Evaluation of flexible mini-prisms by Rothbucher Systems

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Client:

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1 Evaluation order

Rothbucher Systems of Bad Reichenhall, Germany, manufactures surveying accessories, including a range of different swivellable and rotatable miniprism adapters. Compared to conventional standard reflectors, these prism adapters are characterized by their method of attachment (screwing, gluing or plugging onto base plates), their flexible handling and last but not least by their significantly lower price. On the other hand, they are manufactured from less stable materials and have a lower degree of centering accuracy due to the more varied degrees of freedom in prism alignment and the necessary play of the snap-in device.

In a test series of the Geodetic Laboratory of the Chair of Geodesy at the Technical University of Munich, several specimens of different prism types and adapters were tested for their accuracy characteristics. The focus was deliberately on testing under practical application and handling aspects, in which not extreme constellations were examined, but average application cases. This means, for example, that when prisms were targeted, they were aligned in the way they are used in practice and not in the peripheral areas or outside the specifications. In principle, all prisms can be measured in a range of ± 35°, although deviations in the determined coordinates may occur in the boundary areas. On the one hand, this is an effect of a changed light path geometry in the prism[1], on the other hand, however, it is mainly caused by the detection of the prism center with automated target recognition algorithms, as they are almost exclusively used in practice today. The usual alignment of the swivellable prisms to the measuring device in one of the specified snap-in positions is well within the unproblematic directional deviations. The results shown here therefore represent characteristic values for the usual use of the prisms under investigation and not limit values for the entire parameter interval of the prisms.

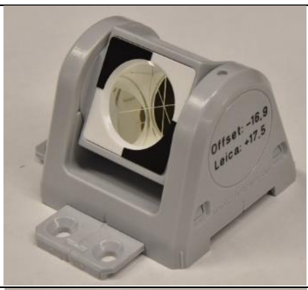
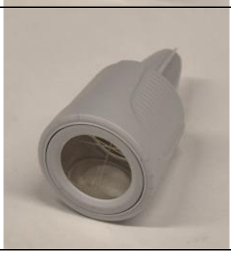
2 Prism types under investigation

For the test series, three specimens each of different prism types were taken from current production by the Rothbucher Systems and made available to the Geodetic Laboratory. An overview of these prism types can be found in Table 1.

Since the manufacturer states that copper-coated prisms (abbreviation C) should preferably be used for Leica instruments and silver-coated prisms (abbreviation S) should preferably be used for Trimble instruments, most investigations have been carried out with both types of instruments. The instruments used were modern, high-end quality and high-end price class instruments, namely a Leica TS60 and a Trimble S9 Total Station.

[1] See also: Surveying Reflectors – White Paper, Characteristics and Influences. Leica Geosystems AG, Heerbrugg, Switzerland, last updated 2017

Table 1: Overview on the prism types tested

1		RSMP380 – Silver coated ∅ 25,4 mm Offset -16,9 mm (Leica +17,5 mm)
2		RSMP380 – Copper coated ∅ 25,4 mm Offset -16,9 mm (Leica +17,5 mm)
3		RSMP280 – Silver coated ∅ 17,5 mm Offset -11,0 mm (Leica +23,4 mm)
4		RSMP390 – Copper coated ∅ 25,4 mm Offset -16,9 mm (Leica +17,5 mm)
5		RSMP390 – Silver coated ∅ 25,4 mm Offset -16,9 mm (Leica +17,5 mm)
6		RSMP12 – Copper coated ∅ 17,5 mm Offset -5,4 mm (Leica +29,0 mm)
7		RSMP10 – Silver coated ∅ 12,7 mm Offset -5,6 mm (Leica +28,8 mm)

3 Distance offset

An electronic distance measurement (EDM) on reflecting prisms is subject to a constant offset if either the electronic origin of a measuring unit does not coincide with its reference point and/or the origin of the reflector does not coincide with the measuring point. This offset is also called "addition constant" and represents a correction value for the corresponding combination of measuring unit (e.g. total station) and reflector. In practice, the influence of the measuring unit is often neglected and the offset is regarded as a reflector-specific parameter, but strictly this is not correct. Particularly in the case of precisely manufactured reflectors, the share of the measuring unit may even predominate.

In the case of movably (swivellably) arranged reflectors, offsets may exist for both reflector positions, provided that the swivelling axis lies in front of or behind the standing axis of the reflector with respect to the reference point. If the offsets are determined by measurement with unknown sections in all combinations (Schwendener method[2], Fig. 1) and the prism is tilted accordingly, this influence is expressed in the magnitude of the standard deviation of the addition constant determined in each case. The basic accuracy level of the EDM used must also be taken into account, which must allow the swivel axis offset to be determined with regard to its resolution. The influences of the offset, deviation of the tilt axis and other geometric manufacturing tolerances are usually summarized in a 3D centering accuracy value; direct values for the interval of the offset itself are usually not given. If we assume for the sake of simplicity that the proportion of the centering accuracy of the manufacturer's specifications is the same in all spatial components, the expected values of the offset acting in measurement direction are about 0.58 mm for 1 mm centering accuracy and 1.15 mm for 2 mm centering accuracy and thus represent a reference for the expected offset magnitude.

In the given study, a calibrated Leica TS60 total station with an angular accuracy of 0.5" and an absolute distance measurement accuracy of 0.6 mm + 2 ppm under known and considered meteorological conditions was used to determine the offset values. In order to check the offset of any existing tacheometric offset share, a reference

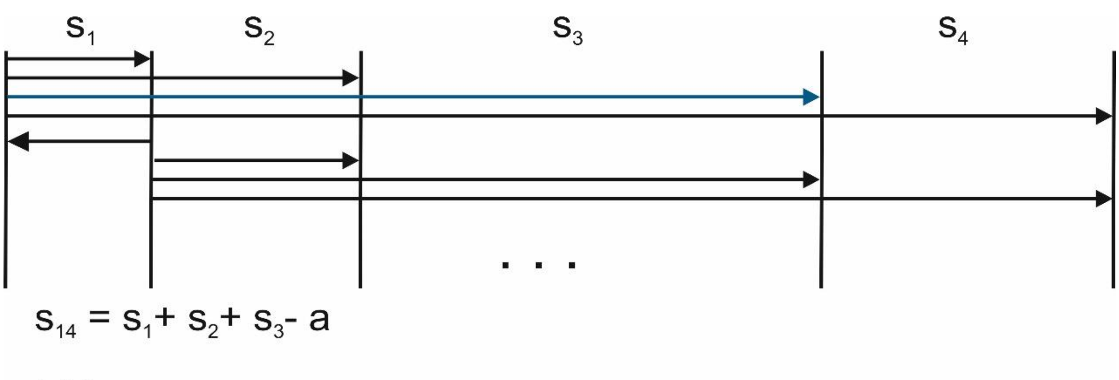


Figure 1: Principle of an offset determination in all combinations. The offset value a is part of each individual measurement in the overdetermined evaluation system; in the example, the measurement from 1 to 4, consisting of the sections s_1 to s_3 and a.

[2] Schwendener, H.R.: Elektronischer Distanzmesser für kurze Strecken – Genauigkeitsfragen und Prüfverfahren. Schweizerische Zeitschrift für Vermessungswesen, Photogrammetrie und Kulturtechnik, S. 59ff, Winterthur, 1971

measurement was first carried out on the four-part laboratory test track with a length of 25 m using a Leica GPH1P precision reflector. The manufacturer specifies a centering accuracy of 0.3 mm. The calibration was carried out by measuring the distance from each position to each target point four times (measurement in all combinations) and produced an offset value of +0.16 mm ± 0.08 mm for the reference prism. This is slightly significant, but within the specifications of EDM and prism. It describes the sum of the device and reflector components. From the later horizontal measurement network, a device-specific offset value of +0.11 mm (not significant) was estimated. There is therefore no indication that the EDM unit of the TS60 used has a significant proportion of a determined offset. The offset values of the later tests can therefore solely be assigned to the prisms examined in each case. A device-specific offset was also determined for the Trimble S9. This is -0.46 mm ± 0.08 mm and is highly significant. It was therefore taken into account in the investigations for the prisms under test. Thus the remaining proportion offset share can also be related exclusively to the respective prism being examined.

Prism types 1 - 3 were subsequently examined with regard to their addition constants; types 4 and 5 are basically identical in construction and differ only in the additional rotatable base plate. The results are shown in table 2.

The determined offset values differ in the sample group-wise in dependence of the reflector diameter and have a magnitude of up to 0.5 mm. The accuracy of the examined prisms is in the order of magnitude of conventional standard prisms.

It should be noted that determining the addition constant on a Schwendener basis for each prism only takes into account two notch positions and the results may be different if other notches are used. This can be done by a comprehensive check of all orientations within an adjustment network by estimating the addition constant, as is usually done in prism testing of swivellable prisms before they are introduced to the market. The addition correction is then included as the mean value for all orientations.

Table 2: Remaining offset values of the tested prism types

Prism type		No.	Offset value [mm]	Standard deviation [mm]
1 – RSMP380 - S		1	-0,38	0,06
		2	-0,39	0,07
		3	-0,34	0,07
2 – RSMP380 - C		4	-0,33	0,07
		5	-0,49	0,07
		6	-0,38	0,07
3 – RSMP280 - S		7	-0,02	0,05
		8	+0,04	0,05
		9	+0,16	0,05

4 Centering accuracy of swivellable prisms

In addition to the pure investigation of the offset values, the variance of the embodied spatial position when panning the prisms can also be investigated more closely.

In comparison with standard prisms, it should be noted that the significance of centering accuracy is slightly different in both cases:

- A conventional prism is usually attached by means of a prism holder or similar along a defined (standing) axis and at a defined distance above a reference point. If one assumes that the centering of the prism holder (e.g. tripod, tribrach, above a floor point or, more simply, a screw plug in a wall bolt) is free of errors and its dimensions are correct, the 3D centering accuracy corresponds to the deviation of the optical center of the prism from the theoretical reference point embodiment. In this case, axial deviations from the center of rotation and the offset value also include geometric errors in the prism dimensions.
- The swivel prisms examined here usually do not refer to a reference point, since the dimensionally accurate mounting option is missing. Rather, they embody the reference point themselves through their prism center. The requirement for certain reference point values is therefore not given, but the constancy of the prism center itself, even when the prism is moved according to the existing degrees of freedom (tilting / swivelling or additional turning with the corresponding base plate).

To test the quality of simple swing prisms, it is therefore sufficient to mount them in a stable manner and then measure different positions with different orientations. In doing so, the prisms are deliberately aligned to the respective point of view and oblique aiming is avoided, as this is the usual measurement procedure in practice.

The comparison of the individual prism orientations is done by coordinate comparison of the measured target points. For this purpose, a measurement layout consisting of four points of view with mutual observations on standard prisms is created as a network from which the individual test object alignments are measured and coordinated as individual single points (Figure 2). The deviations of the individual coordinates result in the stability of the point centering and thus in a measure for the stability of the respective axes of rotation and the influence of the offset described above.

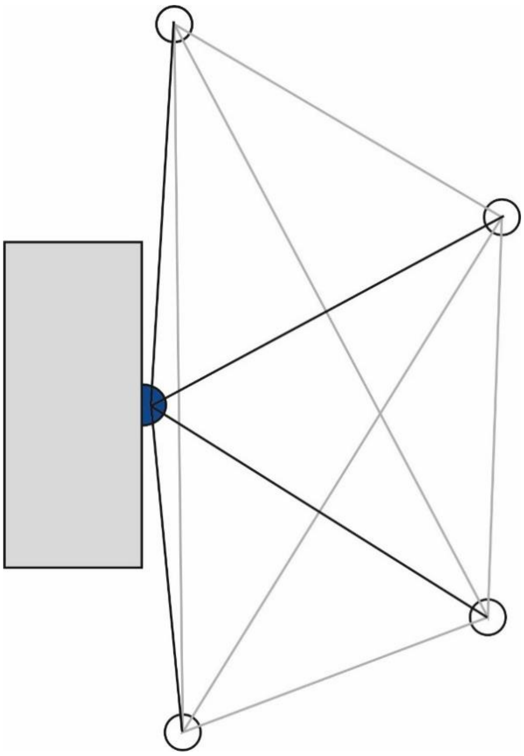


Figure 2: Network configuration for investigating the stability of the prism center when swiveling (top view)

In a first trial, the nine type 1 - 3 (RSMP280 and RSMP380) swing prisms were again investigated. The prisms were fixed to a wall with a vertical swivel axis, simulating the most common application. The points of view form a semicircle to represent all possible directions of view in the Hz plane.

The investigations were carried out in separate setups for the Leica TS60 and the Trimble S9.

The basic network used for the Leica TS60 from the four points of view has an average standard deviation of 0.15 mm in position and 0.04 mm in height after the adjustment. The measurement setup is therefore suitable for determining the coordinates of the various orientations of the prisms to be investigated with sufficiently high accuracy without the influence of the position measurements. All measurements were carried out in four sets and two faces under controlled and considered meteorological conditions, so that even the distance measurement accuracy of the TS60, which is weaker than the directional measurement accuracy at close range could be improved to about 0.3 mm due to statistical overdetermination. For each prism, four different sets of coordinates are thus available in addition to a jointly compensated set of coordinates.

The base network used for the Trimble S9 has an average standard deviation of 0.08 mm in position and 0.05 mm in height.

The results for the Leica TS60 are shown in Table 3 and those for the Trimble S9 in Table 4.

The variability of the prism center, or the coordinates represented by it, is within ±0.5 mm when measured with a Leica TS60. When measured with a Trimble S9, the variability of the prism center is within ±1 mm.

For the RSMP280 / RSMP380 prism type, the inaccuracies due to the tilting and the measurement accuracy of the total stations used partially overlay a remaining offset correction, so that the latter does not necessarily have to be considered separately if an accuracy of ±1 mm is required.

For both manufacturers, no significantly recognizable quality dependency on the prism coating can be determined in the examined close range, but only on the prism diameter.

The deviation in height is naturally smaller, since no deflection took place here during panning in the test.

Table 3: Reproducibility of the centering accuracy of the tested prism types when swiveling around an vertical axis using a Leica TS60 (maximum deviation from mean value)

Prism type	No.	Max 2D [mm]	Max height [mm]	Std.dev 2D [mm]	Std.dev height [mm]
1 – RSMP380 - S	1	0,47	0,07	0,41	0,04
	2	0,36	0,05	0,32	0,02
	3	0,54	0,10	0,46	0,07
2 – RSMP380 - C	4	0,20	0,05	0,16	0,03
	5	0,49	0,05	0,38	0,04
	6	0,33	0,05	0,28	0,04
3 – RSMP280 - S	7	0,39	0,07	0,29	0,05
	8	0,35	0,06	0,29	0,05
	9	0,42	0,07	0,30	0,05

Table 4: Reproducibility of the centering accuracy of the tested prism types when swiveling around an vertical axis using a Trimble S9 (maximum deviation from mean value)

Prism type	No.	Max 2D [mm]	Max height [mm]	Std.dev 2D [mm]	Std.dev height [mm]
1 – RSMP380 - S	1	1,01	0,11	0,84	0,08
	2	0,89	0,10	0,81	0,09
	3	0,99	0,05	0,81	0,05
2 – RSMP380 - C	4	0,87	0,06	0,73	0,05
	5	1,22	0,08	0,98	0,06
	6	1,00	0,09	0,81	0,07
3 – RSMP280 - S	7	0,87	0,09	0,70	0,06
	8	0,84	0,06	0,65	0,05
	9	0,87	0,07	0,70	0,05

5 Centering accuracy of swivellable prisms on rotation base plates

In a further experiment, an additional degree of freedom was added to the prisms by investigating the combination with horizontal rotating plates (type RSMP390). For this purpose, the rotating plate was fixed on a pillar by means of the magnetic holding adapter offered by the manufacturer and targeted from four total station positions, which were arranged in a square around it (Figure 3).

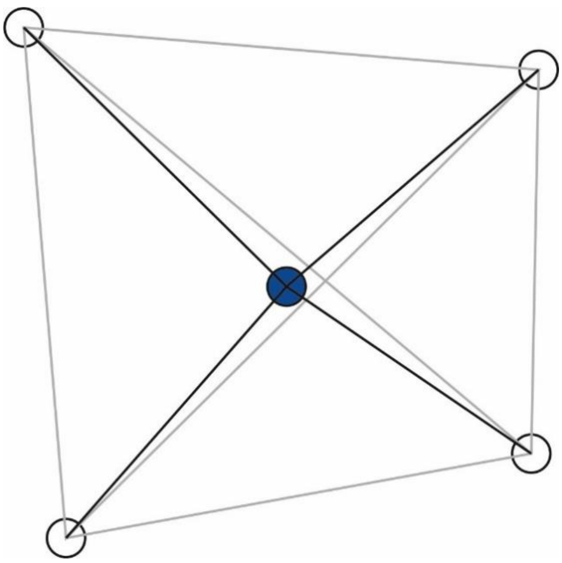


Figure 3: Network configuration for investigating the stability of the prism center when swiveling and rotating (top view)

Targeting was carried out in both prism faces and for each position in 4 sets and 2 instrument faces. The resulting base network for the Leica TS60 achieved an average standard deviation of 0.12 mm in position and 0.03 mm in height, for the Trimble S9 it was 0.13 mm in position and 0.10 mm in height. The measurement setup is therefore also suitable for determining the coordinates of the various orientations of the prisms to be examined with sufficiently high accuracy without the influence of the standpoint measurements. The results are shown in Table 5 and Table 6.

The magnitude of the deviations already determined for this type of prism is confirmed in the adjustment network, with an additional influence of up to 1 mm due to the measurement in two prism faces (i.e. when the base plate is rotated by 180° and the prism is simultaneously swiveled around its tilting axis). This can be interpreted as eccentricity fraction of the prism reference point from the rotation axis of the plate adapters.

The variability of the prism center, or the coordinates represented by it, is in the order of ±1 mm for all prisms for the Leica TS60 and up to ±1.5 mm for the Trimble S9.

For both manufacturers, no significantly recognizable quality dependency on the prism coating can be determined in the examined close range.

Table 5: Reproducibility of the centering accuracy of the tested prism types on a horizontal rotation adapter using a Leica TS60 (maximum deviation from mean value)

Prism type	No.	Max 2D [mm]	Max height [mm]	Std.dev 2D [mm]	Std.dev height [mm]
4 – RSMP390 - C	11	0,99	0,12	0,52	0,07
	12	0,69	0,37	0,52	0,24
	13	0,72	0,10	0,48	0,06
5 – RSMP390 - S	14	0,72	0,28	0,51	0,23
	15	0,64	0,34	0,42	0,24
	16	0,62	0,27	0,42	0,24

Table 6: Reproducibility of the centering accuracy of the tested prism types on a horizontal rotation adapter using a Trimble S9 (maximum deviation from mean value)

Prism type	No.	Max 2D [mm]	Max height [mm]	Std.dev 2D [mm]	Std.dev height [mm]
4 – RSMP390 - C	11	1,31	0,17	0,80	0,11
	12	1,03	0,30	0,65	0,23
	13	0,96	0,16	0,63	0,10
5 – RSMP390 - S	14	1,08	0,34	0,62	0,21
	15	0,85	0,35	0,57	0,26
	16	1,19	0,31	0,78	0,22

6 Accuracy of plug-in mini-prisms

Prism types 6 and 7 (RSMP12 and RSMP10) are designed as plug-in prisms for cracks and holes. Accordingly, there are offsets to the two possible support points, spike and back of the housing, according to the manufacturer's specifications. In order to achieve a correct measuring result, the manufacturer specifies that the prisms must be aligned with the measuring direction.

In an examination with a measured reference point and manual attachment of the prism spikes at this point, the offset values variations for both prism types with a Leica total station for all six specimens examined were within 0,7 mm, which is a repetition value as applicable when the prisms are permanently installed.

For the investigation of the centering accuracy at different angles of sight (as it would happen when the prism gets rotated around its holding point), the two prism types were clamped in a rotating and swiveling adapter whose dimensions are known and taken into account. However, a certain inaccuracy share from this device of up to 0.5 mm is unavoidable. The reference for the measurement was the back of the housing, which should nominally have an offset of 10 mm from the prism center. The targeting was carried out in the same network as in the investigation of the rotating plate prisms. The targeting was again carried out in both prism faces per point of view and in 4 sets and 2 instrument faces each. In this experiment, only the Leica TS60 was used, not the Trimble S9. The results can be found in Table 7.

The variability of the prism center when using a RSMP10 or RSMP12 plug-in prism with alignment to the total station can be specified with ±2 mm.

In the case of repeatable or permanent installation (when alignment is determined e.g. by a drilling hole), the value improves to ±1 mm.

Table 7: Reproducibility of the centering accuracy of the plug-in mini-prisms implemented on a tilting adapter using a Leica TS60 (maximum deviation from mean value)

Prism type	No.	Max 2D [mm]	Max height [mm]	Std.dev 2D [mm]	Std.dev height [mm]
6 – RSMP12 - C	21	0,86	2,21	0,52	1,60
	22	0,98	2,13	0,73	1,32
	23	1,31	1,48	1,01	1,16
7 – RSMP10 - S	31	1,87	2,01	1,09	1,03
	32	1,69	1,24	1,37	1,35
	33	1,73	2,25	1,08	1,42

7 Possible measurement ranges

The prism types RSMP380 with copper and silver coating and RSMP280 with silver coating were examined for their (automatic) targeting ability at increasing distance from the total station. The Trimble S9 and the Leica TS60 were used again. The test under normal, cloudy weather conditions resulted in the feasible measuring distances listed in Table 8.

The prism diameter shows to be the primary factor for the achievable range. Only at long distances above 1000 m does the Leica instrument show that a copper-coated prism can be aimed at slightly longer distances using ATR.

In addition, it must be taken into account that, depending on the weather conditions, the achievable distances can be significantly different (especially with strong sunshine or fog the distances can be much shorter).

Table 8: Possible measurement ranges using the prisms under test at normal, cloudy weather conditions

Prism type	Using Trimble S9	Using Leica TS60
1 – RSMP380 – S	up to ca. 550 m using AutoLock up to ca. 1200 m without AutoLock	up to ca. 1100 m using ATR up to ca. 1300 m without ATR
2 – RSMP380 – C	up to ca. 550 m using AutoLock up to ca. 1200 m without AutoLock	up to ca. 1250 m using ATR up to ca. 1300 m without ATR
3 – RSMP280 – S	up to ca. 500 m using AutoLock up to ca. 1200 m without AutoLock	up to ca. 900 m using ATR up to ca. 1300 m without ATR

Responsible for the measurements and this report:

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