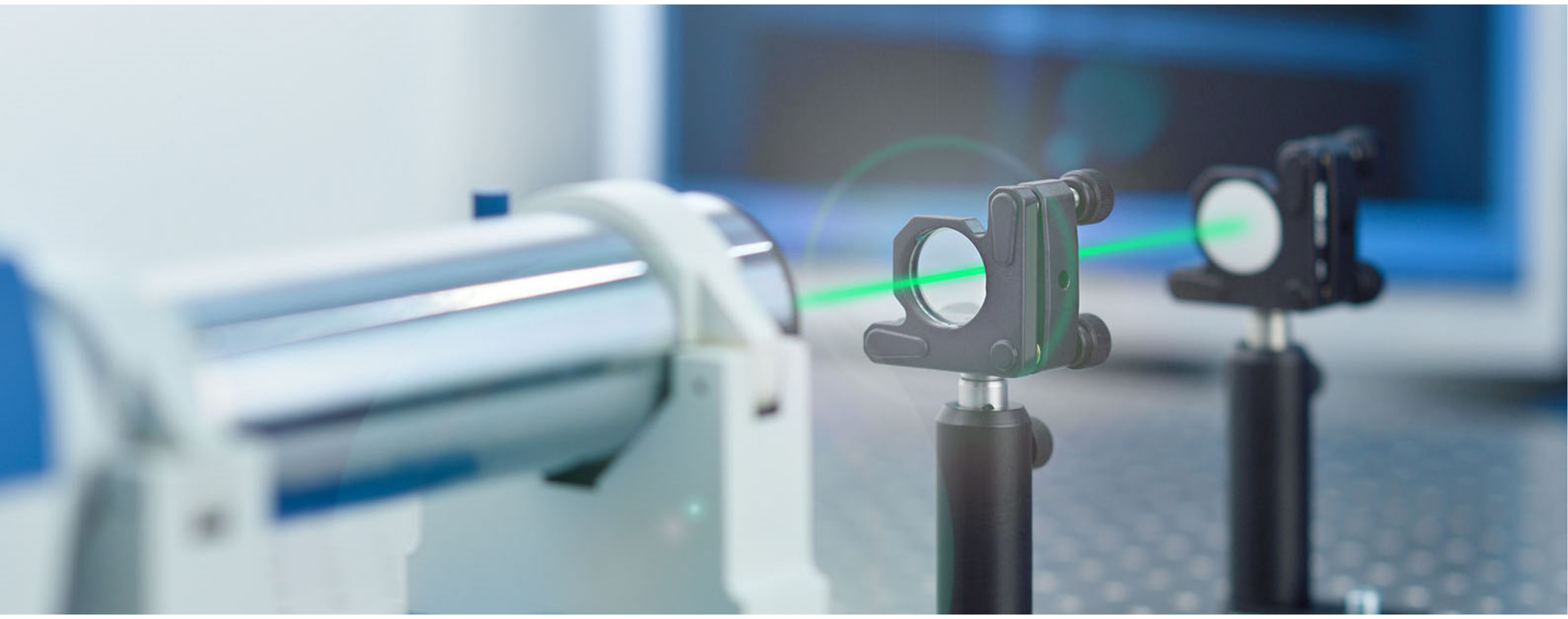

TriAngle UltraSpec

A performance evaluation at various metrological institutes

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1. Introduction

Since its founding in 1991 TRIOPTICS has focused on high precision and quality metrological instruments for optics and optical components. By now the product portfolio has diversified and has given users exceptional analysis quality for their optical systems. One of the most prominent products for angle metrology is the electronic autocollimator TriAngle UltraSpec (US).

TRIOPTICS has striven to maintain strong and reliable manufacturing standards for its products and has always taken pride in being traceable to national and international standards. TRIOPTICS certifies the accuracy of the TriAngle product group by evaluating them through national metrological institutes. The TriAngle US has reached a maturity and quality status in manufacturing that the specification is met during serial production and also when checked by different international institutes in various parts of the world.

Table 1 gives an overview of the specifications of the TriAngle UltraSpec series. All of these properties will be addressed and analyzed in this whitepaper and will give the reader an idea of what is to be expected from a TriAngle US.

Model	Resolution [arcsec]	Accuracy within 10” FOV [arcsec]	Accuracy within 20” FOV [arcsec]	Accuracy within entire FOV” [arcsec]
TriAngle US 300-57	0.005	± 0.05	± 0.10	± 0.25
TriAngle US 500-57	0.003	± 0.05	± 0.10	± 0.25

Table 1: The specifications of the TriAngle UltraSpec series

1.1. Basics of an autocollimator

An autocollimator is an optical instrument for angle measurements, combining the two optical functions of a collimator and a telescope. It contains an illumination part, a reticle, a beam-splitter, an objective lens and a camera. The reticle sits in the focal plane of the lens and its image is being projected to infinity, also referred to as a collimated beam. If this beam is reflected back from a mirror surface and reenters the autocollimator, it will be focused onto the camera sensor as an image of the reticle. The reflection angle under which the beam reenters the autocollimator depends upon the angle of the mirror surface with respect to the optical axis of the autocollimator. This inclination causes a displacement of the reticle image that is measured by the camera sensor. A conceptual layout of an electronic autocollimator and its functional parts can be found in Figure 1.

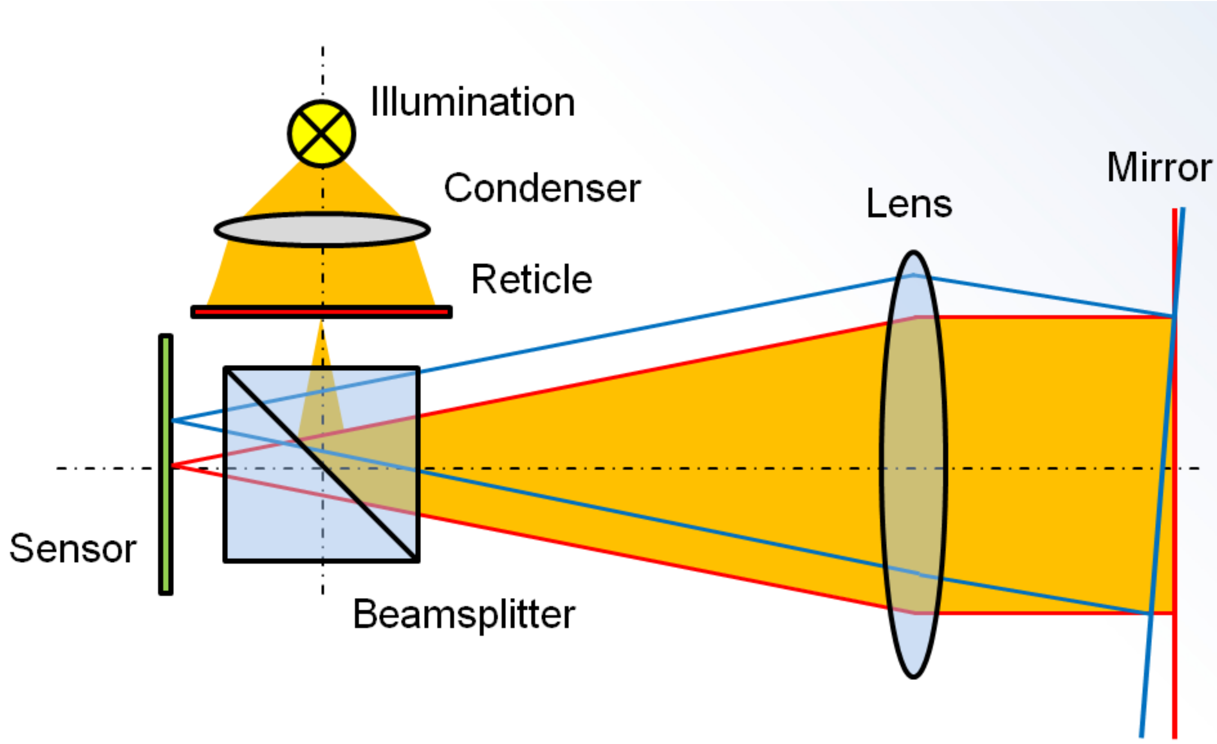

Figure 1: Conceptual setup of an autocollimator measuring the inclination of mirror.

Compared to simpler visual devices, electronic autocollimators have the advantage of computer-aided measurements. This allows for much higher accuracies and resolutions, which will be demonstrated in the following chapters.

2. Noise levels

2.1. Ideal conditions

High precision measurements are easily perturbed by environmental factors such as temperature changes, air turbulences and mechanical vibrations. In order to minimize these effects, we had a TriAngle US evaluated in the laboratories of the PTB (Physikalisch-Technische Bundesanstalt), i.e. the National Metrology Institute (NMI) of Germany, which has an environment stabilized to 0.1°C.

The data shown in Figure 2 depict the residual noise level in terms of standard deviation of an electronic autocollimator TriAngle UltraSpec of type TA US 500-57 over its entire measuring range. According to Figure 2 the TriAngle US achieves an average noise level of 0.002 arcsec, outperforming the specified resolution of 0.003 arcsec in Table 1. Furthermore the diagram illustrates that this noise is achieved across the full measuring range. The outliers towards the outer edges indicate the limits of the measurement range and are due to aberrations of the optics and beam vignetting.

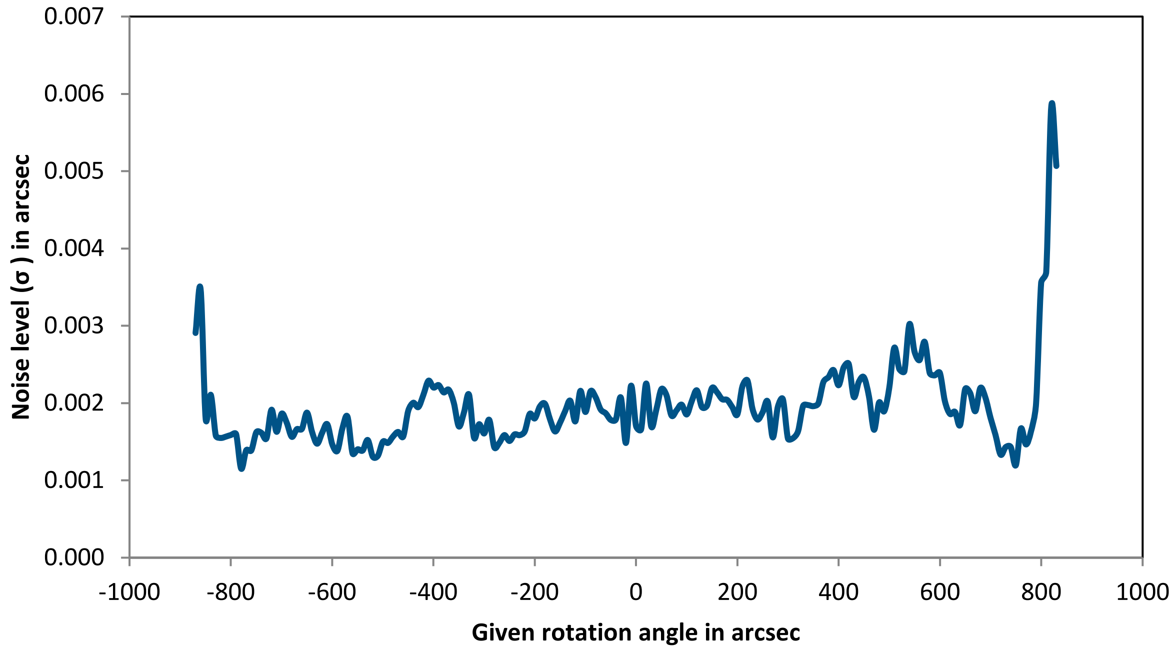

Figure 2: Noise level of a TriAngle US 500-57 evaluated by PTB (SN: 15-032-0010)

2.2. Working conditions

The majority of customers cannot use a TriAngle US in or close to laboratory conditions, in fact, most applications have to be performed under factory conditions. As for every high precision instrument, the environment exerts a great influence on the performance. For electronic autocollimators the main influence factors are temperature changes, air turbulences and mechanical vibrations. Their effect can be minimized by keeping the optical path length between the aperture and the reflecting target as short as possible. The larger the measuring distance, the greater the environmental influence. Figure 3 connects these two parameters.

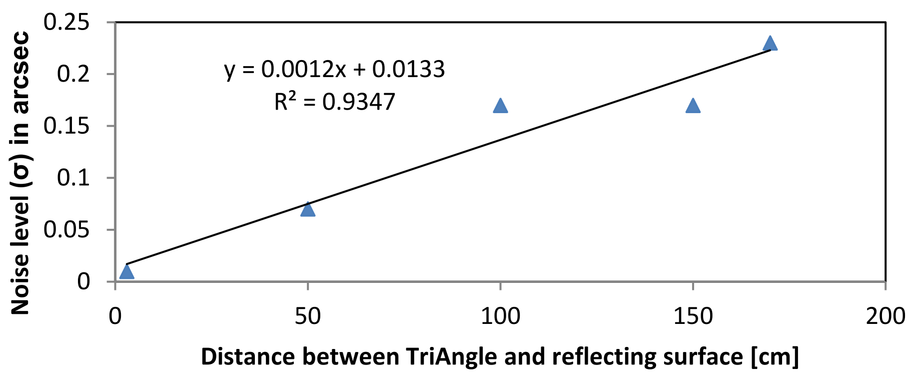

Figure 3: Noise levels of a TriAngle US 300-57 at different measurement distances.

The values of Figure 3 were taken on the TRIOPTICS shopfloor. As expected, the measurement distance has a strong and linear influence on the noise level. At short distances noise levels of less than 0.05 arcsec can easily be reached, however with increasing distance these noise levels rise up to 0.25 arcsec.

As a conclusion, it should be ensured that the distance between the TriAngle and the target is kept at a short distance, mitigating environmental influences. Special focus needs to be laid on this effect, when the autocollimator is used under shopfloor conditions. Of course, best performance is reached under controlled laboratory conditions with stabilized room temperature.

3. Accuracy

3.1. Overall

The most prominent feature of the TriAngle US is its measurement accuracy over the entire measurement range. With an absolute accuracy of ±0.25 arcsec it ranges among the most accurate electronic autocollimators on the market. These specifications are verified at different international institutes. Figure 5 and Figure 6 show measurement results of different TA US 300-57 being tested by the following metrology institutes:

- AIST (National Institute of Advanced Industrial Science and Technology – Japan)
- METAS (NMI – Switzerland)
- PTB (NMI- Germany)

Table 2 contains the information about measurement configurations at different metrology institutes.

Institute name and country of origin	Distance between mirror and TriAngle US [mm]	Measurement uncertainty U(k=2) [arcsec]
AIST - (National Institute of Advanced Industrial Science and Technology – Japan)	230	0.05
METAS (NMI - Switzerland)	100	0.05
PTB (NMI - Germany)	300	0.01

Table 2: Overview of the three different institutes, their country of origin, the measurement distance and their expanded measurement uncertainty U with a coverage factor k=2, which corresponds to a confidence interval of 95%.

All of the three institutes have measured in a similar setup. They establish a (true) reference angle with a high-precision and properly calibrated goniometer table, where the TriAngle US autocollimator measures this rotation angle. Both values are then compared to the measurement accuracy of the autocollimator. Figure 4 depicts the schematic hardware setup. The measurement results are shown in Figure 5 and Figure 6.

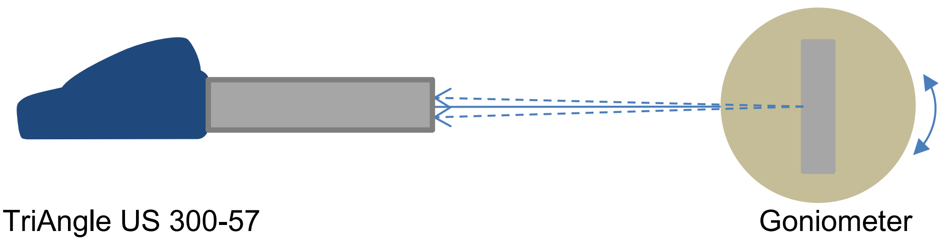

Figure 4: Schematic measurement setup used at the three different metrological institutes. The mirror is mounted on a goniometer

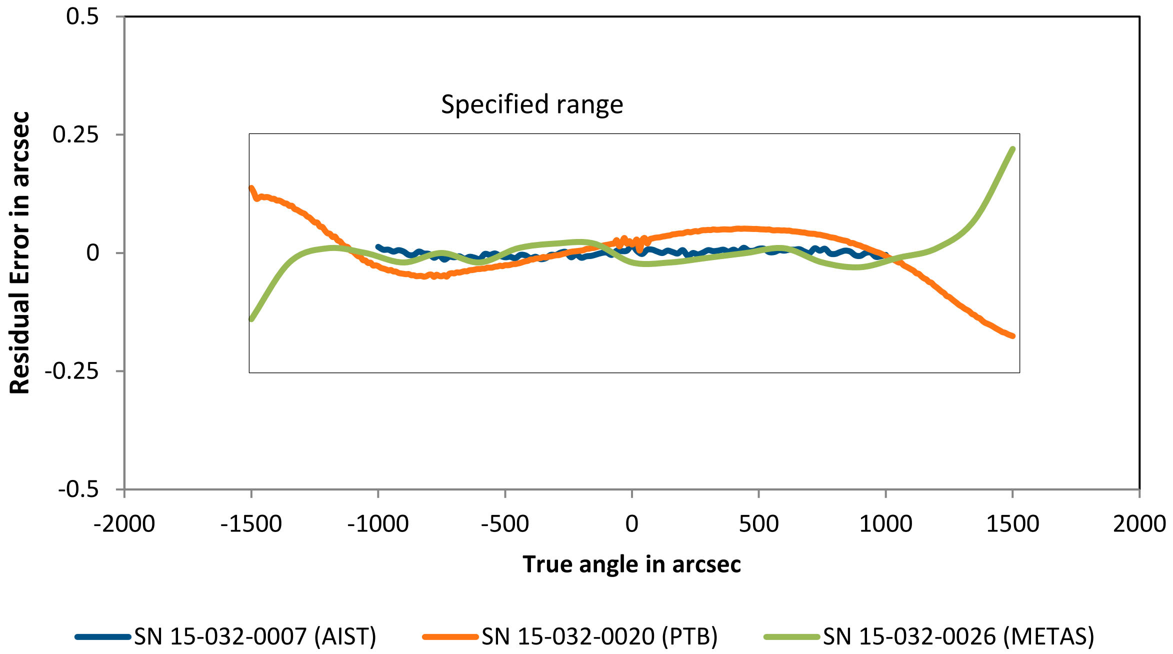

Figure 5: Measurement accuracy of a TA US 300-57 of X-axis (Azimuth) compared to references by AIST , PTB, and METAS

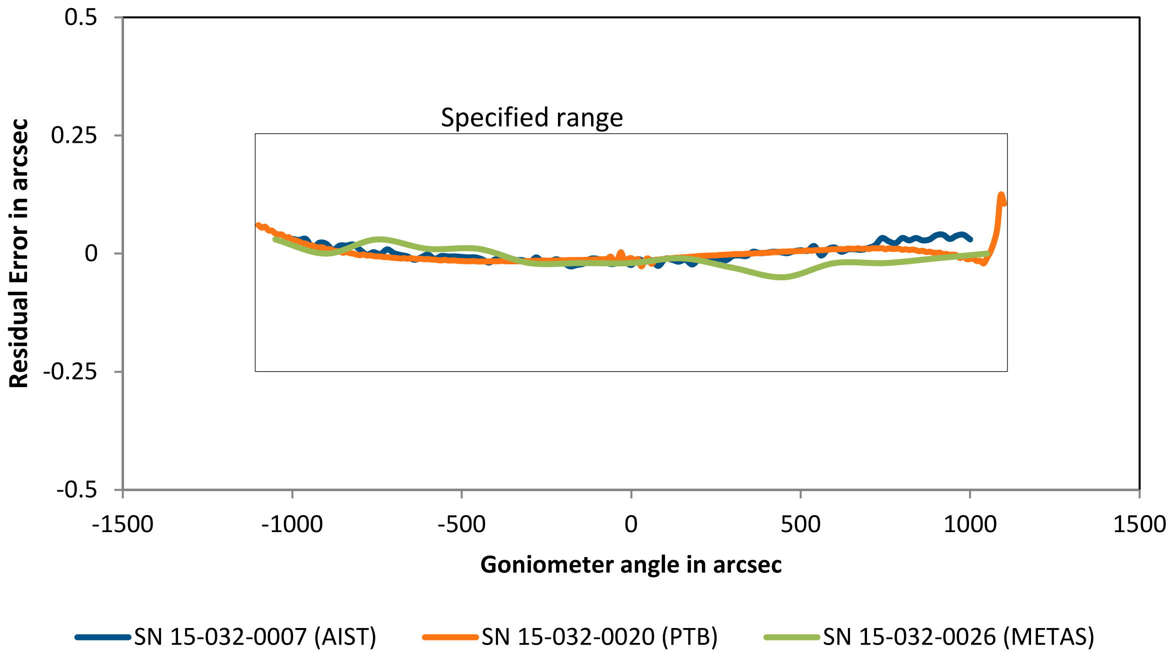

Figure 6: Measurement accuracy of a TA US 300-57 of Y-axis (Elevation) compared to references by AIST, PTB and METAS

All three TA US 300-57 share one characteristic: The residuals between measured angle and reference value are well below the specified accuracy of ±0.25 arcsec, except for the aberration induced inaccuracies towards the outer measuring range. This is true for all different TriAngle autocollimators evaluated by the various measuring institutes in this study. It is evident that the accuracy specification for the TriAngle US autocollimators is a conservative statement. For the most important and central part of the measuring range the accuracy is well within the range of ±0.05 arcsec for all TriAngle US models under test.

3.2. Measurement range ± 20 arcsec and ±10 arcsec

Next to the full-range accuracy, the TriAngle US autocollimators are known for improved accuracy within smaller measuring ranges. TRIOPTICS specifies ±0.05 arcsec and ±0.10 arcsec accuracy within ±10 arcsec and ±20 arcsec measuring range, respectively. Below is a collection of data obtained by AIST, METAS and PTB evaluating the different TA US 300-57 autocollimators within the central measuring ranges of ±20 arcsec and ±10 arcsec.

Once again it is evident that the specified accuracies of ±0.05 arcsec and ±0.1 arcsec are a conservative statement. In fact, all three instruments exhibit an accuracy better than ±0.03 arcsec, which is about 40% or 70% less than the specified values. The artifact in the central region is caused by the mechano-optical setup and can be found in every type of autocollimator of similar design.

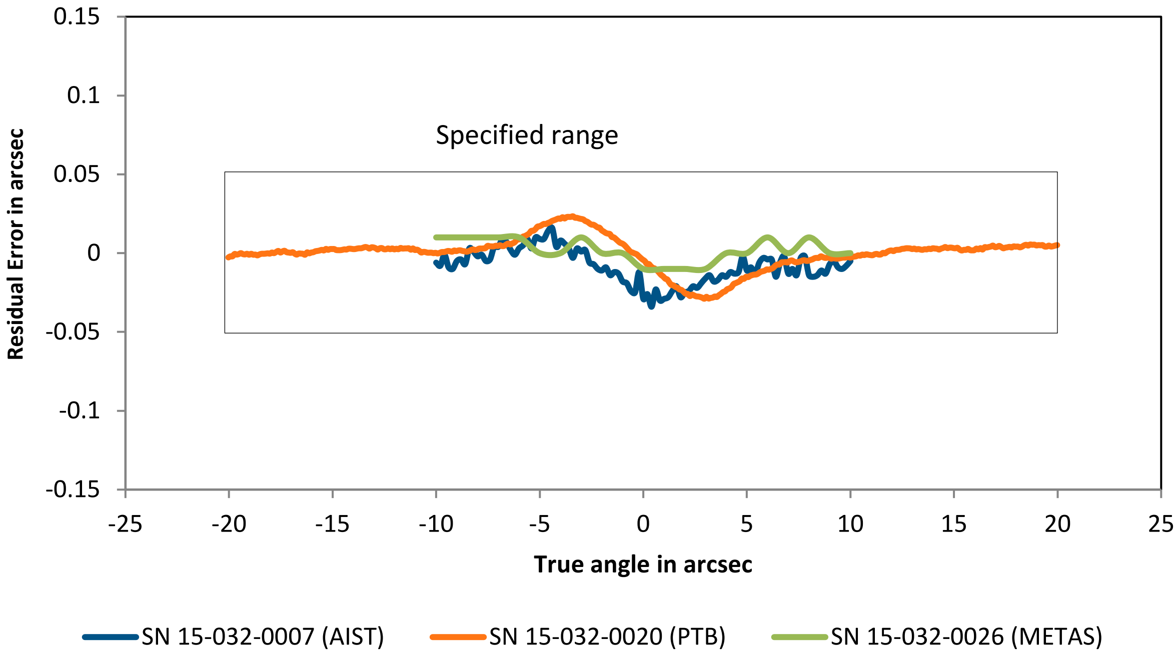

Figure 7: Accuracy of different TA US 300-57 within ±10" and ±20" in central measurement region for X-axis (Azimuth) analyzed by AIST, PTB, and METAS

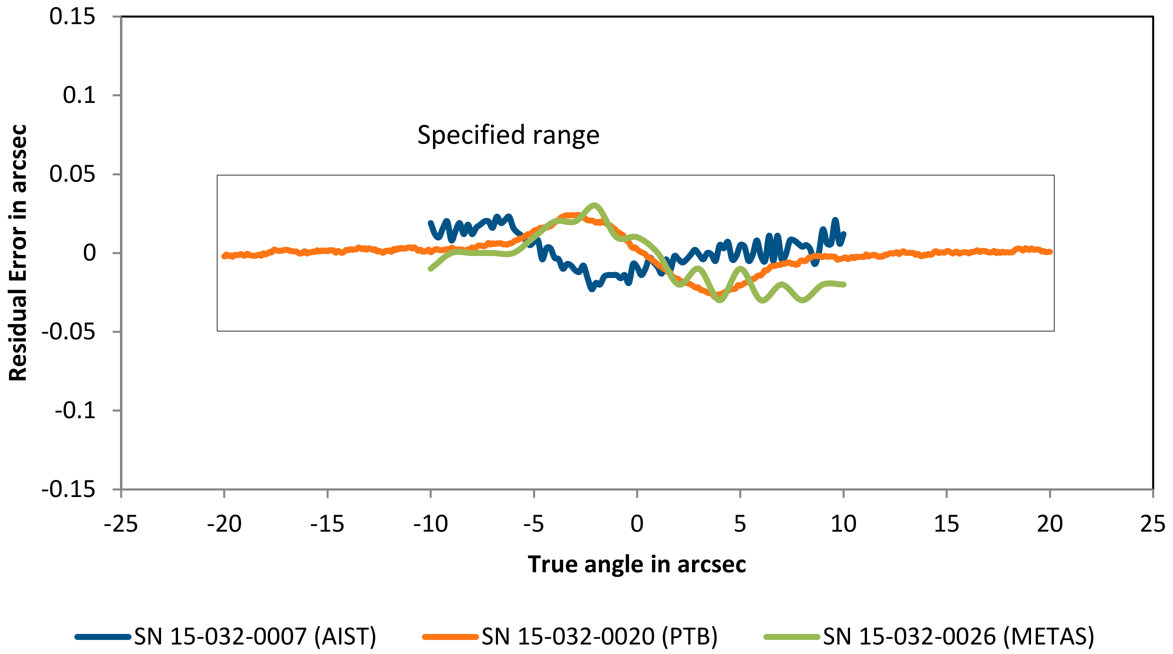

Figure 8: Accuracy of different TA US 300-57 within ±10" and ±20" in central measurement region for Y-axis (Elevation) analyzed by AIST, PTB, and METAS

4. Conclusion

The above results illustrate the high performance of the TriAngle US autocollimators. They exhibit a high resolution and accuracy, which are met routinely in serial production. The TRIOPTICS specifications for these instruments are conservative values, meaning that in general and in suitable environment, the user can expect even better results than specified. For all three TriAngle US the measurement accuracy is better than ± 0.05 arcsec which is an improvement of 80% with respect to the specified value. For smaller measuring ranges the analyzed TriAngle US show a maximum residual error of ±0.03 arcsec, which corresponds to a performance level improvement of 40% - 70%. The TA US exhibits resolution levels between 0.002 and 0.005 arcsec. However, it became apparent that near-perfect ambient conditions are required for optimum performance. Yet, all of the above mentioned characteristics render the TriAngle Ultraspec electronic autocollimators a safe choice for every user who needs to measure angles reliably and accurately to fractions of arcseconds.