INTERNATIONAL STANDARD

ISO 17123-9

First edition
2018-12

Optics and optical instruments — Field procedures for testing geodetic and surveying instruments —

Part 9:
Terrestrial laser scanners

Optique et instruments d'optique — Méthodes d'essai sur site des instruments géodésiques et d'observation —

Partie 9: Scanners laser terrestres

Reference number
ISO 17123-9:2018(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 6, *Geodetic and surveying instruments*.

A list of all parts in the ISO 17123 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document specifies field procedures for adoption when determining and evaluating the uncertainty of measurement results obtained by geodetic instruments and their ancillary equipment, when used in building and surveying measuring tasks. Primarily, these tests are intended to be field verifications of suitability of a particular instrument for the immediate task. They are not proposed as tests for acceptance or performance evaluations that are more comprehensive in nature.

These field procedures have been developed specifically for *in situ* applications without the need for special ancillary equipment and are purposely designed to minimize atmospheric influences.

The definition and concept of uncertainty as a quantitative attribute to the final result of measurement was developed mainly in the last two decades, even though error analysis has already long been a part of all measurement sciences. After several stages, the CIPM (Comité Internationale des Poids et Mesures) referred the task of developing a detailed guide to ISO. Under the responsibility of the ISO Technical Advisory Group on Metrology (TAG 4), and in conjunction with six worldwide metrology organizations, a guidance document on the expression of measurement uncertainty was compiled with the objective of providing rules for use within standardization, calibration, laboratory, accreditation and metrology services. ISO/IEC Guide 98-3 was first published in 1995.

With the introduction of uncertainty in measurement in ISO 17123 (all parts), it is intended to finally provide a uniform, quantitative expression of measurement uncertainty in geodetic metrology with the aim of meeting the requirements of customers.

ISO 17123 (all parts) provides not only a means of evaluating the precision (experimental standard deviation) of an instrument, but also a tool for defining an uncertainty budget, which allows for the summation of all uncertainty components, whether they are random or systematic, to a representative measure of accuracy, i.e. the combined standard uncertainty.

ISO 17123 (all parts) therefore provides, for defining for each instrument investigated by the procedures, a proposal for additional, typical influence quantities, which can be expected during practical use. The customer can estimate, for a specific application, the relevant standard uncertainty components in order to derive and state the uncertainty of the measuring result.

Optics and optical instruments — Field procedures for testing geodetic and surveying instruments —

Part 9: Terrestrial laser scanners

1 Scope

This document specifies field procedures for determining and evaluating the precision (repeatability) of terrestrial laser scanners and their ancillary equipment when used in building, civil engineering and surveying measurements. Primarily, these tests are intended to be field verifications of the suitability of a particular instrument for the immediate task at hand, and to satisfy the requirements of other standards. They are not proposed as tests for acceptance or performance evaluations that are more comprehensive in nature.

This document can be thought of as one of the first steps in the process of evaluating the uncertainty of measurements (more specifically of measurands).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99:2007, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

ISO 3534-1, *Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability*

ISO 4463-1, *Measurement methods for building — Setting-out and measurement — Part 1: Planning and organization, measuring procedures, acceptance criteria*

ISO 7077, *Measuring methods for building — General principles and procedures for the verification of dimensional compliance*

ISO 7078, *Building construction — Procedures for setting out, measurement and surveying — Vocabulary and guidance notes*

ISO 9849, *Optics and optical instruments — Geodetic and surveying instruments — Vocabulary*

ISO 17123-1, *Optics and optical instruments — Field procedures for testing geodetic and surveying instruments — Part 1: Theory*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 3534-1, ISO 4463-1, ISO 7077, ISO 7078, ISO 9849, ISO 17123-1, ISO/IEC Guide 98-3 and ISO/IEC Guide 99 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Symbols and subscripts

4.1 Symbols

Symbol	Quantity	Unit
c	sensitivity coefficient	—
d	calculated distance	m and mm
$\bar{d}$	calculated mean distance	m and mm
d_{obs}	measured distance	m
Δ	distance difference	m and mm
e	eccentricity	mm
F	F-distribution	—
I	turning axis error	°
k	coverage factor	—
k_0	zero point error	m and mm
z_0	zero point error	m and mm
ν	degree of freedom	—
Ω	sum of squared residual	m^2 and mm^2
θ	tilting angle	°
φ	turning angle	°
r	residual calculated by means of single distances	m and mm
$\bar{r}$	residuals calculated by means of the mean distances	m and mm
S	instrument station	—
$\hat{s}$, s	experimental standard deviation for a precision measure	m and mm
$\hat{\bar{s}}_0$	experimental standard deviation for an accuracy measure	m and mm
σ	theoretical standard deviation of a population	m and mm
T	target point	—
u	uncertainty	various
U	expanded uncertainty with coverage factor k	various
x, y, z	Cartesian coordinate	m
χ	Chi-Square distribution	—
ζ_v	Index error of tilting axis	°
ζ	resolution	mm

4.2 Subscripts

Subscript	Term
c	collimation axis error
cen	centring of targets
d	calculated distance
$\bar{d}$	calculated mean distance
Δ	difference
diff	diffusion of the measuring beam
ec	eccentricity of the collimation axis
I	turning axis error
ia	incident angle
i,j	index for target
ISO-TLS	of standard uncertainty of the TLS (type A)
k_0	zero point error
m	maximum
ms	manufacture specification
$m0$	scale factor
n	index for station
φ	turning angle
p	typical influence quantities for the TLS measurements
pr	pressure
pri	primary rotation axis
r	measured range
rc	roughness
rh	relative humidity
S	instrument station
se	sighting axis deviation
sec	secondary rotation axis
sta	stability setup
T	target point
temp	temperature
θ	tilting angle
$v0$	tumbling deviation
w	set number or repetition number
xyz	3D point
x,y,z	cartesian coordinate
ζv	index of tilting axis
$\zeta\theta$	resolution tilting angle
$\zeta\varphi$	resolution turning angle

5 Requirements and recommendations

Before commencing the measurements, the operator shall ensure that the precision in use of the measuring equipment is appropriate for the intended measuring task.

The laser scanner and its ancillary equipment shall be in known and acceptable states of permanent adjustment according to the methods specified in the manufacturer’s handbook.

The coordinates are considered as observables because of modern laser scanners they are the standard output quantities. All coordinates shall be measured on the same day. The instrument need not, but may be levelled.

Meteorological data shall be recorded during the data acquisition in order to derive atmospheric corrections. If possible the option for meteorological corrections within the software of the laser scanner should be used. If the systematic deviations, created by the non-consideration of the atmospheric corrections are too significant, and the automatic correction is not possible, then the raw distances shall be corrected manually.

The operator should note the actual weather conditions at the time of measurement and the type of surface on which the measurements are made. The conditions chosen for the tests should match those expected when the intended measuring task is actually carried out (see ISO 7077 and ISO 7078).

Tests performed in laboratories would provide results which are almost unaffected by atmospheric influences, but the costs for such tests are very high, and therefore they are not practicable for most users. In addition, laboratory tests yield precisions much higher than those that can be obtained under field conditions.

This document describes one field procedure with two different amounts of work as given in Clauses 7 and 8. If enough time is available, the full test procedure according to Clause 8 is recommended. It allows a more refined and reliable judgement of the instrument.

6 Test principle

6.1 General

As raw observation values of laser scanners the x-, y- and z-coordinates of single points are treated. In contradiction to other geodetic instruments, for example total stations, these coordinates do not have a representative geometrical meaning. Furthermore, single points cannot be reproduced by repetition. The quality of the scans can only be derived from estimated geometrical elements, like planes, spheres or cylinders.

In the proposed test procedures the targets and the software for the target centre detection, which are both important parts of the standard laser scanner equipment, shall be used as key elements for the evaluation of the achievable precision. The 3D distances between the targets serve as indicator for the quality of the measurements. The distances are chosen as datum independent measures for levelled and non-levelled instruments.

Other targets, like spheres, may be used instead of the standard targets, which are recommended by the manufacturer.

6.2 Procedure 1: Simplified test procedure

The simplified test procedure provides an estimate as to whether the precision of a given laser scanner equipment is within the specified permitted deviation in accordance with ISO 4463-1.

The simplified test procedure is based on a limited number of measurements. This test procedure relies on measurements of x-, y- and z-coordinates in a test field without nominal values.

An accurate standard deviation cannot be obtained. If a more precise assessment of the laser scanner under field conditions is required, the more rigorous full test procedure as given in Clause 8, should be used.

6.3 Procedure 2: Full test procedure

The full test procedure shall be adopted to determine the best achievable measure of precision and partly accuracy of a laser scanner and its ancillary equipment under field conditions within an acceptable time. The geometry of the test field is identical to the geometry of the simplified test procedure. In this test procedure three series of measurements are taken instead of one series as in the simplified test procedure. In addition, the statistical tests are applicable only for this test procedure.

7 Simplified test procedure

7.1 Configuration of the test field

In total two instrument positions and four target marks, also called targets, are arranged in a horizontal and a vertical triangle. The measurement setup is shown in Figure 1 and Figure 2. Both triangles share one edge. The two instrument stations S_1 and S_2 as well as the two targets T_1 and T_2 are aligned on the shared edge. This is necessary in particular for the determination of a systematic distance deviation. The dimensions of the triangles and also the distance between the two instrument stations are determined essentially by the range of the examined TLS and by the maximum distance for capturing the targets as recommended by the manufacturer.

The following recommendations concerning the measurement setup shall be taken into account:

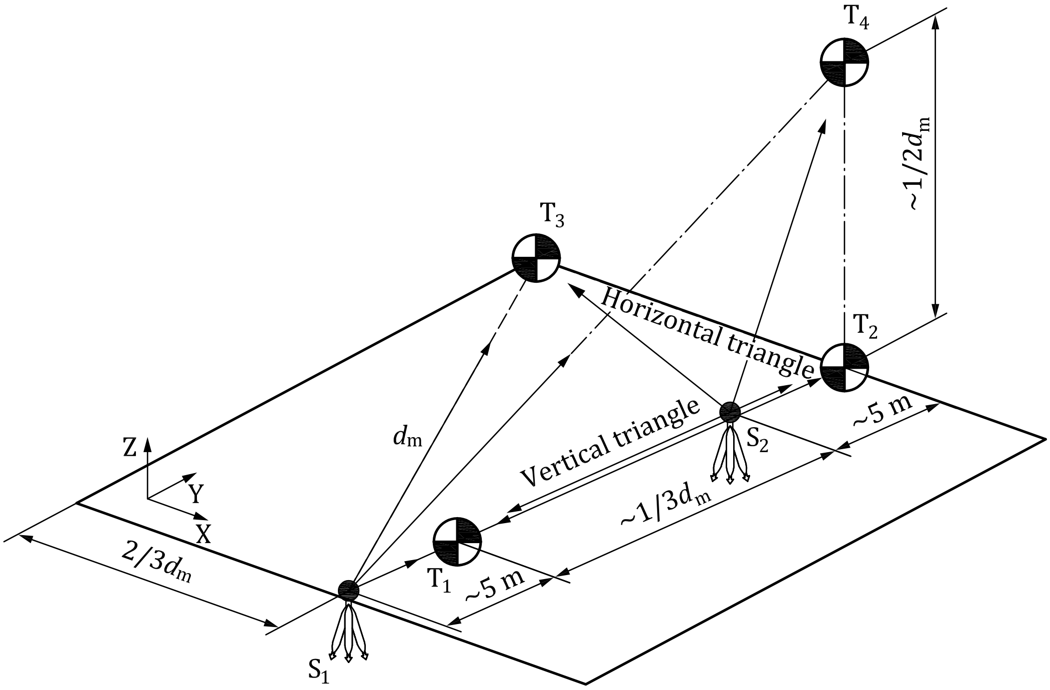
— The two instrument stations S_1 and S_2 as well as the two targets T_1 and T_2 shall be aligned on a line in space.

— Both the horizontal and the vertical triangle shall be realized as right-angled triangles (each with a right angle at target T_2).

— The hypotenuse S_1T_3 of the horizontal triangle shall match the maximum recommended distance for target capturing. This distance will be called maximum distance d_m in the following.

— The distance T_2T_4 of the vertical triangle should be made as long as the local conditions permit and it shall however be at least one third of the maximum distance. Moreover, the target T_4 shall be observed in steep sighting. The minimum value of 27° for the tilting angle, under which T_4 shall be observed from S_1, is recommended (see Figure 2). Table 1 gives some examples for possible configuration of the test field.

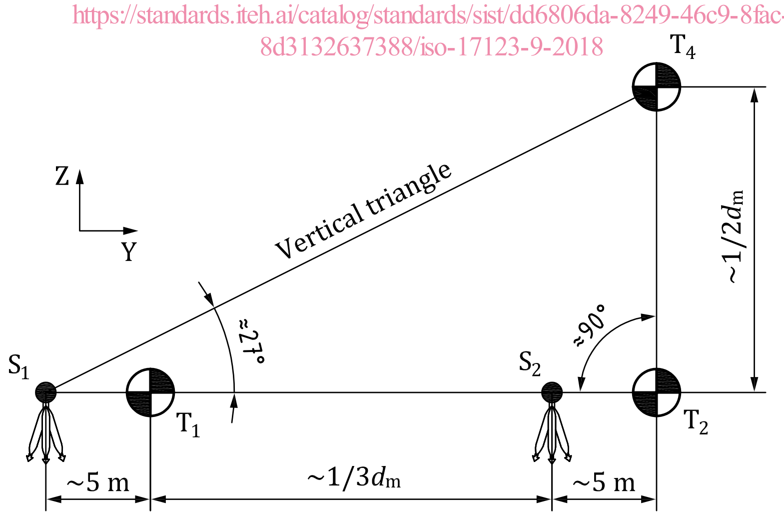
— The desirable ratio of the cathetus in the vertical triangle is 1:1. If possible, a ratio of 2:1 shall not be exceeded, however only in case the site allows for placing T_4 sufficiently high.



Key

S_1, S_2	instrument station
T_1, T_2, T_3, T_4	target point
d_m	maximum distance

Figure 1 — Configuration of the test field



Key

S_1, S_2	instrument station
T_1, T_2, T_3, T_4	target point
d_m	maximum distance

Figure 2 — Vertical plane of the test field

Table 1 — Examples of distances for the testfield-setup based on the maximum distance d_m

$\|S_1T_3\|$[a] m	$\|S_2T_1\|$[b] m	$\|S_1T_4\|$[c] m	$\|S_2T_3\|$[d] m	$\|S_2T_4\|$[e] m	Elev. Angle on S_1 to T_4 °
20,00	6,67	19,44	11,06	10,00	30,964
25,00	8,33	22,19	17,00	12,50	34,287
30,00	10,00	25,00	22,36	15,00	36,870
35,00	11,67	27,85	27,49	17,50	38,928
40,00	13,33	30,73	32,49	20,00	40,601
45,00	15,00	33,63	37,42	22,50	41,987
50,00	16,67	36,55	42,30	25,00	43,152

a d_m

b 1/3 d_m

c $\sqrt{|T_2T_4|^2 + (5\text{m}+|S_2T_1|+5\text{m})^2}$

d $\sqrt{d_m^2 - (5\text{m}+|S_2T_1|+5\text{m})^2}$

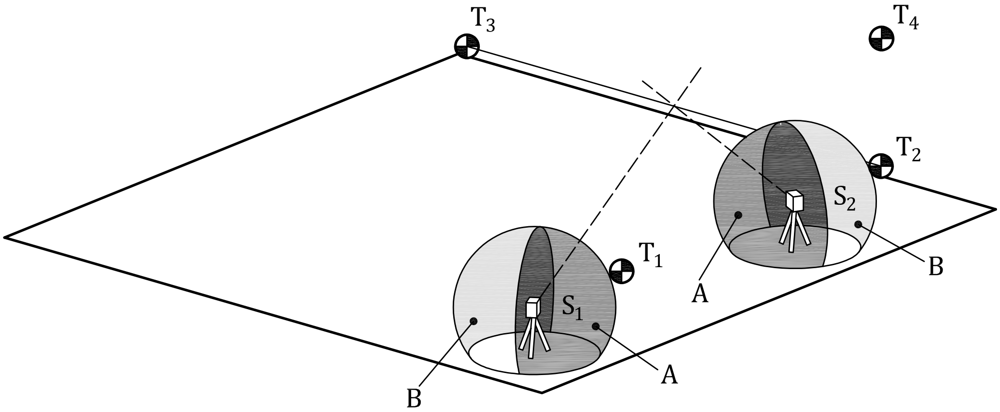
e 1/2 d_m

— Several laser scanners deflect the laser beam by rotations about two orthogonal axes, one slowly rotating axis (primary rotation axis) and one fast rotating axis (secondary rotating axis). This type of laser scanners typically can scan the complete surrounding by turning only by 180° about the slowly rotating axis, while the fast rotating axis deflects the laser beam to the front side (face I) as well as to the back (face II) of the laser scanner. In order to detect systematic deviations (e.g. axis misalignments) of the laser scanner and reliably check the instrument the following orientation rule is required.

On station S_1 as well as on S_2 the face in which T_3 is scanned shall be different from the face in which T_2 and T_4 are scanned. This means, in case the targets are scanned in a full-dome scan, the "seam line" of the full-dome scan always shall run between T_3 and T_2/T_4. On instrument station S_2 the targets T_2, T_3 and T_4 shall be scanned in a different face than on S_1 (see Figure 3 and Figure 4 dark grey hemisphere and bright grey hemisphere of the dome).

7.2 Example 1: Target scan by full dome scan

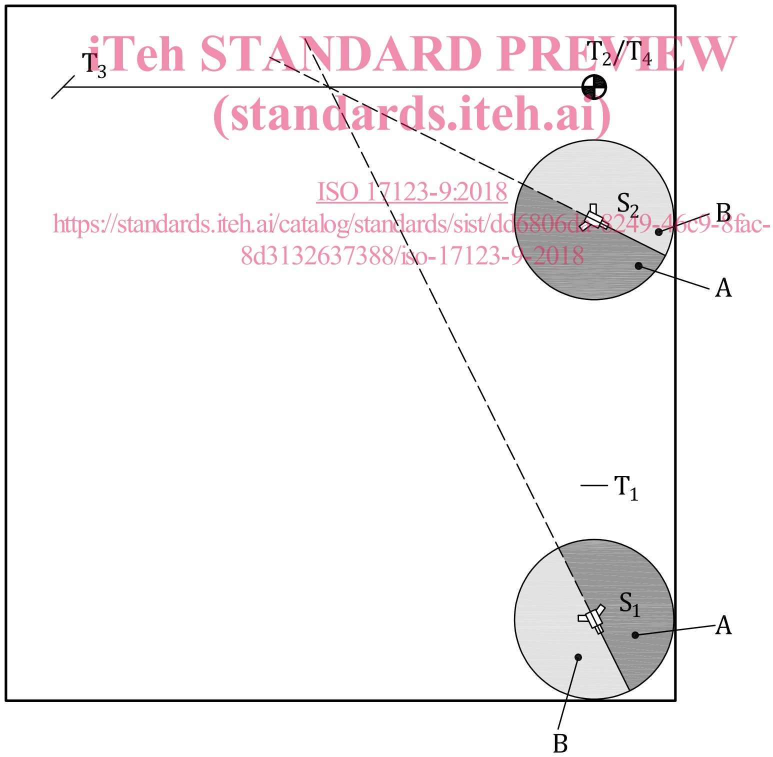
The targets will be scanned by a single full-dome scan on each station. On instrument station S_1 the TLS instrument is oriented in a way that the first vertical scan line will run between T_3 and T_2/T_4. The targets T_1, T_2 and T_4 will be scanned in face I and T_3 will be scanned in face II. On position S_2 the instrument will again be oriented in a way that the first vertical scan line will run between T_3 and T_2/T_4, but now T_2 and T_4 are scanned in face II, while T_1 and T_3 are scanned in face I.



Key

A	face I
B	face II
S_1, S_2	instrument station
T_1, T_2, T_3, T_4	target point

Figure 3 — Instrument orientations on both positions (side view)



Key

A	face I
B	face II
S_1, S_2	instrument station
T_1, T_2, T_3, T_4	target point

Figure 4 — Instrument orientation on both positions (top view)

The seam line of the full-dome scan needs to run between T_3 and T_2/T_4. The faces on both instrument positions shall be inverted but can also be vice versa. Dark grey colour indicates the face I and the bright grey one the face II.

7.3 Example 2: Two face target scan

The TLS instrument offers target scanning functionality in both faces. If all targets will be scanned in both faces a selection process shall be carried out. When evaluating the measurements on instrument station S_1 for T_1, T_2 and T_4 the target scans in face I will be considered, while for T_3 the target scan in face II shall be considered. When evaluating the measurements on S_2 it shall be vice versa: For T_2 and T_4 the target scans in face II shall be considered, while for T_1 and T_3 the target scan in face I shall be considered.

7.4 Measurements

Before beginning the measurements the instrument shall become acclimatised to the ambient temperature (if not stated else by the manufacturer in the user manual, use 2 min/°C difference for acclimatization). All coordinates shall be measured within a 24 hour period.

After completing the measurements, point clouds of the targets in form of three-dimensional Cartesian coordinates are available, from which the centre coordinates, e.g. of spheres or chessboard targets shall be determined. For this work step, the corresponding processing software of the manufacturer should be used. It shall be ensured that irregular pixels are eliminated before determining the target centers. After this work step, three-dimensional Cartesian coordinates for the centre points of the targets T_1 through T_4 are available.

The four targets are scanned once from each station. The results are local 3D coordinates for each target. Each station is defining a locale Cartesian coordinate system. The resulting coordinates are listed in Table 2.

Table 2 — Coordinates of the local scans from S_1 and S_2

Station S_n	**Target** T_j	$x_{n,j}$	$y_{n,j}$	$z_{n,j}$
S_1	T_1	$x_{1,1}$	$y_{1,1}$	$z_{1,1}$
	T_2	$x_{1,2}$	$y_{1,2}$	$z_{1,2}$
	T_3	$x_{1,3}$	$y_{1,3}$	$z_{1,3}$
	T_4	$x_{1,4}$	$y_{1,4}$	$z_{1,4}$
S_2	T_1	$x_{2,1}$	$y_{2,1}$	$z_{2,1}$
	T_2	$x_{2,2}$	$y_{2,2}$	$z_{2,2}$
	T_3	$x_{2,3}$	$y_{2,3}$	$z_{2,3}$
	T_4	$x_{2,4}$	$y_{2,4}$	$z_{2,4}$

7.5 Calculation

The distances between the targets are calculated for instrument stations S_1 and S_2 according to Formulae (1) and (2):

$$d_{S1,j,i} = \sqrt{\left(x_{S1,i} - x_{S1,j}\right)^2 + \left(x_{S1,i} - y_{S1,j}\right)^2 + \left(z_{S1,i} - z_{S1,j}\right)^2} \quad (1)$$

$$d_{S2,j,i} = \sqrt{\left(x_{S2,i} - x_{S2,j}\right)^2 + \left(y_{S2,i} - y_{S2,j}\right)^2 + \left(z_{S2,i} - z_{S2,j}\right)^2} \quad (2)$$

with $i = 2, 3, 4$ and $j = 1, 2, 3$