OPTTIMIZATION AND STRENGTH ASPECTS FOR GEO-REFERENCING DATA WITH TERRESTERIAL LASER SCANNER SYSTEMS

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Abstract: Geo-referencing data is one of the most important terrestrial laser scanner data processing steps. It means to collect the separated scans of the object in one scan world coordinate. Geo-referencing, some times called data registration, is important when the scan object, regardless its size, has a significant variation in depth and one scan is not sufficient to describe it geometrically. Methods for data registration have been widely investigated, but practical rules for capturing the data haven't been examined yet. An example, is the distribution of the tie-points which are used in the registration and their position according to the laser scanner position in every two adjacent scans. In order to evaluate the accuracy of the complete model obtained by the scanning process, a lot of measurements in different positions for distance and orientation of the laser scanner have been performed. In this paper the results of the precision achieved using the registration of two adjacent scans are described. Also some practical rules to mange the geometrical distribution of the tie points and generate their optimal location for improving the precision of the final 3D model are examined.

Key words: Laser scanner, Registration, Algorithm, 3D model

1. Introduction

Laser scanning is a technique that becoming popular for 3D model acquisition. (TLS) is used for architecture, virtual reality, heritage documentation, preservation and lots of civil engineering applications. The market offers a lot of terrestrial laser scanners (TLS) with different system specifications. If the scanning object is large or has complex shape, several scans is recommended in this case. Every scan has a local coordinate system according to the scanner reference system. Laser Scanners are spherical measurement systems that measure the area of interest with a very high frequency. For each point one oblique distance ρ and two orthogonal angles θ and α are measured, together with the additionally registered intensity of the returning signal distance. The geometric relation between these measurements and three-dimensional information of the scanning points can be calculated from equation 1.

$$\begin{bmatrix} x \\ y \\ y \end{bmatrix} = \rho \begin{bmatrix} \sin\theta\sin\alpha \\ \cos\theta\sin\alpha \\ \cos\alpha \end{bmatrix} \quad (1)$$

where x, y and z are cloud point coordinate, ρ is the slope distance between laser scanner instrument and object, θ and α are horizontal and vertical angles for the measured points. TLS does not have any of the hard ware facilities for orienting the scanner, so all the scans must be put together in one common reference coordinate system.

2. Problems and objectives

There is a need to obtain an accurate 3D model for the scan object. The accuracy of the final 3D model affected by the uncertainty of the transformation parameters and the observations precision for the scanning system. The geometrical distribution of registration targets around scanner position is very important task. Errors computed for the transformation parameters will be propagated into the geo-referenced scan cloud points, and also registration solution will be unstable.

With computer-based simulations, [9] has considered that the laser scanner data could be registered by calculating the origin of the scanner from three or more ground control points (GCPs) from 3D resection solutions and also investigated the effect of the control geometry on the quality of 3D resection solutions with a narrow field of view (*Cyrax 2500*). But simulation is performed under ideal conditions, which are rare to meet in the field. For example the linear shape of the scan object and the conditions of work around the building or working inside the building. For such cases the geometric configuration of target registration will not be ideal for the registration accuracy. [3] describes a 3D resection using two horizontal angles and two vertical angles to compute the coordinates of occupied point from two control points. He recommended that horizontal angle between the control points should not be greater than 30° to get stable solution for 3D resection problem. [7] and [8] recommended that by using spherical targets for data registration the accuracy is improved, also by using range square between target and laser scanner to give different weighting for the same target in every adjacent scans with the combined least squares solution model, the results are improved. In this paper, the combined least squares as a method for data registration has been used to calculate the transformation parameters. For the purpose of analysing the quality of the estimated transformation parameters, the standard deviations and covariancees are extracted from the covariance matrix of the parameters. These values of the standard deviations are function of the distribution of registration targets. Optimal location of the registration points to improve precision of the final 3D model will be a main target for this work

3. Computation of transformation parameters

Transformation parameters between the first scan world coordinate system and adjacent scans will be calculated in two steps :

1. Calculation of the approximate parameters.
2. Refine the approximate parameters by using least squares solution.

The first step is based on the approach proposed by [13]. Assume we have more than one scan to be registered, in every scan a set of n registration targets with there x, y and z coordinate in global system (assuming that all the scans will be transferred into the first scan coordinate system) and local system. The relation between the 6 transformation parameters and two systems is defined as follows:

$$X_i = T + R \cdot U_i \tag{2}$$

where:

X_i - vector containing the 3 coordinates of point n_i in global system.

T - translation vector

R - otation matrix.

U_i - vector containing the 3 coordinates of the same point n_i in local system.
Assuming that the scale factor not significant for the laser scanner observation. All the set of *n* registration targets coordinates should be referred to the geometric centres X_g and U_g where:

$$X_g = \frac{\sum_{i=1}^{i=n} X_i}{n} \tag{3}$$

$$U_g = \frac{\sum_{i=1}^{i=n} U_i}{n} \tag{4}$$

Vectors coordinate according to the geometric centres will take the following forms:

$$x_i = X_i - X_g \tag{5}$$

$$u_i = U_i - U_g \tag{6}$$

The rotation matrix takes the following form:

$$R = \begin{pmatrix} \cos\phi\cos\kappa & -\cos\phi\sin\kappa & \sin\phi \\ \cos\omega\sin\kappa + \sin\omega\sin\phi\sin\kappa & \cos\omega\cos\kappa - \sin\omega\sin\phi\sin\kappa & \sin\omega\cos\phi \\ \sin\omega\sin\kappa - \cos\omega\sin\phi\cos\kappa & \sin\omega\cos\kappa + \cos\omega\sin\phi\sin\kappa & \cos\omega\cos\phi \end{pmatrix} \tag{7}$$

where ω, ϕ and κ are rotations about the *x, y*, and *z* axes respectively. The rotation matrix also takes another form based on *Quaternions:*

$$R = \begin{pmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & -2q_{0.} \cdot q_3 + 2q_2 \cdot q_1 & 2q_{0.} \cdot q_2 + 2q_3 \cdot q_1 \\ 2q_{0.} \cdot q_3 + 2q_2 \cdot q_1 & q_0^2 - q_1^2 + q_2^2 - q_3^2 & -2q_{0.} \cdot q_1 + 2q_3 \cdot q_2 \\ -2q_{0.} \cdot q_2 + 2q_1 \cdot q_3 & 2q_{0.} \cdot q_1 + 2q_2 \cdot q_3 & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{pmatrix} \tag{8}$$

The rotation matrix in this case has four-elements unit quaternion $q = [q_0 \quad q_1 \quad q_2 \quad q_3]^T$ .The relation between the 4 elements take the form:

$$q_0^2 + q_1^2 + q_2^2 + q_3^2 = 1 \tag{9}$$

The quaternion operations are faster because they can be done using fewer operations. The solution of the unknowns [13] is found. by the solution of four homogeneous linear equations A .in the components of q .

$$A \cdot q = \rho \cdot q \tag{10}$$

Where ρ and q are respectively an eigenvalue and an eigenvector of the symmetrical matrix A that constructed from the vectors coordinate according to the geometric centres data as described in equations 5 and 6 ($x_i = [x_i \quad y_i \quad z_i]^T$ and $u_i = [u_i \quad v_i \quad w_i]^T$).

$$A = \frac{1}{n}\begin{bmatrix} -\left[\sum_{i=0}^{n} u_i \cdot x_i + \sum_{i=0}^{n}(v_i \cdot y_i + w_i \cdot z_i)\right] & -\left[\sum_{i=0}^{n}(v_i \cdot z_i - w_i \cdot y_i)\right] & -\left[\sum_{i=0}^{n}(w_i \cdot x_i - u_i \cdot z_i)\right] & -\left[\sum_{i=0}^{n}(u_i \cdot y_i - v_i \cdot x_i)\right] \\ & \left[\left(\sum_{i=0}^{n} u_i \cdot x_i + v_i \cdot y_i + w_i \cdot z_i\right) - 2\sum_{i=0}^{n} u_i \cdot x_i\right] & -\left[\sum_{i=0}^{n}(v_i \cdot x_i + u_i \cdot y_i)\right] & -\left[\sum_{i=0}^{n}(w_i \cdot x_i - u_i \cdot z_i)\right] \\ & & \left[\left(\sum_{i=0}^{n} u_i \cdot x_i + v_i \cdot y_i + w_i \cdot z_i\right) - 2\sum_{i=0}^{n} v_i \cdot y_i\right] & -\left[\sum_{i=0}^{n}(w_i \cdot y_i - v_i \cdot z_i)\right] \\ & & & \left[\left(\sum_{i=0}^{n} u_i \cdot x_i + v_i \cdot y_i + w_i \cdot z_i\right) - 2\sum_{i=0}^{n} w_i \cdot z_i\right] \end{bmatrix} \tag{11}$$

The eigenvector of the matrix A corresponding to the smallest eigenvalue is the correct solution of vector q . Translation vector could be calculated by rearranging equation 2 by taking in consideration the geometric centres X_g and U_g of the two coordinate systems. The important advantage of this method is that no convergence problem arise and the ability to determine the large rotation angels between two coordinate systems.

For the second step in the transformation parameters calculation, the combined least squares adjustment model could be used, which has the following mathematical model:

$$f\left(\hat{l}, \hat{x}\right) = 0 \tag{12}$$

where $\hat{l}$ is the vector of adjusted observations, $\hat{x}$ is the vector of adjusted transformation parameters. The mathematical form has two types, equation 2 describes the relation between unknowns and observations and equation 9 describes only the relations between the unknowns.

$$g(\hat{x}) = 0 \tag{13}$$

The correction vector from least squares solution was found equal zero, That means the approximation values from [13] solution method was a final solution. The only advantage of using least squares solution is providing a set of equality parameters for the unknowns, which measures the accuracy of the solution. Details of combined least squares solution can be found in [12].

4. Test field

In order to test the registration algorithm and get the results, laser system Leica Geosystems HDS has been used to scan a part from a wall in HANNOVER MESSE. The dimensions of the wall are about 500x12 m. The scanner system Leica HDS3000 (formerly known as the Cyra 2500) can be optically centred over a known point and levelled. Unlike a total station, however, it is not optically oriented toward a known point but uses high resolution scanning and a centred estimation algorithm to observe the centre of the back sight target A summary of the most important features of the HDS 3000 are reported in table 1. More details can be found in [10].

Measurement technique	Time of flight
Optimal effective range	1m-100m
Position accuracy	6mm
Distance accuracy	4mm
Vertical angle accuracy	60 micro radiance
Horizontal angle accuracy:	60 micro radiance
Scan rate1	Up to 1800 points/sec
Color	Green
Laser class	Class 3R
Field of view horizontal	360°
Field of view vertical	270°
Spot size	$\leq$6mm from 0-50m
Maximum sample density	1.2mm

Table 1: Technical specifications for HDS 3000 laser system.

Eight Cyra's retro-reflective targets (figure 1) are placed along one side of the wall and measured with the reflector-less total station. Coordinates of corresponding target center have been then used to control data geo-referencing. From five standpoints, five scans has been made with a Leica HDS 3000 laser scanner, the newest high precision Leica HDS family product. This scanning system allows for a larger Field of View (360o H x 270o V).

[1] Maximum scan rate dependent on scan resolution and selected field of view.

For the registration purpose, 12 uncelebrated spherical targets figure 1 (9 with diameter 30 cm and 3 with diameter 10 cm) with special holder have been placed. Figure 2 describe the registration targets configuration, which has been used for a real test data.

A. Cyra Target B. phere targets

Figure 1. Registration targets.

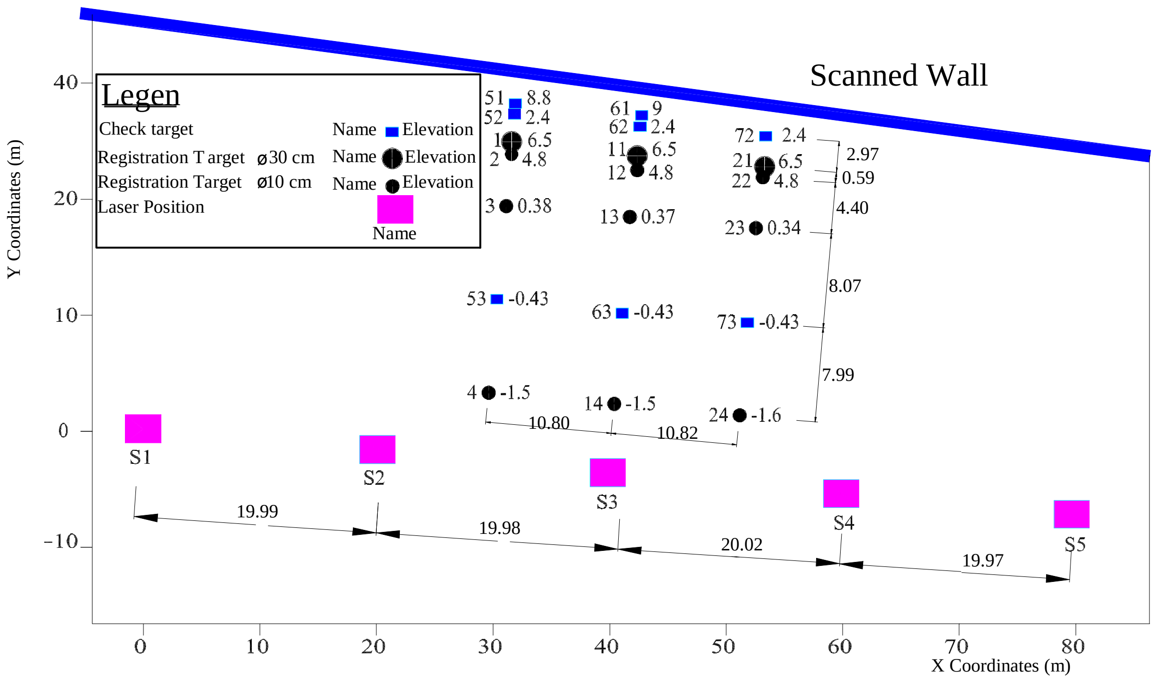


Figure 2. Registration and check targets configuration along one side of the wall.

The surface coordinates of all sphere targets in every scan have been manually selected and exported to a special c++ program [7] order to fit the spheres to calculate center coordinate for the registration purpose. Laser system Leica HDS 3000 has the possibility of automatically searching and scanning the reflecting targets with a very high resolution and estimating their coordinates. The reflecting targets have been used to check and evaluate registration results.

5. Registration results with different target configurations

First scan coordinate system has been considered as global coordinate system, then the other 4 scans have been registered onto the first scan using only coordinates of three targets. Three different target configurations have been studied to evaluate the accuracy, which was obtained from the registration step:

- Targets in a collinear fashion parallel to the line, which connects laser scanner set-up locations, configuration codes 1, 2, 3 and 4 (four trails).
- Targets in a collinear fashion perpendicular to the line, which connects laser scanner set-up locations, configuration codes 5, 6, and 7 (three trails).
- Targets in a zigzag fashion between Laser scanner set-up locations, configuration codes 8, 9, 10, 11, 12, 13 and 14 (seven trails).

Using the known coordinates of reflecting targets, estimated from a very high resolution scanning, and those computed after the registration process, the differences (distances between the known point and the calculated position after registration) expressed in meters have been calculated. Table 2 shows the configuration codes, which used to describes the horizontal axis in figure 3, 4 and 5), and an example of the maximum, minimum and mean of the difference on check points after the registration process in case of registration targets in a collinear parallel, collinear perpendicular and Zigzag configurations.

Configuration code	Used target	Collinear parallel configurations (m)		
		Max..Diff.	Min..Diff.	Mean.Diff.
1	1-11-21	0.2789	0.0820	0.1742
2	2-12-22	15.6190	8.9992	12.3870
3	3-13-23	0.4898	0.2828	0.3401
4	4-14-24	0.1090	0.0152	0.0485
		Collinear perpendicular configurations		
5	1-3-4	0.0851	0.0102	0.0305
6	11-13-14	0.0879	0.0139	0.0332
7	21-23-24	0.0791	0.0121	0.0302
		Zigzag configurations		
8	11-4-24	0.0762	0.0124	0.0296
9	11-3-23	0.0786	0.0088	0.0290
10	11-2-22	0.0810	0.0143	0.0310
11	3-24-21	0.0801	0.0106	0.0301
12	3-11-14	0.0793	0.0115	0.0302
13	3-23-22	0.0834	0.0106	0.0322
14	3-13-12	0.0787	0.0126	0.0295

Table 2 Difference on check points after registration process between scan numbers S1 and S5.

Figure 3 shows the standard deviations of the orientation and translation parameters between scan 1 and scan 5 with three different target configurations. Collinear parallel, collinear perpendicular and zigzag configurations. As expected, it has been shown that the configurations of registration target in a collinear or neared collinear made the registration solution to fail, or to contain inflated levels of accuracies. Figure 4 shows more zooming in the results only for perpendicular and zigzag configurations. The distribution of the targets in a zigzag form will give the best results. As the three registration targets in a zigzag form but near from collinear form, the results were very bad (see figure 3 case configuration number 10). κ parameters were independent of these configurations. The standard deviations of all parameters were lower and homogeneous in two configuration numbers 9 and 11.

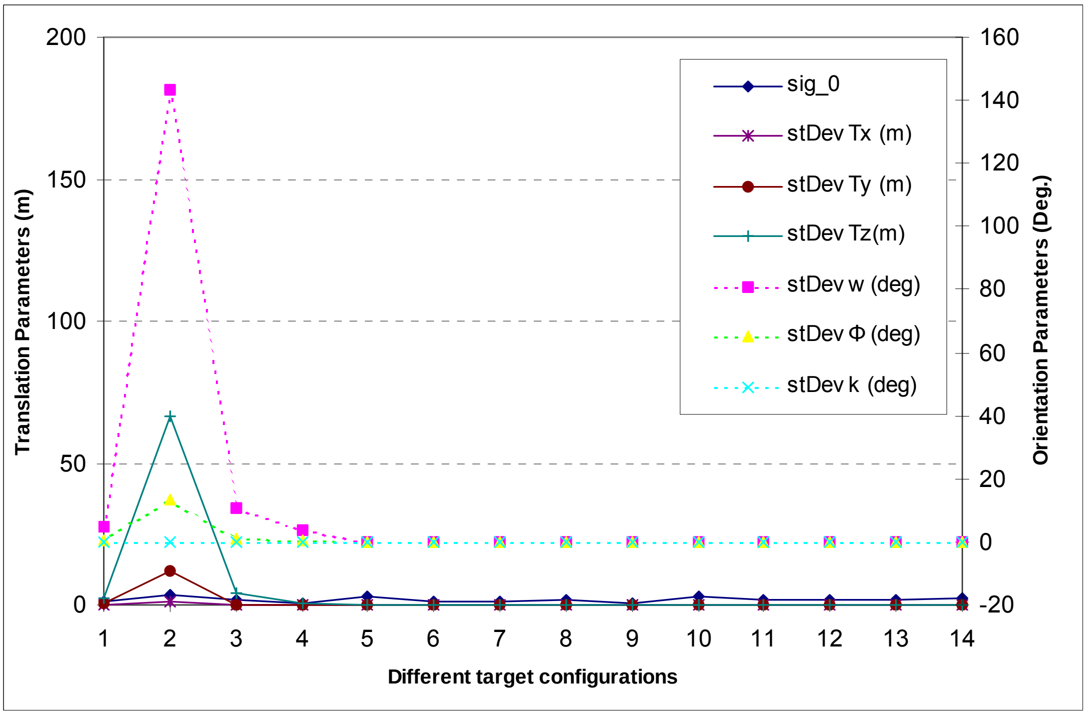


Figure 3. Standard deviations of registration parameters between scan numbers S1 and S5, (Collinear parallel, collinear perpendicular and zigzag configurations).

Figure 5 shows the standard deviations of the orientation and translation parameters between scan 1 and all the scans for only target configuration numbers 9 and 11, the results indicated that configuration number 9 is the most accurate one.

6. Concluding remarks

The accuracy of the registration of laser scanner data depends on the geometric distribution of registration targets. The combined least squares as a method for data registration has been used to calculate the transformation parameters. For the purpose of analysing the quality of the estimated transformation parameters, the standard deviations and covariancees are extracted from the covariance matrix of the parameters. Many registration targets geometric configurations has been studied.

Analysis was performed on a real field data. It has been shown that the poor target configurations , the low quality of the transformation parameters.

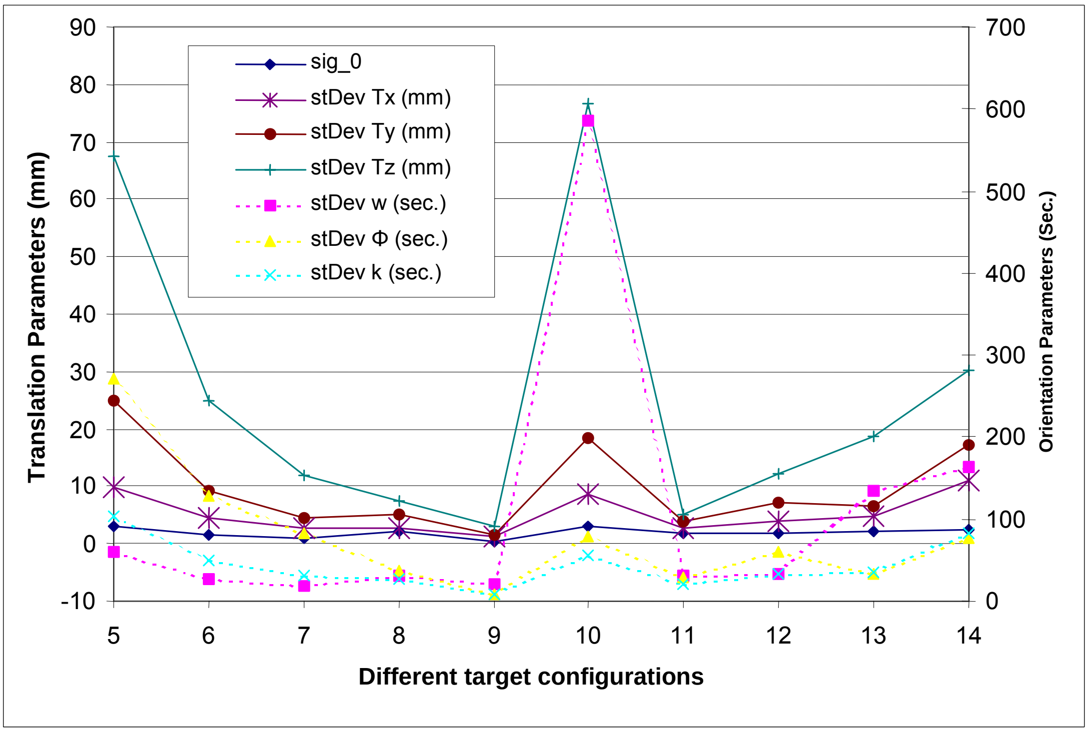
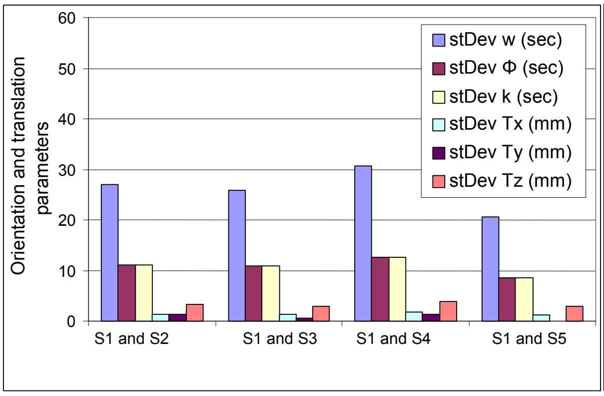
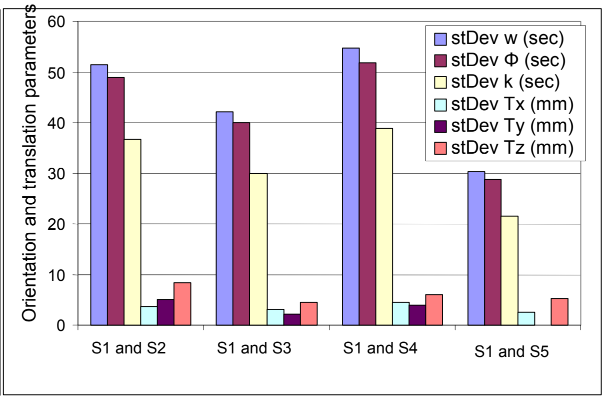


Figure 4. Standard deviations of registration parameters between scan numbers S1 and S5, (collinear perpendicular and zigzag configurations).



A. Configuration number 9.



B. Configuration number 11.

Figure 5. Standard deviations of registration parameters. between scan number S1 and the available other scans for configuration numbers 9 and 11.

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