

Study on a Method of Horizontal Position Measurement for Suspended Target Based on Single Camera

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Abstract. The low gravity test is an indispensable test for space manipulators before launching into the outer space. This paper aims to propose a position measurement method for the suspended target, which is a component of a low gravity test system. In order to obtain the position of lower hanging point in real time, an active target is designed with 7 infrared LEDs. A single camera is employed to acquire images of the feature points on the target. After that, the region growing, centroid extracting and locally searching methods are adopted to get the feature points location on the image plane. And then the perspective-n-point pose determination method (PnP) is used to calculate the relative position of the upper and lower hanging points. Experimental results show that this method can measure the horizontal position accurately and efficiently, and the maximum error is 0.128mm.

1. Introduction

Space manipulator is an important tool for human activities of space exploration. It plays a key role in the construction and maintenance of space station. The space manipulator actually works in the outer space environment, which is a typical low gravity environment. Since the high cost of space missions, the space manipulator must be highly safe and reliable. A large number of ground tests need to be carried out before launching into the space. Therefore, the technology of low gravity environment simulation on the ground has an indispensable position in the whole space engineering system [1].

At present, the technology of low gravity environment simulation on the ground has been developed for several decades. The methods to obtain low gravity environment mainly include the falling tower method [2], the parabolic flight method [3], the water floating method [4], the air flotation method [5] and the suspension method [6-8], etc. The suspension method is widely used in the low gravity experiment of space deployable mechanism, space manipulator, lander and star vehicle, as well as the operation training of astronauts. The suspension method has the advantages of simple structure, easy indoor implementation, unlimited test time, and low gravity environment in 3D space.

In order to achieve the motion simulation of space manipulator in 3D space on the ground, our team designed a low gravity simulation device based on suspension method, which consists of hanger mechanism, ropes, tension control device, horizontal position measuring and tracking device, etc. The tension control device adopts a servo motor and a reel structure. A force sensor is used to measure the



tension of the sling in real time. The measurement result is taken as input to control the servo motor which keep a constant tension and track the vertical motion of the target. The horizontal position measuring and tracking device accurately tracks the horizontal movement of the lifting point to make the gravity compensation force of the sling vertical upward.

This paper aims to study the method of horizontal position measurement for the suspended target based on a single camera. An active infrared target is fixed on the lower end of the sling, which can be on behalf of the target on the position. The projection of 3D space to 2D image plane is achieved using a camera. The position of the target in the camera coordinate is calculated by the classical PnP algorithm, and then the relative position between the upper and lower ends of the sling is obtained using coordinates transformation. The deviation of horizontal position is taken as an input to control the tracking device moving.

2. System architecture

The position measurement system consists of a camera, a target, a platform and a hanger. As shown in Fig. 1, the platform and the upper hanging point are installed on the movement tracking device, and the camera is fixed on the platform. The target is installed on the hanger and fixed with the lower hanging point. Its working principle is to calculate the relationship between the coordinates defined by the target and the camera, according to the visual perspective model, by collecting the projection images of the infrared LED on the target. Since the camera and the upper hanging point are fixed on the platform, the target and the hanger are fixed together, the offset of the upper hanging point relative to the lower hanging point in the horizontal direction can be calculated by coordinate transformation.

There are three coordinates defined, including the camera coordinate, the upper hanging point coordinate and the target coordinate. It is ensured that the coordinate Z_u is directed toward the sling, and the X_u , Y_u is the movement direction of the position tracking device. The camera coordinate is connected with the upper hanging point coordinate, while the target coordinate system is fixedly connected with the lower hanging point.

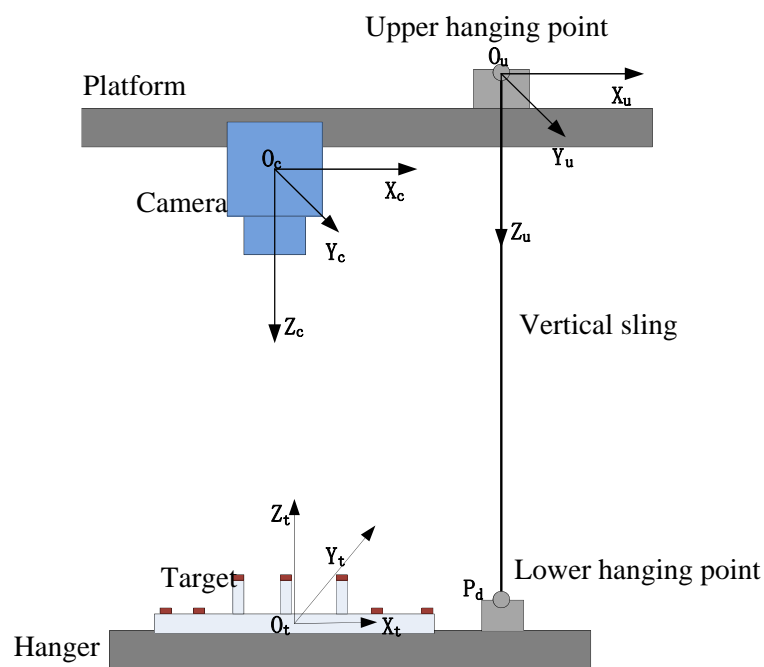


Figure 1. Position measurement system.

There are seven infrared LEDs with different height on the 3D target, three of which are 70mm and the remaining are 10mm. Their relative positions are known according to the design parameters. 5

feature points are used in the calculation, and the other 2 are used as backups. In the process of measurement, the relationship between the image of the camera and the coordinate of the feature point in the target coordinate is calculated by the 5 feature points. The relationship between the target coordinate and the camera coordinate (rotation and translation) is calculated. The position of the camera coordinate and the upper hanging point is known, and the lower hanging point is in the target coordinate. Finally, the relative deviation of the upper and lower hanging points is calculated in horizontal direction. The infrared luminescent LED is used as the optical feature point, and the filter is added to the outer end of the lens. At the same time, the light intensity of the infrared luminescent LED can be adjusted to improve the signal to noise ratio. Therefore, the influence of the background noise can be eliminated effectively. The positioning accuracy of the feature points can be further improved by subpixel subdivision method, and the whole system is further improved.

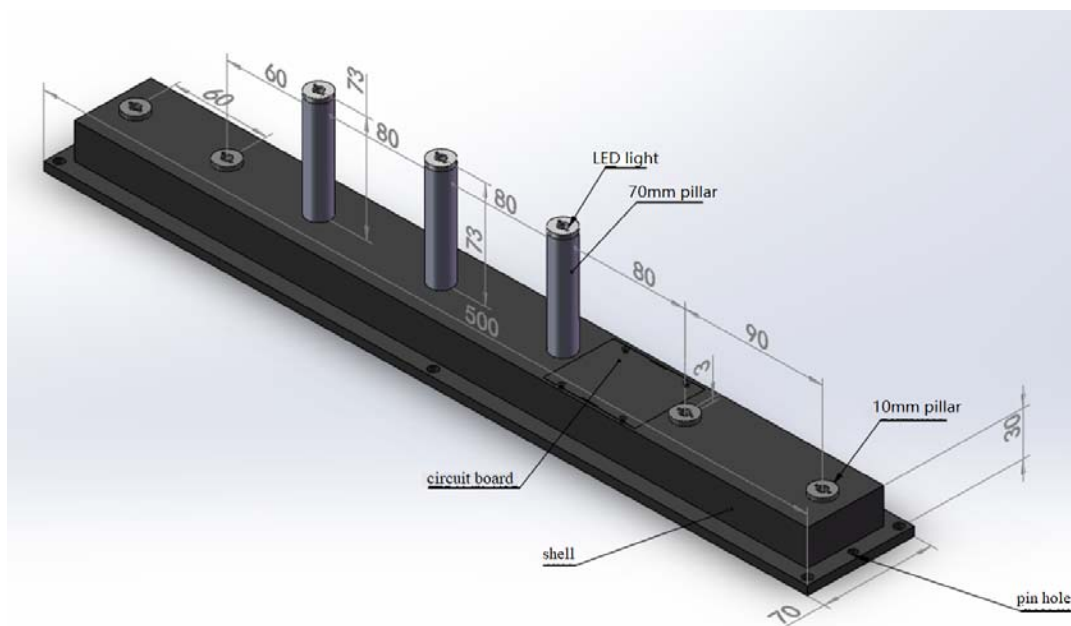


Figure 2. Three-dimensional target.

3. Horizontal position measurement method

The process of position measurement can be divided into the following phases, including camera initialization, images acquisition, feature points extraction, position calculation. In the first phase, the parameters of the camera are configured by calling the dynamic library, including the exposure time, the sampling rate, etc. Image acquisition begins after the camera initialization. The images are stored in a particular queue and then send to feature point's extraction and the position calculation units using the GigE protocol. The detail process of position measurement is shown in Figure 3.

3.1. Extraction of image feature points

This paper employs the region growing method to extract the feature points, which can be implemented as follows.

1) *Image binary processing*: Since the monochrome camera is used in this paper, the images collected is in the form of gray value. The gray threshold is set to 10, the pixel value greater than the threshold is set to 1, otherwise it is 0.

2) *Region growing*: Based on the binary images, a point with the value of 1 is selected as a seed for region growing. Thereby the region that may contain the feature points is reducing further.

3) *Region segmentation*: After the feature point region is completed, the size of the region range of each feature point in the image is detected and the feature points are separated from the same size.

4) *Centroid extraction*: This paper adopts the method of Gauss surface distribution to extract the centroid of the feature points. By adding virtual pixels into the imaging area, the number of effective pixels can be increased, thus improving the centroid positioning accuracy of the landmark.

$$f(u, v) = f(i, j)(1 - \alpha)(1 - \beta) + f(i + 1, j)\alpha(1 - \beta) + f(i, j + 1)(1 - \alpha)\beta + f(i + 1, j + 1)\alpha\beta \quad (1)$$

Where $i = [u]$, $j = [v]$, $\alpha = u - [u]$, $\beta = v - [v]$.

5) *Local searching*: Since the global search time is too long, a local search algorithm is designed. Before the local search algorithm works, the global search method is employed to find the location of the feature point on the image plane as the center of the search window. When the required pixels appear in the window, the pixel will be used as the seed to the surrounding image region growth. The location of the feature point obtained by local search method will serve as the center of the next local search box. In case of failure, the global search will theoretically appear only once, and the image processing will always use the local search mode.

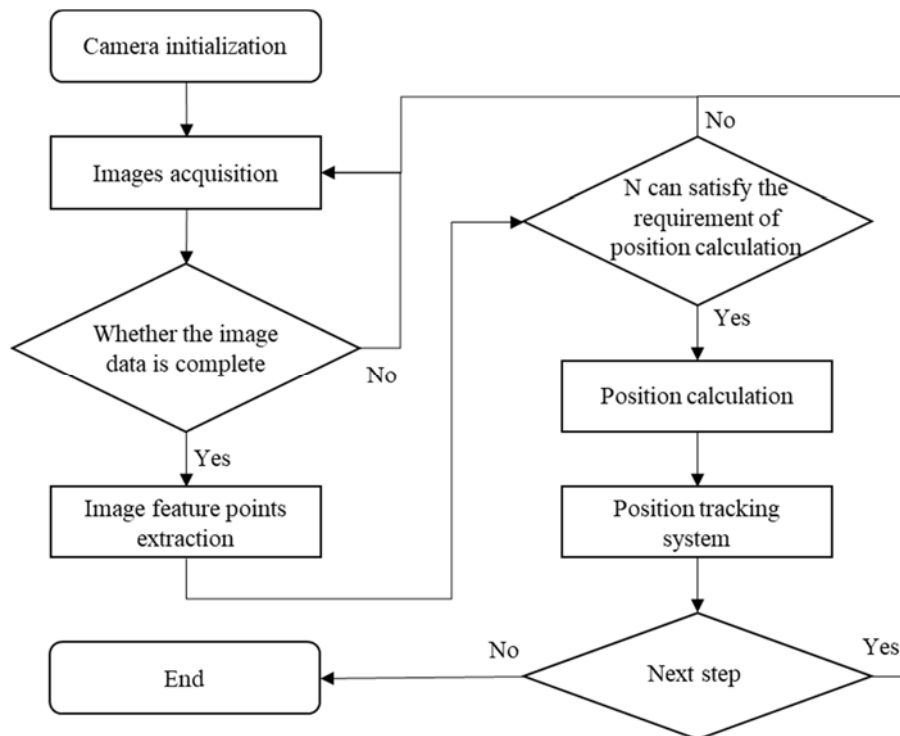


Figure 3. The process of position measurement.

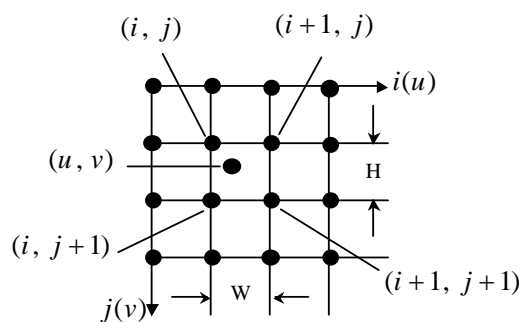


Figure 4. Bilinear interpolation.

3.2. Location of target coordinate

After extracting the feature points, the next step is to calculate the relative position based on the location of the feature points on the image plane using PnP algorithm. The perspective-n-point pose determination problem (PnP) has been studied for various numbers of points (from the minimum of 3). There are many mature solving methods to this problem [9, 10], so this paper does not give much introduction.

In this paper, the PnP algorithm need 5 feature points, of which 3 feature points are used for the calculation of the PnP problem, and the other 2 points are used for LM iteration to improve the solving precision. In order to ensure the uniqueness of the solution, 2 projection points of the high pillars and 3 points of the low pillars must be included in the 5 feature points.

4. Experimental results and error analysis

The target is calibrated accurately using 2D projector. The first feature point is selected as the original point of the coordinate during the calibrating process. The results of the calibration of other points are shown in table 1.

Table 1. Calibration result of target feature points (mm).

Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7
-0.01	-60.15	-120.46	-200.56	-281.12	-360.77	-451.23
-0.01	-0.35	-0.40	-0.21	-0.34	-0.18	0.03
0.00	0.09	55.19	55.24	55.22	-0.05	0.24

In order to verify the effectiveness of the presented approach, several experiments were carried out in the laboratory. The target is fixed on a high precision CNC turntable. The turntable can provide real-time information including vertical displacement, pitching angle, yaw angle and roll angle of the target. For the working distance, we can adjust the position of the visual acquisition system to simulate.

The distance between the camera and the target is changing at 1740mm, 3010mm and 5560mm in the test. The turntable makes the Y direction distance moving up at 0m, 50m, 100m, 150m, 200m, 250m, 300m, and then the turntable is revolved around the single axis 20 degrees. Errors of the position measurement are shown in Fig.5. The results show that the maximum error is 0.128mm, which meets the requirements.

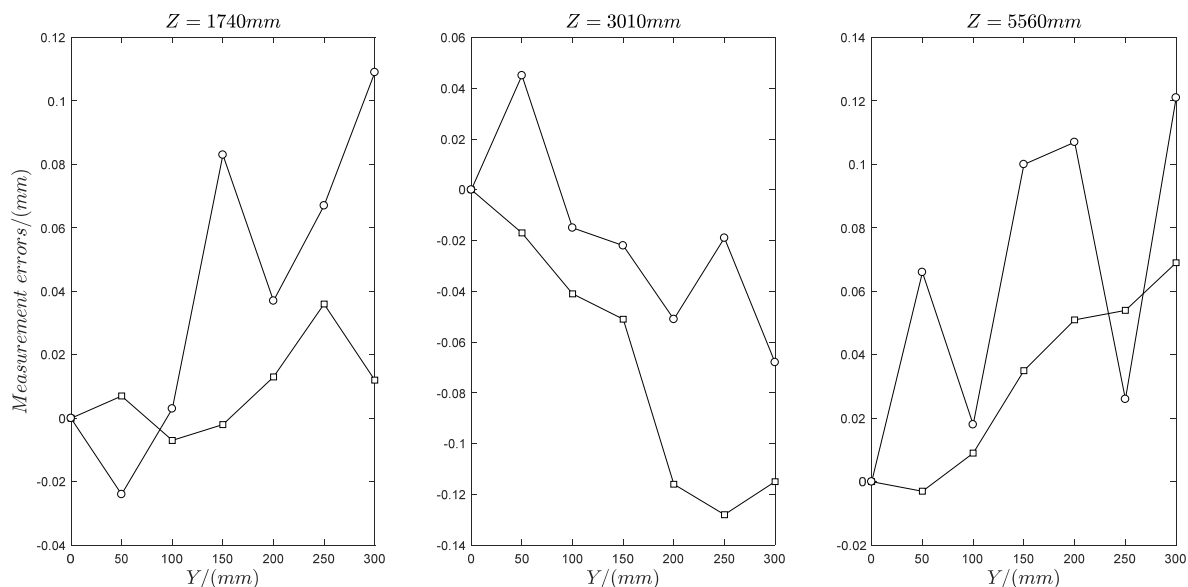


Figure 5. Measurement errors of the horizontal positions.

5. Conclusion

A measurement system and method for the suspended target using a single camera are presented in this paper, in order to solve the hanging point tracking problem. Since a 3D target with active infrared LEDs is designed to suppress the image noise using a filter, the workload of image processing is greatly reduced. The application of the region growing method and the local search method greatly improves the computation efficiency and ensures the real-time measurement. The experimental results show that this method can measure the position offset of the upper and lower hanging points with high accuracy, which does not vary with the Z-axis distance. It should be noted that the reliability of the proposed method has a great relationship with the size of the local searching window, which will also be the focus of our future research.

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