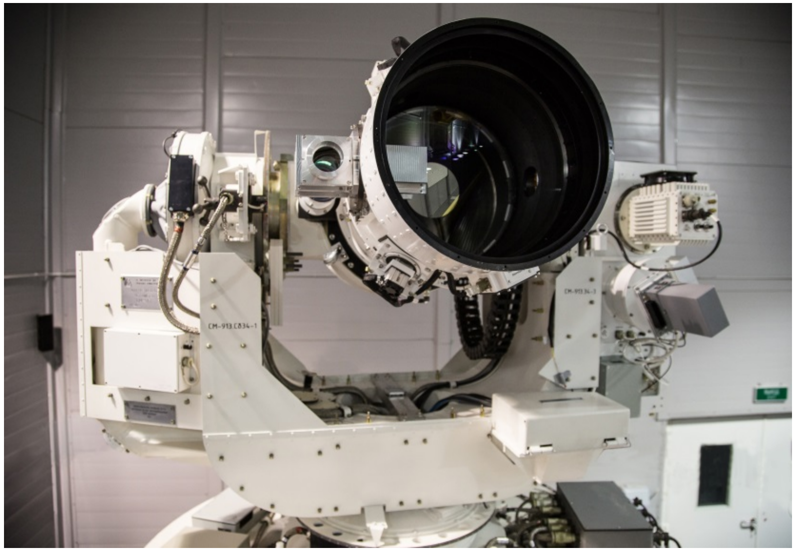
ILRS Technical Workshop
Improving ILRS Performance to Meet Future GGOS Requirements
Riga, Latvia, October 01-06, 2017

METHODS TO INCREASE RANGING PERFORMANCE AND ACCURACY IMPLEMENTED IN THE RUSSIAN NEW GENERATION LASER STATION «TOCHKA»



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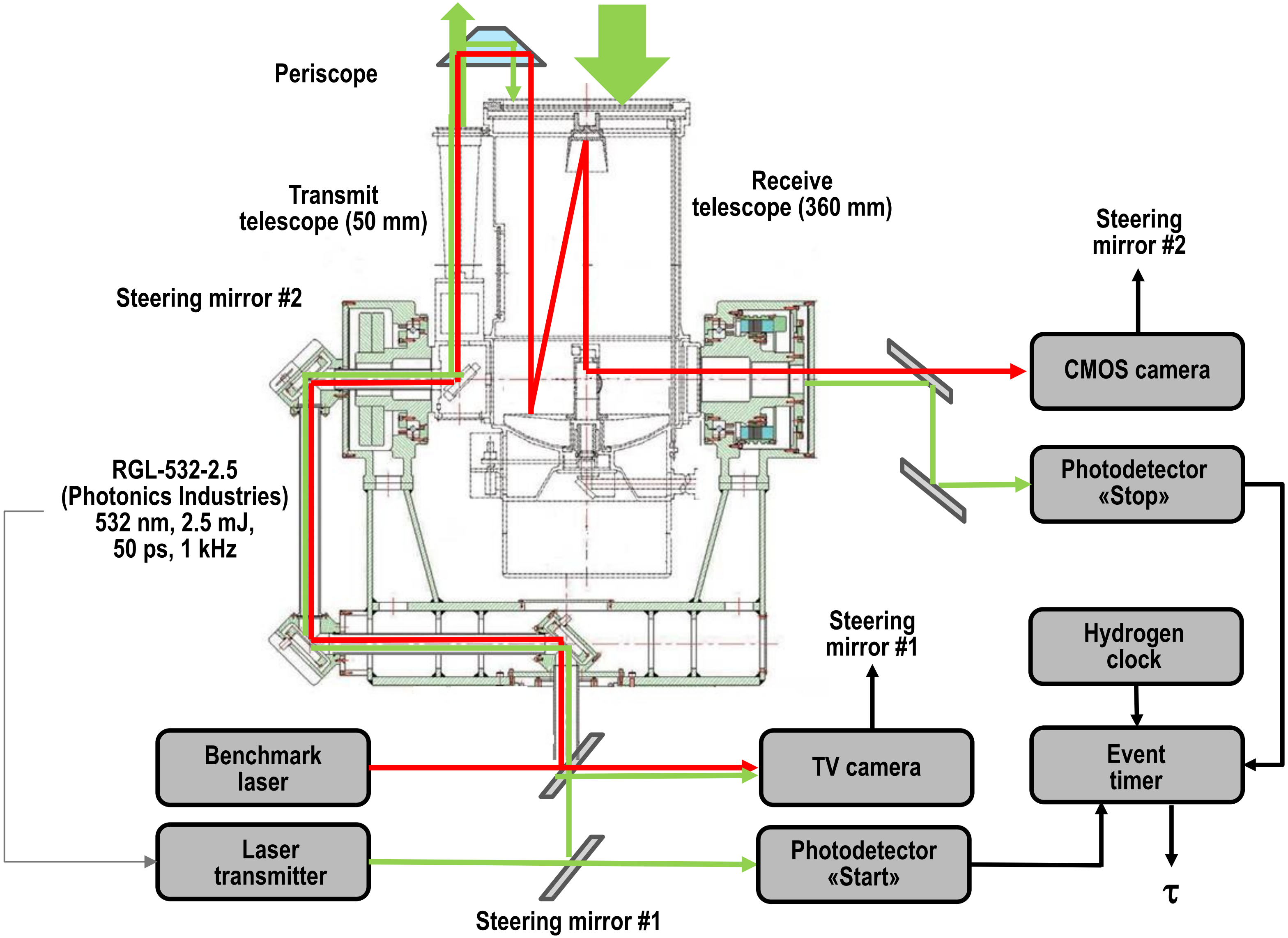
Agenda

1. **Structure, characteristics of components and development status of the station «Tochka»;**
2. **Methods for high-accuracy laser beam control and pointing implemented in the laser station «Tochka» to increase the ranging performance and accuracy;**
3. **Tracking automation implemented in the station «Tochka» and prospects of automation of tracking under partly cloudy conditions;**
4. **Methods to provide a single-electron laser pulse reception mode to increase the ranging accuracy;**
5. **Methods to calibrate measurements and to achieve a submillimeter systematic measurement error upon normal point generation.**

Structure and characteristics of components of the laser station «Tochka»

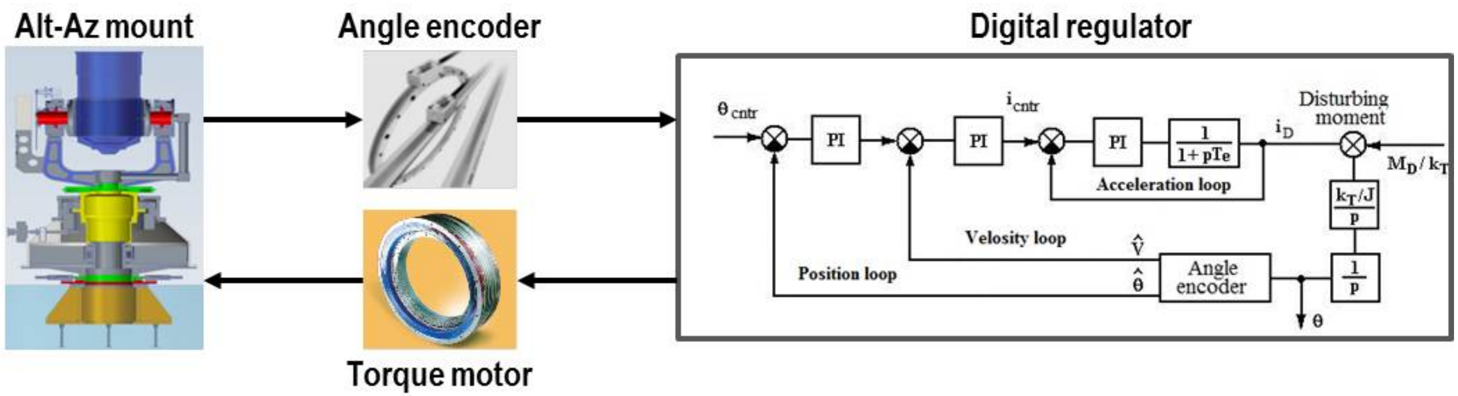


Development status of the laser station «Tochka»

By now the station «Tochka» has been developed, produced and has successfully passed the initial bench tests. Installation of the station at an operating site will be completed at the end of 2017, followed by its further tests under natural conditions.

Methods for high-accuracy control over the laser beam in space

Achieving a high accuracy of control over the laser beam in space and high accuracy of laser beam pointing at space objects is a key prerequisite to increase the ranging performance and accuracy. The laser beam control system structure in the station «Tochka» has the following pattern:



Key technical characteristics of the laser beam control system implemented in the station «Tochka» which were measured during the bench tests are given in the following table:

Parameter	Azimuth	Elevation
Resonance frequency of the torsional oscillation	47 Hz	63 Hz
Static error of the pointing (rms)	0.08 arc sec	0.05 arc sec
Dynamic error of the pointing (rms): at the speed 5 arc sec/ sec at the speed 20 grad/sec	 0.05 arc sec 0.53 arc sec	 0.15 arc sec 1.08 arc sec

Obtained static and dynamic accuracy values do not exceed 0.1 and 1 arcsec, respectively, and meet the most severe requirements set for laser beam position control systems.

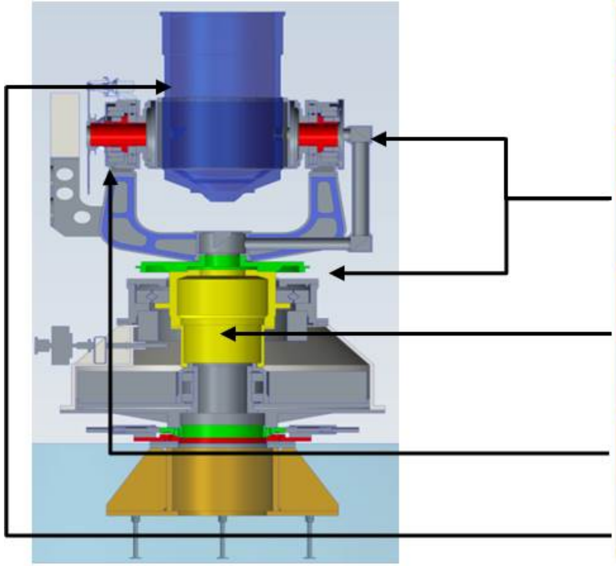
Methods for high-accuracy laser beam pointing

Task of pointing can be defined as a task of laser beam orientation in the direction set by numeric values of two angular coordinates (target predictions) in a topocentric reference frame.

To accurately follow up target predictions, the pointing system is calibrated by reference stars. The LS «Tochka» provides global calibration modes featuring calibration performed using a large number of stars at night, as well as dynamic calibration modes used when calibration is performed by day and at night just before taking every ranging session using the stars close to the target's path of motion (3-5 stars).

Corrections by azimuth ΔA and elevation ΔE are calculated as a sum of the known functions F and G with the coefficients C_i:

$$\Delta A = \sum_{j=1}^{m} C_j \cdot F_j(A, E) \qquad \Delta E = \sum_{j=1}^{m} C_j \cdot G_j(A, E)$$

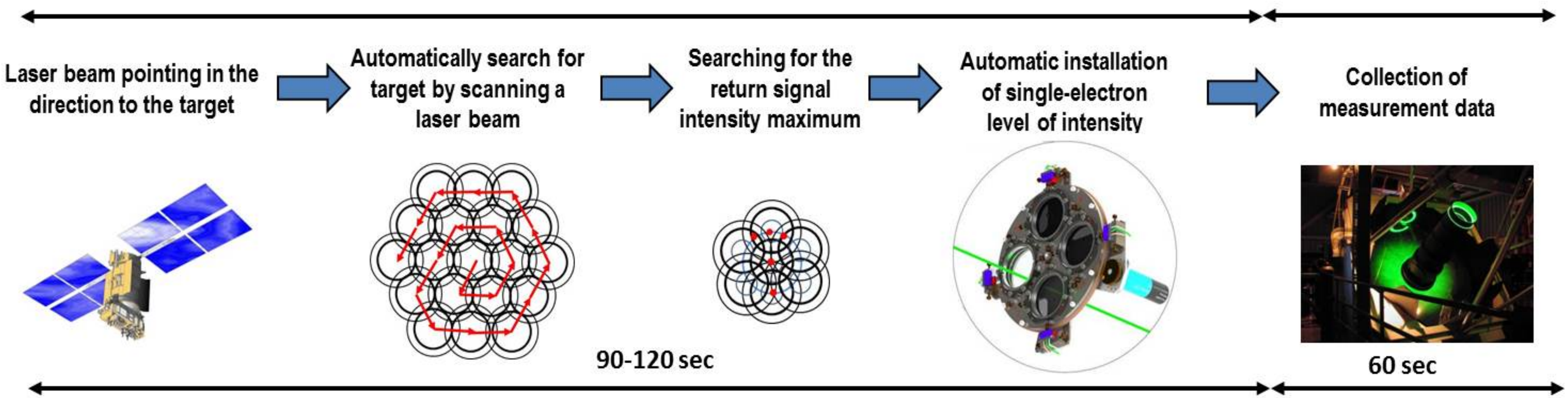


Coefficient	Description	Function F	Function G
Mandatory components of the correction model			
C_1	Zero offset azimuth encoder	1	0
C_2	Zero offset elevation encoder	0	1
C_3	Deviation of the azimuth axis from the zenith (north-south)	$-\cos A \cdot \tan E$	$\sin A$
C_4	Deviation of the azimuth axis from the zenith (east-west)	$-\sin A \cdot \tan E$	$-\cos A$
C_5	Non ortogonality of the axes of rotation	$-\tan E$	0
C_6	Collimation error	$\sec E$	0

Thus, the laser station «Tochka» implements the «blind» pointing method, at which a target or a scattered laser beam track are not seen directly by TV cameras of the station.

Automation of measurements implemented in the «Tochka» station and prospects of automation of measurements taken under partly cloudy weather conditions

Method of «blind» pointing allows one to completely automate the process of ranging under both night and daytime conditions. An automatic ranging session is subsequently executed in 4 stages in accordance with the following diagram:



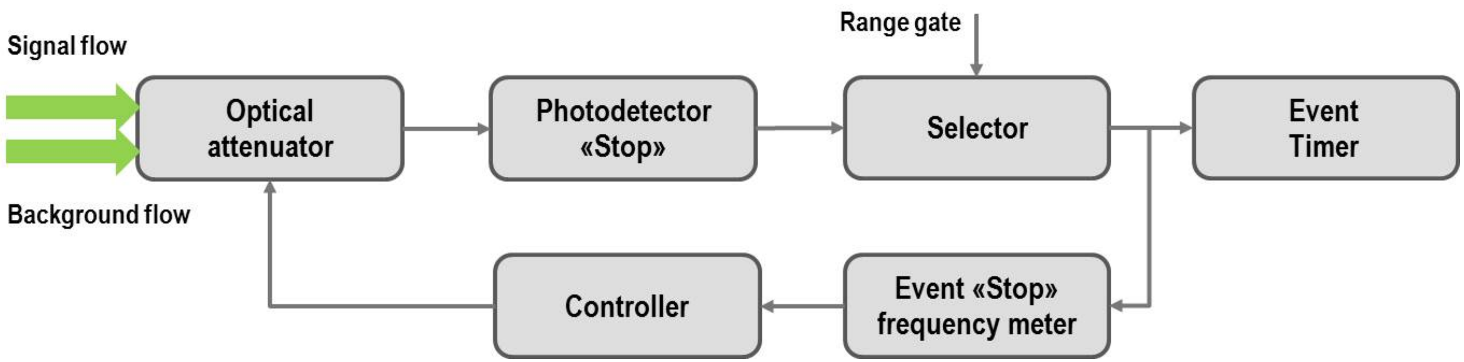
The length of a session in automatic mode does not exceed 2.5-3 min provided that the data collection time period is 60 sec, so the expected performance rate of the LS «Tochka» tracking the navigation SC does not exceed 500 NP per 24 hours.

When the station operates under partly cloudy weather conditions (sky openings), the efficiency of the automatic algorithm decreases due to that significant time is spent on waiting for return signals. In that case, an efficiency increase can be achieved through using a survey photometer evaluating the atmosphere transparency in various directions.

Methods to automatically support a single-electron mode of return pulse reception

The LS «Tochka» features a system for automatic support of single-electron return pulse reception mode upon tracking any space object within the range of altitudes reaching 40,000 km.

When working in the daytime, it also becomes necessary to adjust the intensity of the background stream. In the LS «Tochka» adjustment of the signal and background streams is performed using a single optical attenuator in the receive channel in accordance with the following diagram:



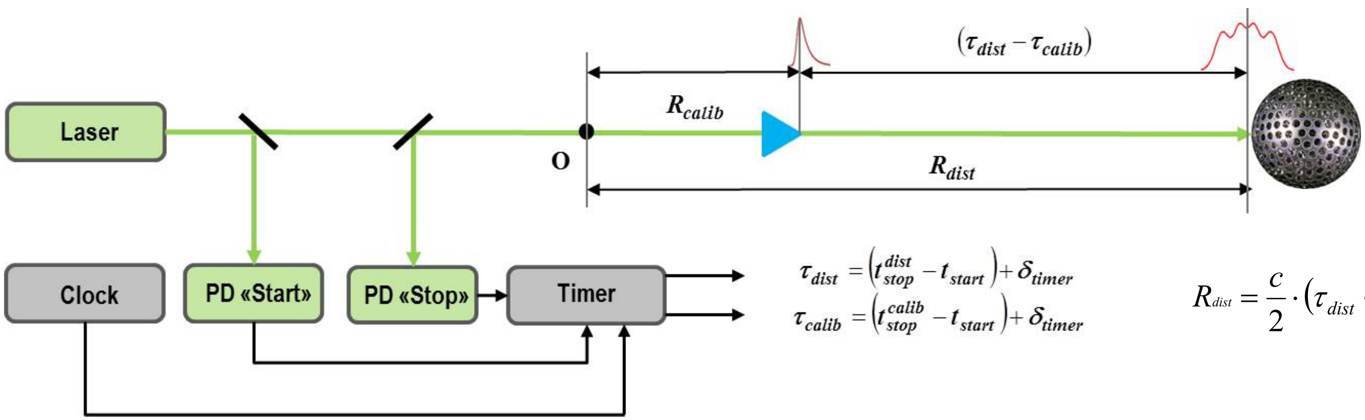
Automatic adjustment of intensities of background and signal streams pursues two goals:

- to set a number of background events in a single ranging gate at the level of less than 0.1;
- to set a number of signal events in a single ranging gate at the level of less than 0.1.

Automatic adjustment is executed through measurement of a common frequency of background and signal events in the ranging gate at the event timer input and introduction of an attenuation at which the common frequency of events does not exceed 1/10 of the pulse repetition rate of a laser transmitter.

Automatic support of single-electron return pulse reception mode is a necessary requirement for achievement of a submillimeter systematic error of ranging.

To achieve a submillimeter error by both random and systematic components, the LS «Tochka» takes range measurements in differential mode in accordance with the following diagram:



$$\tau_{dist} = \left(t_{stop}^{dist} - t_{start}\right) + \delta_{timer}$$
$$\tau_{calib} = \left(t_{stop}^{calib} - t_{start}\right) + \delta_{timer}$$

$$R_{dist} = \frac{c}{2} \cdot \left(\tau_{dist} - \tau_{calib}\right) + R_{calib}$$

In differential mode, the station simultaneously takes measurements of time needed for a pulse to reach a target and the reference target. The inclined range is defined by the difference of the measured delay times.

The feature of this methodology is that a hardware delay (common in both measurements), start pulse registration error and event timer's systematic error have no impact on the measurement results.

Residual systematic error of NP generation is determined by the difference of an average numbers of photoelectrons in return and calibration pulses and by the difference of their lengths over the course of a single ranging session. To achieve a submillimeter accuracy, we introduce the following correction to the measurement result:

$$\Delta\tau_{NP} = \frac{1}{2 \cdot \sqrt{\pi}} \cdot \left(n_{dist} \cdot \sigma_{dist} - n_{calib} \cdot \sigma_{calib}\right)$$

Cumulatively, this method for differential measurement of arrival times of return and calibration pulses based on their gravity centers in single-electron reception mode is another necessary requirement to achieve a submillimeter ranging accuracy by both random and systematic components.

Summary

1. By now the station «Tochka» has been developed, produced and has successfully passed the initial bench tests. Installation of the station at an operating site will be completed at the end of 2017, followed by its further tests under natural conditions.

2. Preliminary benchmark tests have confirmed the design objectives with regard to the pointing system accuracy and random component of the ranging system error.

3. Technical solutions adopted upon designing the LS «Tochka» enable one to implement the automatic ranging mode under both night and daytime conditions and provide a submillimeter measuring accuracy by both random and systematic components.

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