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Visual servo for gravity compensation system

Ye Jin*, Rui Wu, Weiming Liu, Xianglong Tang

Harbin Institute of Technology, Harbin, China

A R T I C L E I N F O

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A B S T R A C T

This paper proposed a visual servo framework for the tower-crane-like Gravity Compensation System that is widely used in various aerospace ground tests. In this framework, a real-time detection algorithm is proposed to measure the position of the target. Using this algorithm, the target's original position is marked firstly in a well-designed calibration step, and then compared to its real-time position to calculate the offset for tracking. To realize the high precision tracking, a 2-level servo mechanism is investigated, in which a large-inertia crane servo system is utilized for the rough tracking and a 2-DOF (2 Direction Of Freedom) platform is used for the precise localization. The proposed method leads to a high responding speed and low time-drift in wide range tracking, and greatly decreases the compensation error in the microgravity simulation for space manipulator and moon vehicle.

1. Introduction

It is necessary to do ground test for spacecraft before launching to eliminate potential problems. Apparently ground test of spacecraft should be done in microgravity environment that is similar to spacecraft's real working environment [12]. There are several ways to achieve manmade microgravity: free-falling object [1], bearing table, neutral buoyance [14] and suspension system [13].

Free-fall method, include drop town [4] and parabolic flight [11], directly provides a real weightless condition in the free-fall process. However, due to the short duration and limited experimental space, they are mainly used for the astronaut training or the validation of small device.

Buoyancy method is another widely used compensation technique [7], may simulate a large-scale and long-time weightless environment by buoyancy device such as buoyancy pool [10] air balloon. But taking into account the liquid/air resistance, they are only suitable for the low-speed experiments.

Among these methods, suspension system [8] is widely adopted because of its relative simple structure, easy construction and 3-D simulation with unlimited time [6]. As nonlinear systems, various identification and control methods [2,3] are investigated to improve the servo speed and compensation accuracy. Traditional suspension system [5,9] usually uses the gantry crane structure, which requires large amount of space and a long time. An alternative design adopts a tower crane structure that consumes less space, uses shorter time to build and fits need of various experiments. However, the tower crane structure suffers from deformation caused by limited weight and rigidity, thus it is harder to measure accurately under this structure.

In order to overcome these problems, based on the single-cable gravity compensation model [9], we proposed a tower-crane-like CCS (Gravity Compensation System) as shown in Fig. 1. This CCS is composed by a 2-level servo system, in which a tower-crane-like device is utilized for the rough tracking and a 2-DOF (2 Direction Of Freedom) platform is used for the precise localization. As shown in Fig. 1(a), the manipulator is hanged by a C-shape hook. Using a springless wire and a set of fixed pulley, the hook is suspended by the 2-DOF platform, and then connected to the force compensation device that composed by counterweight and torque motors.

The visual target is fixed on the top of the hook, and the corresponding image sensors are installed on the platform to detect the horizon offset between target and platform, which we denoted as **d**. As show in Fig. 1(b), let l denote the vertical distance from platform to target, and let ϕ denote the offset angle. The CCS's offset error rate is defined as

$$e = \tan\phi = \|\mathbf{d}\|/l = F/G \quad (1)$$

where F is the horizon force, and G is the compensated gravity. On the test, **d** and ϕ are measured in real time by a well-calibrated visual system, and the 2-level servo method is proposed to achieve a stable and precise tracking process, which keeps the offset error close to zero.

In Section 2, the visual detection method is discussed in detail. In Section 3, the servo framework is proposed including system calibration and 2-layer position control. The experimental results are shown in Section 4.

* Corresponding author.
E-mail addresses: jinye@hit.edu.cn, 48549712@qq.com (Y. Jin), simple@hit.edu.cn (R. Wu), weimingliu@hit.edu.cn (W. Liu), tangxl@hit.edu.cn (X. Tang).

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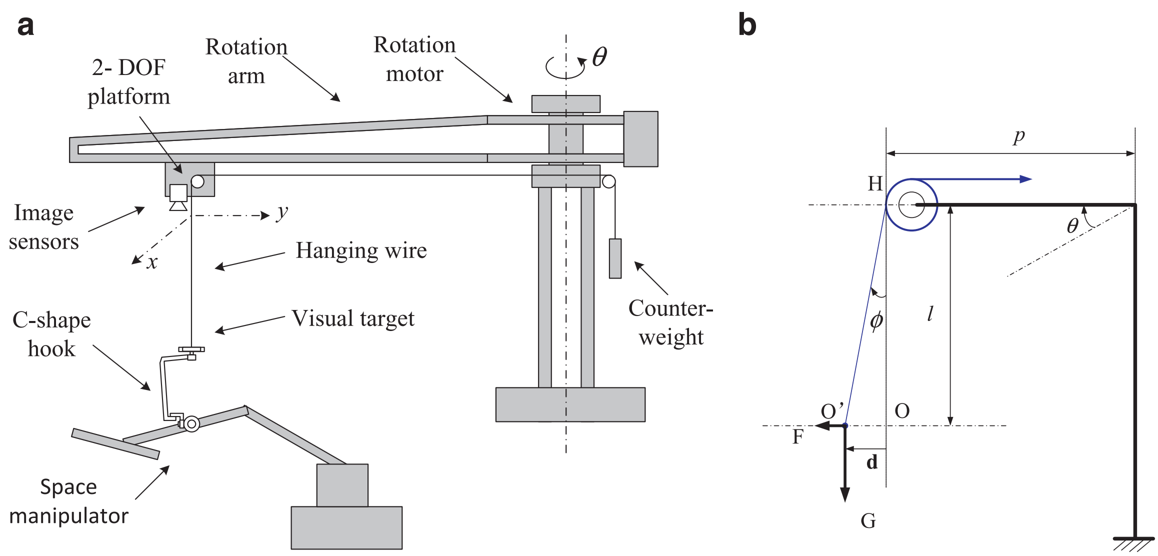

Fig. 1. Structure and servo principle of CCS. (a) Global structure, (b) servo principle.

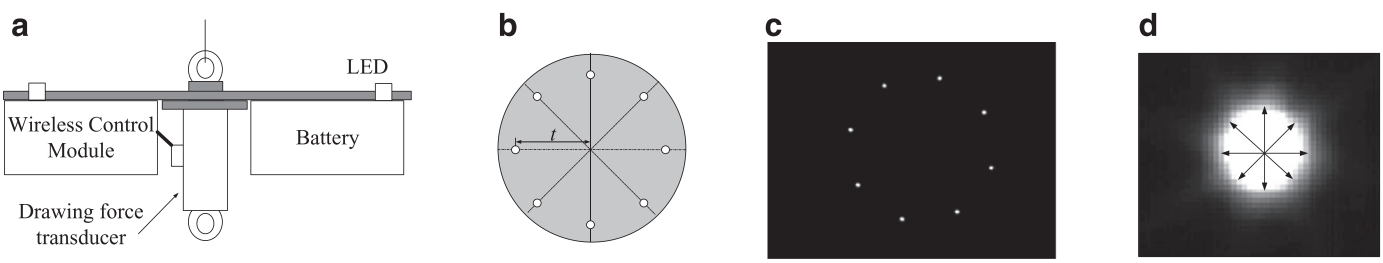

Fig. 2. Target construction and sensed image. (a) Target structure, (b) LED light, (c) target image, (d) sensed light spot.

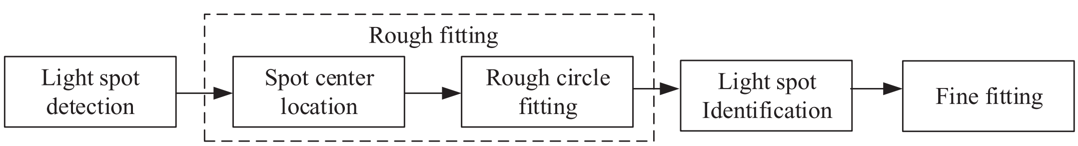

Fig. 3. Target detection diagram.

2. Visual detection method

The visual detection system is composed by a round LED target fixed on the top of the hook and several image sensors installed at the bottom of the platform toward the target. A real-time detection algorithm is proposed to measure the center and the radius of the target. Using this algorithm, the target's original position is marked firstly in a well-designed calibration step, and then compared to its real-time position to calculate the compensating error.

2.1. Target structure

As show in Fig. 2, 8 LED light are uniformly mounted on a circle with radius of t. Under the light plate, a battery, a drawing force transducer and a wireless control module are installed. Using a band-pass optical filter to filter interference light, we can get a desired target image with pure black background as show in Fig. 2(c).

In many ground tests, we should simulate the cruel space environment such as direct sun shine, drift of lunar regolith, etc. To overcome those disturbances, as show in Fig. 3, a hierarchical detection algorithm is proposed to robustly detect the center coordinate and the radius of the target image.

2.2. Light spot detection

According to the intensity, the pixels are classified into three types: background, light and scattering area. When a light pixel is detected, an 8-neighbourhood search method is used to locate its light and scatter area, which form a candidate region.

In order to assure that only the LED light spots are extracted, each candidate region needs to fulfill the following requirement:

$$\begin{cases} \dfrac{n_{\text{light}}}{n_{\text{scatter}}} > \text{Ratio}_{\text{light,scatter}} \\ \dfrac{n_{\text{light}} + n_{\text{scatter}}}{W \times H} > \text{Ratio}_{\text{size}} \\ \dfrac{1}{\text{Ratio}_{\text{width,height}}} < \dfrac{W}{H} < \text{Ratio}_{\text{width,height}}, \end{cases} \tag{2}$$

where n_{light} denotes the number of light points, n_{scatter} denotes the number of scattering points, W and H denote the width and height of the candidate region in pixel. According to (2), only the clear round spots can be extracted as the valid light spot, which will be used for the following rough fitting. In our system, we set $\text{Ratio}_{\text{light,scatter}} = 2.0$, $\text{Ratio}_{\text{size}} = 0.75$ and $\text{Ratio}_{\text{width,height}} = 2$.