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A correction method of encoder bias in satellite laser ranging system

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Abstract: In a satellite laser ranging telescope system, well-aligned encoders of the elevation and azimuth axes are essential for tracking objects. However, it is very difficult and time-consuming to correct the bias between the absolute-position indices of the encoders and the astronomical coordinates, especially in the absence of a finder scope for our system. To solve this problem, a method is presented based on the phenomenon that all stars move anti-clockwise around Polaris in the northern hemisphere. Tests of the proposed adjustment procedure in a satellite laser ranging (SLR) system demonstrated the effectiveness and the time saved by using the approach, which greatly facilitates the optimization of a tracking system.

Key words: correction; encoder index; telescope; satellite laser ranging

1 Introduction

In a telescope used in a mobile SLR system, two sets of angle encoder feedback systems are implemented for the azimuth and elevation axes to determine the position and the velocity of the telescope. When the telescope moves to a new place, the absolute position biases always exist between the absolute feedback coordinates of the encoders and the astronomical ones. In general, the biases are calibrated using an astronomical method[1]. Before feedback systems were implemented, it was nearly impossible for a SLR system to track an object. In addition, a wide-angle finder scope (with a typical FOV of approximately 3 degrees), which can be used for encoder index correction, is usually attached to the main telescope to help find celestial objects because the field of view (FOV) of a normal telescope is small, i.e., less than 300 arcseconds[2].

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When a mobile SLR telescope system moves to a new place, the system needs to be recalibrated. The recalibration typically takes 1-2 hours and may take even longer. In particular, because of the limits of the construction of our system, our telescope is not equipped with a finder scope, so it is far more arduous to search for an object in the vast sky to correct the encoder bias, due to the very small FOV of the main telescope.

In this study, a method for encoder bias calibration in the absence of a finder scope is introduced, based on the phenomenon that all stars appear to revolve anticlockwise around Polaris (α UMi, Alpha Ursae Minoris) in the northern hemisphere.

2 Experimental setup

The horizontal telescope used for experiments belongs to a mobile SLR system, TROS1000, which is schematically shown in figure 1. A portion of the outgoing laser pulse (at a typical wavelength of 532 nm) is received by a detector, which initiates a time-of-flight measurement. The pulse propagates through the atmosphere and is reflected by the satellite retro-reflectors back through the atmosphere into the receiving telescope.

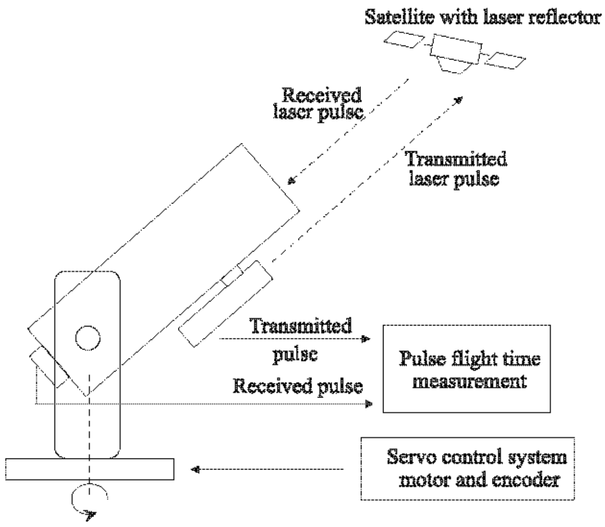

Figure 1 Schematic diagram of the mobile satellite laser ranging system

The telescope collects and focuses the reflected laser pulse onto a high-gain compensated single-photoelectron avalanche detector (C-SPAD). The C-SPAD converts the detected laser pulse into an electrical pulse that stops the time-interval counter of the time-of-flight measurement[3,4]. The round-trip time of the laser pulse flight corresponds to the range from the ground station to the satellite.

To enable continuous observation, a well-designed tracking system is required that includes two sets of motors, encoders for position feedback, and servo-control systems. We used an incremental rotary type of encoder, which provides cyclical outputs when the telescope rotates. The change of angle can be determined from two outputs of the encoder, which are 90 degrees out of phase. There is a third output from a position sensor, known as the "index" signal, which is output once every turn in each axis and is used as an absolute reference. Each time the telescope moves across this sensor, the position counter is changed to a specific number that corresponds to the biases between the feedback of the encoders and the astronomical coordinates[5].

3 Calibration method for the encoder bias

As we know, Polaris is considered to be the current northern Pole Star because it is close to the north celestial pole[6]. Polaris remains nearly motionless in the sky, and all of the stars in the northern sky appear to rotate around it in the anti-clockwise direction. Therefore, Polaris is used as an excellent reference point for celestial navigation and astrometry. Actually, Polaris is slightly off the pole, and it rotates in a tiny circle of approximately 1.5 degrees around the pole, so an accurate ephemeris is normally required when tracking Polaris[7].

An optical diagram of the telescope receiver is shown in figure 2. When the telescope tracks a celestial object, the light from the star is received by the telescope and is subsequently split by the beam splitter. One part of the light is reflected to the C-SPAD for the time-of-flight measurement, and the other part is transmitted to the CCD camera to help track the object.

The tracking steps (based on its ephemeris) on the CCD are schematically shown in figure 3. If the FOV of the telescope is sufficiently large, after the telescope continuously monitors Polaris for a few minutes, Polaris will remain still, while the other stars will move around it in an anti-clockwise direction. This concept of Polar Alignment is widely used in the equatorial telescope[8]. Unfortunately, the telescope FOV is usually less than 300 arcseconds, which is represented by the size of the dashed boxes in figure 3, i. e., the telescope FOV only covers a small fraction of the FOV that can be shown on the CCD screen. The figure also indicates that if a star, such as star A, shown on the CCD screen moves leftward, we can infer that the telescope is directed towards the upper region of Polaris. Similarly, a downward movement represents viewing in the left direction, such as star B, a down-rightward movement represents viewing in the lower-left direction, such as star C, and an upward movement represents viewing in the right region, such as star D. Consequently, we know the direction in which the telescope

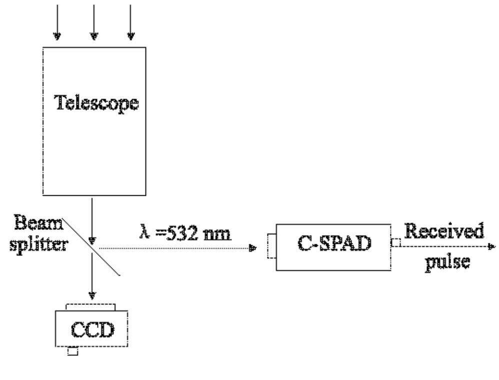

Figure 2 The optical diagram of the receiving system

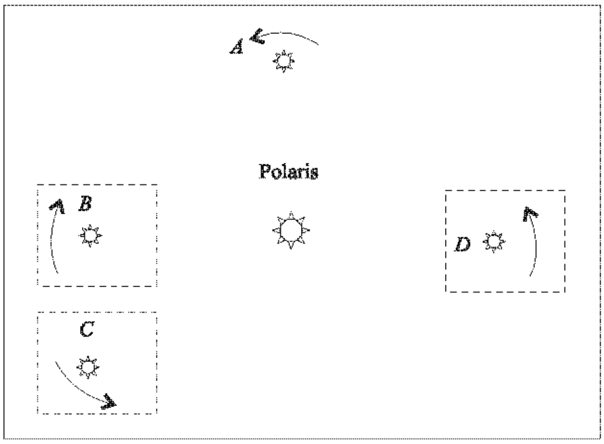

Figure 3 Schematic diagram of the Polaris tracking scheme

should be adjusted according to the movements of the star shown on the CCD screen.

To calibrate the bias of the encoder, we first track Polaris based on its ephemeris and then find a star near Polaris. After 5 minutes, the star's movement state reveals the relative position between this star and Polaris. With this information, we can adjust the telescope direction and then find Polaris. For example, assuming star *C*, as shown in figure 3, was manually found, by monitoring it for 5 minutes. We can determine that its movement direction is right-downward, which indicates that Polaris is in the upper right. We can then correct the telescope direction upward, which is equivalent to correcting the elevation axis, until another star *B* is found. Similarly, according to movement state of star *B*, the azimuth axis of the telescope is corrected rightward, and Polaris, the motionless star, will be finally located. Using a telescope with a 1-m diameter primary mirror and the CCD camera in our SLR system, celestial objects with an apparent magnitude of > 10° can be recognized on the screen, which results in a large number of stars being candidates for acting as a reference near Polaris. In summary, using the successive approximation method, Polaris can be easily found. The corrections of the elevation and azimuth axes are simply the corresponding bias of the encoders.

In fact, the corrections can be achieved using a computer-controlled procedure that includes 4 steps, as described below.

1) Set the bias register of the two axes to "0," drive the telescope across the two index sensors, and then manually move the telescope approximately to the direction of Polaris. After this step, the encoder numbers are the approximate bias values (E_{re} is the approximate error of the elevation axis, while E_{ra} is the approximate error of the azimuth), which are stored in their memories. Next, move the telescope across the two index sensors again.

2) Turn on the motors and drive the telescope, automatically following the ephemeris of Polaris. When the tracking errors become "0," the direction of the telescope is near Polaris.

3) Scan the telescope in the east-west direction, until a star is shown on the CCD screen. After monitoring the star for 5 minutes, the movement state of that star can be determined. Using a Matlab program to analyze the motion of that star, the relative position between that star and Polaris can be calculated. This calculated position enables Polaris to be easily found, based on the regulation procedure mentioned above. If a very bright star found is motionless after 5 minutes, it is Polaris. Move Polaris to the center of the FOV, and then record the correction of the two axes (E_{ce} is the correction error of the elevation axis, while E_{ca} is the correction error of the azimuth).

4) Calculate the biases of the encoder axes according to equations 1 and 2.

$$E_{be} = E_{re} + E_{ce} \tag{1}$$

$$E_{ba} = E_{ra} + E_{ca} \tag{2}$$

Store E_{be} and E_{ba} in the memories of the encoder indices, and test again. When the procedure of correction is finished, the telescope can point to any star without encoder biases.

4 Conclusions

Based on the phenomenon that all stars move around Polaris in an anti-clockwise direction in the northern hemisphere, we developed an efficient method to correct the encoder bias in a mobile satellite laser ranging system. This method significantly reduced the time spent on the system adjustment, from typically over 2 hours to merely 15 minutes, and was demonstrated to be effective and convenient for telescope systems that are unequipped with a finder scope, such as our system.

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