5 \\
F_6 \\
\end{bmatrix}
\]

(7)

3. The Hardware System and Static Calibration of Wrist Force Sensor

3.1. The Elastic Body Structure of New Type Sensor

Therefore, in accordance with the method described above theory, in ADAMS simulation in order to load and load data tables and output data table is as Table 1.

| Table 1. F unit load calibration table. |
|--------------|---|---|---|---|---|---|---|---|
| F  | 0  | 50 | 100 | 150 | 200 | 210 | 220 | 230 | 240 |
| F1 | 0  | 0  | 0   | 25  | 25  | 25  | 25  | 75  | 75  |
| F2 | 0  | 0  | 25  | 25  | 25  | 25  | 150 | 150 | 150 |
| F3 | 150| 150| 0   | 0   | 25  | 25  | 25  | 150 | 150 |
| F4 | 25 | 25 | 25  | 25  | 0   | 150 | 150 | 150 | 150 |

Compact structure characterized by symmetry and parallel mechanism is particularly suitable as a multi-dimensional force sensor prototype. This paper first presents a new innovative way parallel wrist sensor, six telescopic rod parallel mechanism to replace six one-dimensional rod, install additional elastic element on the link, as a sensor for measuring the force wrist sensor and said given sensor configuration parameters. Then start from the structural parameters of the parallel force sensor analyzes the basic principle of the sensor measuring the force that force transformation, derived its power transfer matrix theory, and analyzes the principle of the sensor and decoupled Jacobian matrix analytic number of conditions expression, the next step for the structural design and optimization of sensor laid the foundation.

3.2. The Hardware System of the Wrist Force Sensor

Wrist sensor hardware systems usually consist of two parts processing and signal sensing head. Sensing head portion made of an elastic body and a measuring bridge preamp circuit for generating a force signal and a complete pre-amplifier; stage signal processing section includes amplification, filtering, sample and hold signal, A/D conversion and for system control, computing and online communications computer systems.
For different applications, the system structure will be different. The topic of the wrist sensor system framework was shown in Fig. 2, which has the following functions and features:

1) Weak signal sensor output amplification, filtering;
2) The brightest signal decoupling, get the actual force signals;
3) Can be easily with all types of robots and host computer connection.

![Fig. 2. The topic of the wrist sensor system framework.](image)

### 3.3. Static Calibration of Wrist Force Sensor

Because of this mutual coupling relationship is complex, difficult to describe accurately from a theoretical perspective, typically using the second method, the experimental method for calibration, which will directly affect the measurement accuracy of the calibration accuracy of the sensor when using this method both to reduce the sensor manufacturing process requirements, but also to get a more accurate measurement results.

\[
A(p^{-1})y(k) = B(p^{-1})u(k) \quad \text{(9)}
\]

\[
p^{-1}y(k) = y(k-1) \quad \text{(10)}
\]

\[
A(p^{-1}) = a_0 + a_1 p^{-1} + a_2 p^{-2} + \cdots + a_n p^{-n} \quad \text{(11)}
\]

\[
B(p^{-1}) = b_0 + b_1 p^{-1} + b_2 p^{-2} + \cdots + b_n p^{-n} \quad \text{(12)}
\]

Quantitative relationship between process output readings corresponding with the role of looking sensor on the sensor coordinate origin between static force vector is the static calibration.

\[
Y(z) = \sum_{j=0}^{n} a_j z^{-j} \\
X(z) = 1 + \sum_{i=0}^{n} b_i z^{-i} \quad \text{(13)}
\]

### 4. Result and Simulation

#### 4.1. The Design of Sensor Circuit System

In the strain gauge measuring techniques, the most widely used measurement circuit is a Wheatstone bridge circuit. The test computer data acquisition system block diagram was shown in Fig. 3.

![Fig. 3. The test computer data acquisition system block diagram.](image)

#### 4.1.1. Design of Strain Distribution and Bridge Road

In a one-dimensional force measurement under load output voltage after a gradual change value of each channel, the need for a linear fit to do all the measurement data to understand the impact of each dimension force/torque coupling between that. Because of the inter-dimensional coupled afterburner in a single direction, the other direction will produce a force or torque effect. Single-Axis Force/Torque role under the corresponding voltage output was shown in Fig. 4.

#### 4.1.2. Signal Acquisition and Data Processing System

Main function is required calibration personnel data analysis process is called sampling, the sampling loop wrist force sensor 6-channel signal, the sampling data to append a way to write a data file.
The main data file by channel assigned six data files, access the entire time course of the output signal for each channel, and then call the data processing and performance analysis program to open the data file, the data is processed to obtain a variety of calibration results. Sensor static calibration virtual instrument software components were shown in Fig. 5.

4.2. The Experimental Device and Experimental Method

Sensor circuit system design includes the following aspects: the bridge design, design signal acquisition system, the data processing system and graphics display system design was shown in Fig. 6. Bridge is designed primarily to improve the measurement bridge voltage sensitivity, wide measuring range, a simple circuit structure, high precision, easy to implement temperature compensation.

For the purpose, the data processing system mainly consider amplifying the output voltage signal, signal filtering, analog to digital conversion of the signal, the data acquisition board selection (including sampling rate and sampling precision) and so on. The data processing system and graphics design system includes a static calibration software design, dynamic calibration software design, data processing software and graphics software. Theoretical study of this chapter focuses on the preparation of software measurement circuit design and measurement systems acquisition.

Fig. 6. The data processing system and graphics display system design.
4.3. Data Acquisition and Processing

Data collection using the high-speed data acquisition card PCI-1802L, its main characteristics related to the A / D has been introduced. Dynamic calibration software interface was shown in Fig. 7, the dynamic calibration experiments, the sample rate is set to 10 K, the sampling time of 3 seconds, collecting a total of 30,000 points, after the end of the program automatically saves the results of the sampling data, call LabVIEW data preprocessing and response curves plotted.

Fig. 7. Dynamic calibration software interface.

5. Conclusions

This paper presents a new robot wrist force sensor. Using the finite element method structural static analysis and modal analysis, quantitative analysis of the inter-dimensional coupling, and make a reasonable evaluation of its structural design, while the natural frequencies and mode shapes type; wrist sensor for static calibration, the calibration matrix has been established correspondence between the measuring force signal and the output voltage signal; wrist sensor for dynamic calibration of the sensor to calculate the natural frequency and damping ratio dynamic performance indicators based on dynamic calibration data, using time-domain modeling method to establish a variety of dynamic mathematical model of the sensor, and its spectral estimation method carried out in the frequency domain analysis; relatively low damping for sensors shortcomings dynamic compensator design, compensation good results.

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