The Development of the Automatic Lifting Gear for precision measurement

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Abstract. Precision measurement is an important method to evaluate the performance of spacecraft assembly. As flight missions become more complex, precision measurement has become an important link to ensure the reliability of spacecraft [1]. In order to solve the problems of precision measurement instruments required during the precise assembly of some components in the spacecraft assembly process, the installation height is high, the stability is sensitive, the ground measurement site is limited, the types of matching measurement instruments required are large, and the transportation needs are strong. An automatic lifting platform solution for longitude measurement is proposed, and the prototype is tested. The test results fully meet the requirements, which verifies the feasibility of the scheme.

1. Introduction
In order to ensure the normal operation of the spacecraft, it is necessary to calibrate the positional relationship between the sensitive elements which are located in the ascender, such as digital solar sensor, laser IMU, fiber laser IMU, and star sensor, and the orbiter under the state of four instruments. The precision measuring instruments need to be erected at the height of 8 meters. The precision measurement instruments need to maintain stable during the measurement work for the accuracy. This means the stability of the precision measurement platform has to meet the relevant requirements before the instrument is raised to the maximum height. The precision measurement work is usually performed in final assembly base, which means the supporting platform may be limited by the ground space. Since the precision measurement work needs to be completed by a variety of different instruments, the precision measurement platform needs to be able to match those equipment. The precision measurement work also must meet the requirements of the model launch site as well as the transportation requirements. In this case, this paper give a solution of an automatic lifting platform which can be moved in any direction and has high stability when rises to the maximum working height. The product development has been completed and all the indicators meet the design requirements.

2. The Realization Of The Overall Structure
The precision measurement automatic lifting platform is used to place laser tracker, theodolite and gyro theodolite, which can achieve the optimal layout of large-scale coordinate measurement, when the spacecraft is calibrating the positional relationship between the sensitive elements which are located in the ascender, such as digital solar sensor, laser IMU, fiber laser IMU, and star sensor, and the orbiter under the state of four instruments. Therefore, it is required to achieve a precision measurement height...
greater than 8 meters, with automatic lifting and locking, stable aerial work, omnidirectional movement, compact structure, large load capacity, high safety factor, and strong interface versatility. The schematic diagram of the structure of the precision measurement automatic lifting platform is shown in Figure 1.

2.1. Omni-directional Mobile Base
The omnidirectional mobile base is the foundation of the entire system. Four automatic omnidirectional wheels are installed at the bottom to realize its own omnidirectional movement. The top surface is equipped with telescopic components such as fixed cylinders, elevators, and follow-up telescopic rods to implement measuring equipment automatic lifting. Four manual screw elevators are installed at the four corners to support the base stably to maintain the stability of the equipment during the precision measurement. The internal integration of the charging system, battery system, and control system is used for the power supply of the overall equipment and control, the overall structure is shown in Figure 2.

![Figure 1. The Composition of Automatic Lifting Platform for Precision Measurement](image1)

![Figure 2. The Internal Structure of the Base](image2)
2.2. Full-automatic carbon fiber lifting gear
This set of system, as a precise and automatic support platform, needs to meet the requirements of bearing safety, stability, and transportation requirements of aircraft and trains. In order to meet the above requirements, this structure adopts a design scheme of an electric push rod with a fixed cylinder and a synchronous expansion and contraction of the four cylinders. The transmission scheme is shown in Figure 3. The first stage pusher at the bottom of the transmission process drives the yellow screw nut to move upward, pushing the second telescopic cylinder to extend. At the same time, the external spline designed on the upper part of the first stage pusher transmits the torque to the inner flower designed on the second stage, so the three-stage push rod is driven to rotate. As a result, the three-stage lifting gear is raised, and the four-stage and five-stage telescopic cylinder are raised in the same way. The retraction process is not the reverse process of the ascent process, and finally the synchronous extension and contraction of the entire support cylinder is achieved.

In order to overcome the torque during the entire rotation process, this structure is embedded with three guide rails on the inner wall of the carbon fiber tube to prevent the screw rotation and lifting gear from rotating. Each section of the telescopic cylinder has two upper and lower guides as shown in the green part for smooth operation. For sake of the self-locking function after lifting, the lifting screw uses a trapezoidal screw for mechanical self-locking, and the screw drive uses a turbine worm drive to have a secondary self-locking function.

3. The Control System Design

3.1. Omni-directional mobile base walking system
The omnidirectional mobile base walking control system is used for the omnidirectional mobile base walking and steering control. It is an omnidirectional synchronous control system based on Omron PLC control. Its principle block diagram is shown in Figure 4. The base movement control system mainly includes a PLC main control unit, a DC motor drive unit, a remote control unit, a human-computer interaction unit, an obstacle avoidance unit, and a power supply unit. PLC module A is used to realize the functions of walking control, steering control, obstacle avoidance, power supply and human-computer interaction of the base.
3.2. Implementation of Walking and Steering Drive

The walking system has four steerable drive walking mechanisms, each set of drive wheels are electric universal wheels, and the steering adopts a differential design. In order to effectively control the steering of the wheel set during walking, two walking angle encoders are respectively installed on the four wheel sets for feedback of the walking angle data and the steering angle data of the wheel set. The control schematic diagram of the walking system is shown in Figure 5.

3.3. Lifting Gear Control Scheme

The control system of the automatic lifting gear of the automatic lifting platform mainly includes a main control unit, a driving unit, a remote control unit, a human-computer interaction unit, and a power supply unit. The overall block diagram of the electronic control system is shown in Figure 6.
4. Stability test

4.1. Test plan

4.1.1. Load Theodolite Stability Test
(1) Set the theodolite on the aerial work platform, adjust the height of the lifting platform to 5 meters and 8 meters, adjust the level of the theodolite to within 1″, keep the sighting unit still, and record the readings of the horizontal and vertical angles of the theodolite.
(2) Record the horizontal and vertical readings of the theodolite again after 1 hour, and find the difference between the horizontal and vertical angles twice before and after 1 hour.

4.1.2. Stability of Aerial Work Platforms At 2.8 meters and 6.4 meters
(1) Place the set load (TM6100 theodolite and displacement platform) on the aerial work platform, set an observation target of the tracker at the top of the aerial work platform, and place the tracker on a stable ground position. The horizontal distance from the lifting platform is about 2.8 meters and 6.4 meters (to ensure that the tracker can observe a target of 7 meters high and the elevation angle does not exceed 45°). Adjust the height of the lifting platform to a position of 2.8 meters, use a 1.5″ reflective target, observe the high point target with a tracker, set the interval time to 2 minutes, and continuously monitor for 2 hours, and record the tracker's target point coordinates.
(2) Establish the following coordinate system: where the Z-axis is the height direction of the lifting platform, the X-axis direction is the north-south direction, and the Y-axis direction is the east-west direction. The height of the zero point of the coordinate point is set on the table of the lifting platform.
(3) Calculate the average and standard deviation of the coordinates of all monitoring target points within 2 hours. The standard deviation of each coordinate component represents the stability of the platform at 7 meters when the platform is operating at height in 2 hours. Calculate the maximum standard deviation of the highest position point during this period. This standard deviation can be regarded as the stability of the aerial work platform during this period of time.

4.2. Test Results

4.2.1. Loading the Theodolite Stability Measurement Results. The measurement results of the lifting platform to 5 meters height are shown in Table 1.

| Times       | Original State | 1h later | Offset |
|-------------|----------------|----------|--------|
|             | Horizontal angles/° | Vertical angles/° | Horizontal angles/° | Vertical angles/° | Horizontal angles/° | Vertical angles/° |
| First Time  | 348.7119        | 96.10895 | 348.7118 | 96.10898 | -0.47 | 0.11 |
| Second Time | 348.7118        | 96.10897 | 348.7117 | 96.10898 | -0.11 | 0.04 |
| Third Time  | 348.7117        | 96.10895 | 348.7117 | 96.10897 | -0.04 | 0.07 |

The measurement results of the lifting platform raised to 8 meters are shown in Table 2.

| Times       | Original State | 1h later | Offset |
|-------------|----------------|----------|--------|
|             | Horizontal angles/° | Vertical angles/° | Horizontal angles/° | Vertical angles/° | Horizontal angles/° | Vertical angles/° |
| First Time  | 348.5256        | 186.2027 | 348.5262 | 186.203  | 2.20  | 1.26 |
| Second Time | 348.526         | 186.2033 | 348.526  | 186.2036 | -0.11 | 1.30 |
| Third Time  | 348.5282        | 186.2039 | 348.5292 | 186.2043 | 3.850 | 1.33 |

The measurement results of the lifting platform raised to 8 meters are shown in Table 2.
4.3. Test Conclusions
According to the measurement results, the following conclusions can be drawn: the designed automatic lifting platform meets all design requirements, and the specific data are as Table 3:

Table 3. The specific data of experimental and measurement results

| Serial Number | Experimental Content                          | Measurement Results |
|---------------|---------------------------------------------|---------------------|
| 1             | Stability At 5 meters With Theodolite Loading | 0.1″/h              |
| 2             | Stability At 8 meters With Theodolite Loading | 1.3″/h              |
| 3             | Stability Of Lifting Platform At 2.8 Meters  | ΔZ=0.014            |
| 4             | Stability Of Lifting Platform At 6.4 Meters  | ΔZ=0.015mm          |

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