Design of Spatial Posture Measurement System Based on Camera Perspective Projection Model

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Abstract. Aiming at the requirement of high precision, fast speed and high safety and reliability in ground zero gravity test of space mechanism, the design principle and system composition of space position and attitude measurement system based on camera perspective projection model are elaborated in detail, which effectively reduces the hardware failure rate and meets the requirements of space mechanism products. Interview test requirements.

1. Introduction
Experiments of space mechanism products on the ground need to be carried out under simulated microgravity environment to avoid damage caused by bending moment caused by gravity. In the ground deployment test of space mechanism, the effect of gravity can be counteracted by applying a vertical upward pull force to the suspension rope. However, in the process of ground motion test, it is necessary to keep the suspension rope perpendicular to the space mechanism, so as to ensure that the tension exerted on the space mechanism completely counteracts the effect of gravity [1-3]. Spatial pose measurement system is used to measure the displacement of the suspension point fixed on the space mechanism during the test, and transfer the measurement results to the control system [4]. By controlling the movement of the suspension rope, the purpose of the suspension rope plumb is finally realized [3]. In this paper, the design principle and system composition of the space pose measurement system are described in detail.

2. Measurement Principle of Posture and Position Measurement System
The measuring principle of the space pose measurement system is shown in Figure 1. Three coordinate systems are defined, including camera coordinate system OcXcYcZc, hanging point coordinate system OuXuYuZu and target coordinate system. Ensure that the Z direction of the coordinate system of the hanging point is vertical and the XY direction is the motion direction of the two-dimensional servo subsystem. Because the camera coordinate system and the hanging point coordinate system are fixed together, the target coordinate system and the hanging point are fixed together [5-6].
Figure 1. Measurement principle of a pose measurement system

According to the rigid body transformation relations, the following formulas can be obtained:

\[ O_uX_uY_uZ_u = R_{cu} \times O_cX_cY_cZ_c + T_{cu} \]

The coordinate values of the lower hanging point in the target coordinate system are as follows:

\[ P_d = \begin{bmatrix} x_d \\ y_d \\ z_d \end{bmatrix} \]

Based on visual perspective transformation, the \((R_w, T_w)\) relationship between target coordinate system and camera coordinate system can be obtained.

\[ O_cX_cY_cZ_c = R_{wc} \times O_wX_wY_wZ_w + T_{wc} \]

In this way, the coordinate values of the lower hanging point in the coordinate system of the upper hanging point can be calculated.

\[ P_u = R_{cu} \times [R_{wc} \times P_d + T_{wc}] + T_{cu} \]

When \(P_u = [0 \quad 0 \quad z]\), it means that the Z axis of the coordinate system of the hanging point at the lower hanging point is plumb, because the Z direction of the coordinate system of the hanging point at the upper hanging point is plumb, the hanging rope connecting the hanging point at this time is plumb. In order to facilitate calculation and reduce calculation errors, we set the lower hanging point as the origin of the target coordinate system, that is, \(P_d = [0 \quad 0 \quad 0]\), by translating the coordinate system, so that the coordinate value of the lower hanging point in the upper hanging point coordinate system is:
The actual system ensures that the camera coordinate system and the hanging point coordinate system are parallel by machining and positioning structure, so that the camera coordinate system and the hanging point coordinate system are only translation relations [7-8].

\[
P_u = R_{eu} \times T_{eu} + T_{eu}
\]

Among them, \( T_{eu} \) is measured by visual system and \( T_{eu} \) is determined by mechanical mechanism. Since the coordinate system of the upper hanging point is parallel to the coordinate system of the two-dimensional servo system in \( XY \) directions, the deviation of the lower hanging point from the upper hanging point in the horizontal direction is calculated as \( [x_u \ y_u] \).

3. Composition of Posture Measurement System

The pose measurement system consists of a stereo target, a megapixel camera, a mega resolution lens, an infrared filter and a real-time machine pose measurement system.

3.1. Stereo Target

As shown in Fig. 2, seven infrared light emitting LEDs with known coordinate positions are distributed on the stereo target. The power supply of LED is 9V, which is provided by two-dimensional servo system. Five feature points are used in the calculation, and the other two are used as standby points. In the measurement process, the relationship between the target coordinate system and the coordinate system of the stereo target is calculated through the relationship between the five feature points in the image of the camera and the coordinate values of the feature points in the target coordinate system. The relative pose of the target coordinate system and the hanging point is known, and the coordinate value of the lower hanging point is in the target coordinate system. Finally, the horizontal relative relationship between the upper and lower hanging points is calculated. Deviation. The stereo target uses infrared light emitting LED as the optical feature point, and adds a filter at the outside of the lens. At the same time, the intensity of infrared light emitting LED can be adjusted to improve the signal-to-noise ratio. Therefore, the influence of background noise can be effectively eliminated. The positioning accuracy of feature points can be further improved by subpixel subdivision method, and the measurement accuracy of the whole system can be further improved.

The principle of target circuit is that seven infrared LEDs are connected in parallel under the regulated power supply, which ensures that when one of them fails, it does not affect the luminescence of other LEDs and ensures the normal operation of the target. Each LED is connected with a constant current source in series, which ensures the consistency of luminance in seven LEDs.
Infrared light emitting diodes SE3470-003

Infrared LED is shown in Figure 3. The selected American Honeywell product SE3470-003 has a luminous bandwidth of 840-920 nm. Considering the type of filter, we choose a spectrum of 850 nm. SE3470-003 has good luminous stability and long service life.

Figure 4 shows the parameters of SE3470-003 light emitting diode.

Figure 3. Infrared light emitting diodes SE3470-003

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Figure 4 shows the parameters of SE3470-003 light emitting diode.

Figure 4. SE3470-003 parameters

3.2. Megapixel Camera

The Prosilica GT 1660 camera is shown in Figure 5. The Prosilica GT 1660 is a 2-megapixel Gigabit Network Interface (GigE Vision) digital camera manufactured by Allied Vision Technologies (AVT), Germany. GT1660 is a rugged camera even in extreme temperature conditions and fluctuating lighting environments. The camera uses a CCD chip, which makes the image clearer and the frame frequency up to 62 frames. It can better meet the needs of this project. The sensor sensitivity of Prosilica GT 1660 camera is shown in Figure 6.
3.3. Million resolution lens
The millions resolution lens selected from the Japanese Kowa company LM25JCM can satisfy the change of the depth of field of the master-slave pose measurement system from 2.6 m to 4.3 M. LM25JCM lens distortion is less than - 0.04%, which meets the requirements of high precision vision measurement. LM25JCM schematic diagram is shown in Figure 7.

1) Infrared filter
The bandwidth of different types of filters is fixed. The narrowband filter BN850 is selected here. Its bandwidth is Narrow IR Bandpass 825-870 nm. It corresponds to 850 nm wavelength of infrared LED.
2) Real-time machine pose measurement system

NI embedded vision system, as a robust automation controller, combines the compatibility of industrial camera with the open communication of distributed industrial system and the high performance and flexibility of multi-core PC. It is suitable for high-speed sorting, assembly verification, packaging inspection and other machine vision applications.

The product EVS-1463RT, an American NI product used in this paper, is shown in Figure 8. It is specially designed for industrial-level machine vision processors. The embedded vision system can not only collect images from multiple camera interfaces to perform synchronous detection, but also match powerful and easy-to-use NI software, visual development module and visual students for automatic detection. Complete device. The design of EVS-1463RT is suitable for real-time image processing with multiple basic Camera Link or multiple Gigabit Ethernet cameras, and for machine vision applications (such as high-speed sorting, assembly verification, package inspection, network detection with line-scan cameras). NI EVS-1463RT can synchronize with programmable logic controller (PLC), human-machine interface (HMI) and motion controller with isolation and TTL I/O high channel number, high performance multi-core processors, 2 GB RAM and real-time operating system to achieve more complex and high-speed detection. This pose measurement system does not contain movable parts. It uses DVI distribution cable and contains three-position power connectors, including NI visual acquisition software DVD. It can realize a wide range of digital I/O and industrial communication. That is to say, the system can communicate with programmable logic controller
(PLC), human-machine interface (HMI), robot, sensor and excitation. Exciter and other automation equipment to achieve communication and integration. NI embedded vision system does not contain movable parts; they are naturally cooled by convection (without fans) and contain a solid-state hard disk (SSHD), which can meet the requirements of harsh production conditions.

NI EVS-1463RT function:
1) Real-time machine pose measurement system
2) High performance multicore processor; 2GB RAM for fast detection and large image
3) Connect multiple cameras for synchronous detection (Gigabit Ethernet Vision and Basic Camera Link)
4) Automatic detection with the help of visual generator configuration or programming with visual development module
5) Reliable and robust industrial systems without movable components (fan-free and solid-state hard disks)
6) High I/O Channel Number Suitable for Synchronization and Industrial Communication

4. Conclusion
Aiming at the requirement of high accuracy, fast measurement speed and high safety and reliability, the design principle and system composition of the space Pose Measurement System Based on camera perspective projection model are elaborated in detail. A space pose measurement system is designed on the platform of NI real-time machine pose measurement subsystem. In hardware selection, the real-time machine pose measurement subsystem, developed by NI Corporation of the United States, specializing in industrial machine vision applications, AVT camera of Germany, and LED of Honeywell Company of the United States are selected. High-quality products effectively reduce the hardware failure rate and meet the ground test requirements of space mechanism products.

References
[1] Wei Juanfang. Zero gravity environment simulation equipment for satellite antenna deployment. SPACE ELECTRONIC TECHNOLOGY. 2006, 2(34): 29-31
[2] Qu C C. Research and implementation of ground microgravity simulation system of space robotic arm [D]. Harbin: Harbin Institute of Technology, 2014: 39-54.
[3] Hao F. Research on rotary-arm micro-gravity simulation device of space manipulator [D]. Harbin: Harbin Institute of Technology, 2010: 1-9.
[4] WANG Cheng-ru, ZHAO Na, ZHANG Li-li. Image registration and stitching based on triangle geometry similarity [J]. Opto-Electronic Engineering.
[5] ZHANG Xian-Quan, TANG Zhen-Jun, LU Jiang-Tao. Image Stitching Based on Line Matching [J]. Computer Science.
[6] GAO Chao, ZHANG Xin, WANG Yun-li,et al. Automatic stitching approach of aerial image sequence based on SIFT features [J]. Computer Applications.
[7] David G.Lowe. Object recognition from local scale-invariant features [C]. Proceeding of ICCV. Piscataway, NJ, USA: Institute of Electrical and Electronics Engineers Inc. 1999, 2: 1150-1157.
[8] David G.Lowe. Distinctive image features from scale-invariant keypoints [J]. International Journal of Computer Vision, 2004, 60(2): 91-110.