Automated Operations in Changchun SLR station: Current Status and Future Plans

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ABSTRACT

Current status and future plans are introduced of the automation functions in the Changchun SLR system. Current functions include real-time data recognition, range-gate following, daylight laser beam monitoring and daylight pointing improvement. Planned developments include echo rate optimizing and screen-locking of target and laser beam. Experience in implementation is also summarized.

Key words: Satellite laser ranging (SLR); Automation; Range-gate; Image processing; Data recognition

1. Introduction

The SLR system in Changchun Observatory is among the most productive ones[1]. At present, the system operates 24-7, and automation techniques are being developed to reduce the needed manual work. Most techniques involve software only, but some would require simple hardware modifications.

Current configuration of the operation panel is shown in Figure 1.

2. Current Status of Changchun Station

The Changchun SLR system (7237) is able to track satellite passes in both daytime and nighttime. Both day and night operations involve real-time data recognition and range-gate following function. Extra functions are developed for daylight tracking to reduce difficulty, for example laser beam monitoring and 'blind' pointing improvement.

2.1 Real-time data recognition

In the Changchun SLR system, the existence of echo signal is the final standard for operators to judge if the system is working. It is therefore important to know whether current system configuration is producing echo signals. Data recognition in real time is also useful in knowing the rough number of echo signals, as a basis to estimate the health of current normal point.

The real-time data recognition requires good prediction. Better prediction accuracy leads to more efficient recognition. The mechanism of recognition is that echo signals tend to cluster in a narrow range interval, which can be identified with simple histogram.

However, the current recognition method has its own problems. In noisy conditions, the method tends to give false-alerts. Here noisy condition means bright sky background in daytime, usually a piece of cloud or the area around the solar disk. In another hand, the method cannot recognize very weak signals, usually in the case of MEO or GEO tracking. The operator must wait longer before the recognition can pick up a stronger string of echo signals. Finally, the count of echo points is not accurate, due to both the single-photon level of signal and the limit of the method.

Small FOV
For night

Large FOV
For day

Figure 1.   Current configuration of Changchun SLR operation panel. Video screen in lower left shows the nighttime field of view, about 3 arc minutes. Screen in center right shows the daylight field of view, about 0.5 degrees. The two screens do not work at the same time.

2.2 Range-gate following function

Range-gate is the time window for detector to accept echo signals. It is a central topic in laser ranging systems that use avalanche diode as detector. The relative position between range-gate and echo signals may affect detection delay[2]. Excess prediction error can also cause echo signal to drift away from calculated range-gate. The Changchun SLR system uses a function to adjust range-gate position in real-time, so that to keep safe distance between range gate starting

edge and the echo signal.

The function requires real-time data recognition as mentioned above. First, the angular and range capture of echo signal should be manually done. Then the operator enables range-gate following function. The function will continuously adjust range-gate position to suit echo signals. The function is useful to deal with rapid change in range offset, when range prediction is imperfect for the current pass.

The function has an extension to solve for time and range bias from a short span of data. When range offset variation rate is too high to follow, solving for time bias will significantly reduce the variation rate.
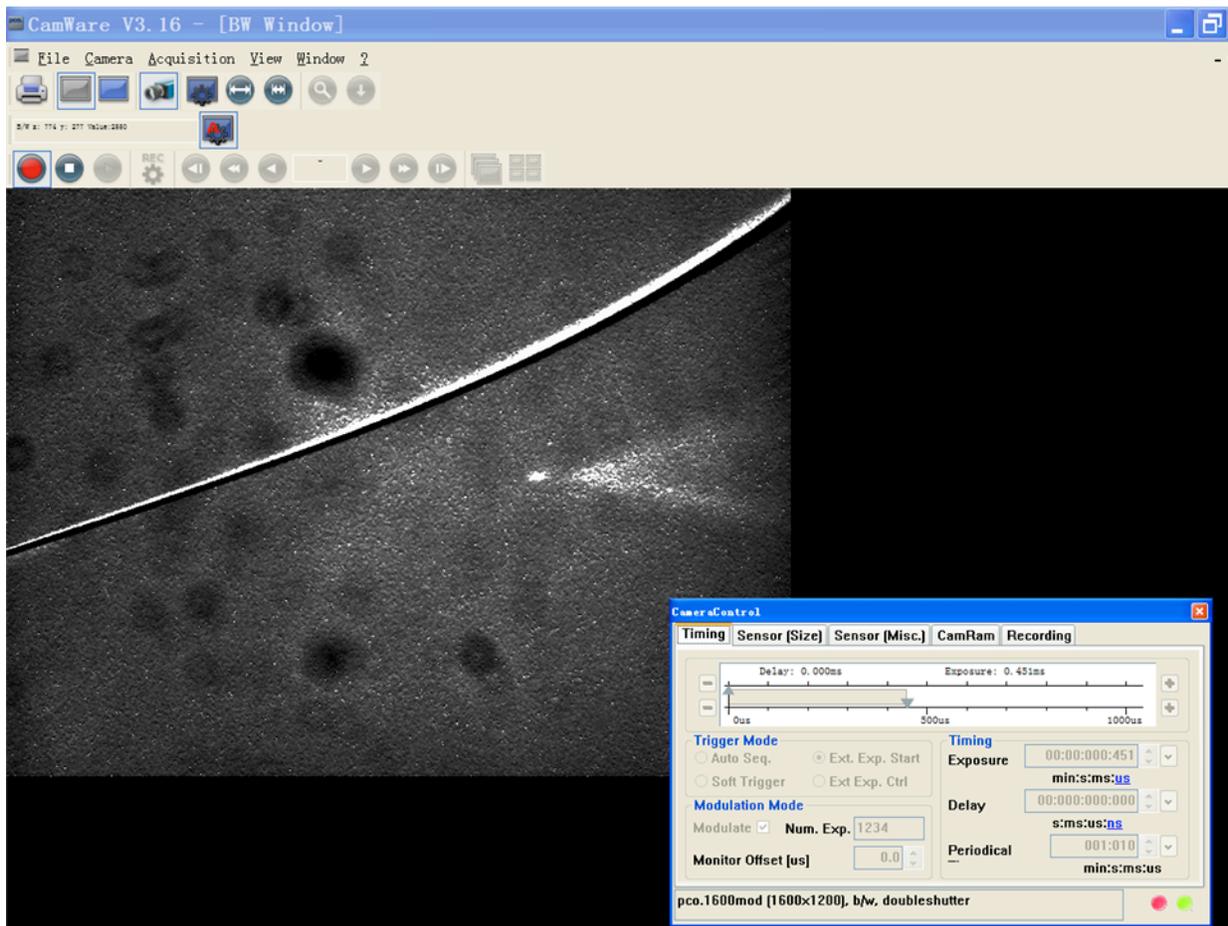

Figure 2. Imaging of kHz laser beam and polar star in daylight. Bright cone in center is the laser beam image, and the bright dot on its tip is polar star. The configuration panel shows that exposure time is 451 micro seconds and number of stacking images are 1234.

2.3 Daylight laser beam monitoring

Conventionally, tracking in daylight is difficult in that the satellite and the (kHz) laser beam are invisible. While the bright sky makes it impossible to see satellites, the laser pulse back scatter is brighter than the sky background in the transmit moment. The Changchun SLR system uses a

high speed camera and 532nm band-pass filter to take image of laser beam in daylight.

The camera accepts external trigger from laser firing signal and take exposure of 50 microsecond length. The short exposures are transferred to interline register to accumulate for 1000 frames. Final frame rate will be about 1 frame per second. Polar star is used to establish a reference point, but imaging the star would require longer exposure time, as shown in Figure 2.

2.4 Daylight pointing improvement

Due to ambient temperature change, telescope pointing error is different between daytime and nighttime. However, it's difficult to acquire sufficient stars for daylight pointing correction. So we use satellites instead of stars as reference object. In this way neither stars or satellites can be seen, so it is regarded as 'blind' improvement.

This method requires good angular prediction accuracy, which is true for stable geodetic satellites like LAGEOS-1/2, Starlette/Stella, LARES, etc.. Stable laser beam position is also required, that can be done with above mentioned laser beam monitoring technique. Whenever echo signals are acquired, corresponding angular offsets are recorded for current direction, as an estimate of correction in this direction. Such correction records are stored degree by degree in array, so that to be applied when other satellite passes through the same piece of sky. In this way, tracking of one pass will improve the performance on intersecting passes.

In the Changchun SLR system, this method improves daylight tracking efficiency to GNSS satellites. However, due to rarity of ranging data in sun-lit part of sky, distribution of correction data is unbalanced, causing it difficult to solve a whole-sky pointing model.

3. Development Plans

Planned developments include target screen-locking, laser beam screen-locking and echo rate optimizing techniques. These are all aimed to keep data production stable and ease the operation.

3.1 Target screen-locking

Due to prediction error and pointing error, the tracked target would drift away from aim area. It is thus necessary to recognize the target and put it back to the center.

Target recognition is difficult in a full-spectrum image because the laser beam occupies a large area to confuse image processing programs. The planned development includes a dichroic mirror to split light from target and laser beam, as well as extra cameras to take both images. Bright stars would appear near target image, but generally it is easy to stably estimate the target position.

Target position should be placed to a spot where it can be best illuminated by laser. Position of such a spot involves target motion, light-time model and position of the actual beam tip. In general the laser beam must point ahead from target, but the amount of offset should be determined from prediction and line search.

3.2 Laser beam screen-locking

Rotation in transmit light path sometimes cause deviation of laser beam. As mentioned above,

the beam can be separated with a dichroic mirror, acting like a band-pass filter for 532nm light. However, laser beam is only visible in atmosphere, and the beam shape varies with weather and elevation. At lower elevation, the laser backscatter beam is longer, and at higher elevation shorter. Due to refraction, the beam would bend a little towards horizon. Polluted lower atmosphere would strengthen nearer part of the beam, and weaken farther part. All these factors make it complicated to determine the real beam tip.

3.3 Echo rate optimizing

Because of prediction and pointing error, the target would drift away from laser beam. Keeping data production stable requires continuously monitoring and optimizing echo rate. The following method is inspired by ILRS Network and Engineering Standing Committee's beam divergence measurement procedure [3], and it requires above-mentioned laser beam locking.

The laser-lit area can be represented by an ellipse in the az-el offset frame. When target offset leaves this area, target is not illuminated by laser. Our method should firstly find the center of this ellipse area. By moving the offset to four different directions, corresponding margin points can be found and the ellipse can be fitted. Repeating this process will give a slow-moving ellipse in the az-el offset frame. If the laser beam has Gaussian profile, the ellipse center will be the optimal point.
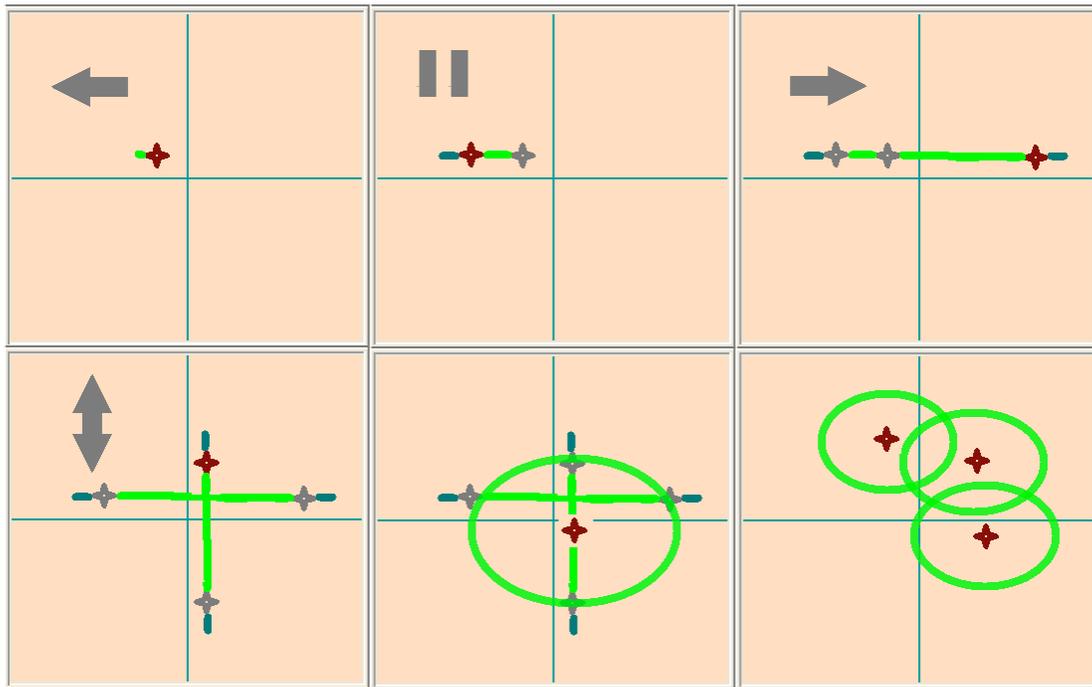

Figure 3.　Optimization of echo rate. Az-el offset charts used. First adjust offset to scan one side until echo diminishes, then repeat on another side. Start from the center to scan up and down and finally determine the ellipse of laser illumination. Continuously determine and follow the moving ellipse.

3.4 Experience implementing automation

While implementing automation techniques, we adopt an incremental strategy. If possible, the new technique will be tried by hand to verify its feasibility. Then other operators are asked to try it and form a concise procedure. Finally a piece of computer software will be developed to substitute the manual procedure.

4. Conclusion and discussion

The automated operations and related techniques in Changchun SLR system are introduced. Future plan of development is described. The basis of most automation techniques is 'recognition', including echo signal recognition from raw range data and target recognition from image. The automated recognition results will certainly be different from manual results, but will conform to statistical rules more strictly and hence more reliable.

Acknowledgement

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