A signalization-free coregistration approach of multiscale and multitemporal survey for structural monitoring

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Abstract

Infrastructure monitoring often calls for multi-scale and multi-epoch approaches: Quantifying and interpreting geometric deformation must be seen in conjunction with very local damages. For instance in the framework of so-called predictive maintenance, both, the quantification of load-depending deformation and the development of local damage, like cracks or spalling is necessary. Furthermore, the related observations must be made in several epochs, over months, years or even decades.
In our DFG-funded project "Optical 3D Bridge Inspection", which is part of the DFG priority program "100+", we investigate the surface geometry and damage of prestressed concrete bridges with high-resolution optical measurement systems to support structural monitoring. For data acquisition, we aim to combine terrestrial laser scanning (TLS) and UAV-supported image blocks, as well as structured light scanning (SLS) and hand-held sensors (cameras, depth images). Our research questions therefore address efficient and signalization-free coregistration methods of multiscale and multitemporal survey and image information on large infrastructure structures.
This paper presents an approach for signalization-free positioning of TLS and SLS by tachymetric positioning. These coregistered point clouds and image data sets then form the basis for detailed analysis of surface deformation and the development of cracks and spalling areas.

Keywords: Signalization-free coregistration, structural monitoring, TLS, SLS

1 Introduction

High precision and reliable sensor positioning and (contact-less) capture of surface geometries is a core task within the field of geodesy, in particular of the sub-domains engineering surveying and close-range photogrammetry. So far, however, methods for combining those complementary techniques (positioning within a pre-defined datum and surface geometry capture) do not operate fully automatically, yet. Using a totalstation, it is possible to compute the position of distinct points in object space; in most of the cases the localization of the device within the target's coordinate system is done using control points, possibly combined with direct positioning approaches supported by GNSS. Those workflows are well established, and they guarantee high accuracy and reliability and the use of marked control points is indispensable if a localization within the (local) datum needs to be performed.

Structured light scanners (SLS) are used to acquire the surface geometry in relatively small volume, applying passive optical technology, based on photogrammetric stereo reconstruction. One scan results in a point cloud or mesh-representation. If additional scans are needed when the object is larger, they need to be combined using targets in object space. This procedure, based on targets placed in object space, is labour intensive and, in certain scenarios, not applicable, for instance, when the object space is not accessible directly or when full automation is necessary for an efficient workflow.

Similarly, areal scans using a terrestrial laser scanner (TLS) are performed to extract a pointwise spatially discretized representation of an object of interest, resulting in a point cloud. Mostly the point clouds from multiple scanning stations are co-registered into one common coordinate frame using artificial targets. When the point cloud or the mesh need to be transformed into a pre-defined datum, again targets with known coordinates in that system need to be provided and measured within the point cloud, or, the targets which are used for co-registration are located in the final coordinate system.

In this paper we describe an automatic method and workflow to set up a multisensory approach with the ultimate aim to derive complex 3D point clouds with high-precision from multi-station SLS- or TLS-scans in object space, with only minimal manual intervention.

2 Methodological approach

Multi-scale and multi-temporal monitoring of a building requires both, surface data on the entire object and, if necessary, information of detailed structures to be recorded in a uniform coordinate frame at different epochs. Even continuous monitoring might be necessary. Changes, such as deformation should be shown accordingly to be able to make a holistic statement if necessary. For this purpose, it is necessary to bring different sensor systems, which are designed for different measurement volumes, into a common coordinate system. As an example, we have implemented this for a TLS and a SLS as part of our work.

The basic idea is that we use a total station via free stationing within our reference frame and determine the position and orientation of the TLS or SLS via angle and distance observations and use those to transform the respective sensor data into the target system. This means that ultimately all points of the point cloud shall be available in the target coordinate system without additional registration information, such as signalized targets or further processing steps.

For this purpose, however, the sensors must be equipped with corresponding targets, such as prisms or target marks.

2.1 Sensor-side adaptation for the TLS

Based on the approach of Paffenholz et al. (2010) an approach was chosen for the positioning and orientation of the TLS system or the SLS in which 3 mini prisms are connected on a stable mount linked to the sensor (s. Fig. 1). This external mount serves as an exterior orientation device (EOD) and was originally designed for positioning with GNSS and now consist of 5 possible positions for prisms.

So far, the two outer positions for a larger reference base and the centre raised position have been used. The 3D position of the centre of the TLS system can be derived from these 3 positions if the corresponding calibration parameters between the prism coordinates and the sensor reference of the TLS have been determined.

Figure 1. TLS with mounted EOD, equipped with three mini prisms

In addition, the prerequisite must be fulfilled that the vertical axis of the total station and the TLS are oriented plumb-vertical and that the 0-direction of the horizontal scanning unit of the scanner is known at the time of the total station measurements.

2.2 Determining the offset parameters for the TLS

To determine the transformation parameters of the EOD to the internal TLS sensor coordinate system, a network measurement with 4 stations and 8 prisms on walls was realised in a measuring volume of approx. 14m*8m*3m and was then adjusted. A total station was then positioned and orientated in this network via free stationing. The 3 points on the stable frame of the EOD were determined in 12 positions, each offset by 30°, in a full set of observations in order to obtain a best-fit estimate of the position of the standing axis of the TLS and also to robustly derive the determination of the height component via the 3 points.

This is followed by a full scan of the measurement volume in which 8 TLS black-white targets with known coordinates, also from the above network measurement, were available. After the automatic estimation of the TLS targets, the transition between the tachymetric coordinates and the coordinates stored in the centre of the scanner was determined using a 7-parameter transformation.

It is important to mention the property of the used Z+F 5016 scanner: It always moves to a horizontal zero position by control command and thus has a clear reference between the scanner coordinate system and the external coordinate system, realized through the mounted EOD can be established.

2.3 Sensor-side adaptation for the SLS

For the Structured Light Scanner (SLS) system StereoScan neo R16 used by us, the manufacturer Hexagon uses a calibrated reference frame for use in a photogrammetric measurement volume. This frame was also supplemented by 3 mountings for mini prisms (s. Fig. 2), so that the observations of the SLS system can also be available in a higher-level reference frame.

The derivation of the corresponding parameters between the prisms and the projection center of the SLS was carried out using an approach similar to that described in 2.2. By aligning the SLS to a fixed measurement volume, identical points in this measurement volume were measured from two stations using two precision total stations, which were also observed with the SLS. Here too, coordinate transformation was used to transfer the local SLS coordinates to the higher-level system.

Figure 2. SLS with positioning frame and three mounted prisms

3 Experiments

3.1 Simulation of the approach

A network simulation was carried out in advance for the expected positioning accuracy of the sensors in order to estimate the expected uncertainties in the object points and the point cloud data: We are facing a typical variance propagation problem as the position estimation of the EOD through the total station as further effect on the pointing accuracy of the TLS. In particular the estimation of the unknown scanner orientation in horizontal direction is based on the relatively short EOD, but during TLS scanning the measured distances are much longer.

We are assuming a typical deployment situation in which the scanner (Z+F 5016) is to be positioned with a free stationing (FS) within 4 connection points (1-4). Regarding the Leica TS 60 total station we were assuming a standard deviation of 0.5 mgon for the horizontal direction and vertical angle measurements and 1 mm for the distance measurements.

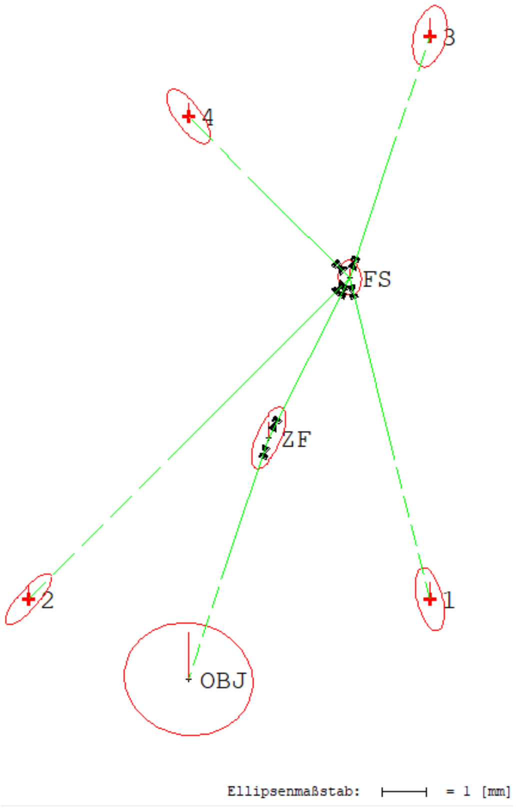

Figure 3. Result from the network simulation of free stationing with positioning of the TLS and derived object point (point cloud) with error ellipses at mm level.

The scan of the object (OBJ) is then simulated. The TLS measurements were introduced into the simulation with 4 mgon for the angles and 1mm for the distances. As shown in figure 3, the datum was based on the 4 reference points during free stationing and a higher uncertainty of better than 1.5mm per coordinate component was derived for the object point OBJ, which is exemplary for the point cloud, according to variance propagation. The following network graphic (s. Fig 3) shows a typical result from the simulation with the corresponding error ellipses. The major axis of the ellipse is pointing orthogonal to the TLS position, which is reasonable given the mentioned effect of most uncertain horizontal orientation estimation.

3.2 Test series

In order to be able to realise consistent test conditions, we used a sports hall for the tests in order to be able to have typical distances of 5m to 15m between the scanner and target object or scanner and total station.

First of all, a coordinate frame with 7 reference points with sub-mm accuracy was again created using a network measurement, in which 2 additional reflex marks to limit the measurement volume of the TLS and 7 black-and-white targets were also determined as reference points for the TLS measurement.

Figure 4. Test measurements with total station, TLS and the reference point field with black and white targets in the background

Figure 4 shows one of the typical test setups with the Leica TS60 total station and in the center with the TLS Z+F 5016 with mounted EOD. The scan section is limited by 2 reflective marks, framed by orange signalling, and defines the identical scan area (ROI) for all comparisons. The TLS reference markers can be seen in the background.

The aim of the test measurements is to investigate the extent to which we can transfer the results from offset determination and network simulation to reality and whether scans from different positions of the same object can provide identical coordinates within the expected accuracies.

To this end, the following questions should be investigated:

1. whether there is a distance dependency with regard to the distance between the TLS and total station on the positioning of the TLS
2. to what extent there is an influence of the orientation of the EOD with regard to the aiming of the total station on the positioning of the TLS
3. how large the differences in coordinates are when the same object is scanned from different positions.
4. whether it is possible to derive object deformations from different scans using this form of georeferencing.

In order to answer these questions, 41 positionings of TLS and total station with subsequent scanning of the ROI in the reference coordinate system of the hall have been carried out to date.

Figure 5 below shows an example of the test set-up for the investigation of the recording distance between total station and TLS, as well as the orientation of the EOD axis to the axis of ROI (blue angle) - total station. Free stationing was used to position the total station (orange square) in the reference system and then observe the TLS with EOD (pink circles).

The left-hand circle represents the TLS position at a distance of 21 meters from the total station, which was also observed three times with the orientation of the EOD perpendicular to the ROI-total station axis, at 45° and in the target direction of the total station to the TLS.

Once the total station had been positioned freely, the three prisms on the EOD were appropriately positioned and the coordinates of the scanner center were calculated, as well as the orientation of the scanner in the reference system. These values were then imported into the header file of the measured point cloud and processed so that all point cloud coordinates were then available in the reference system.

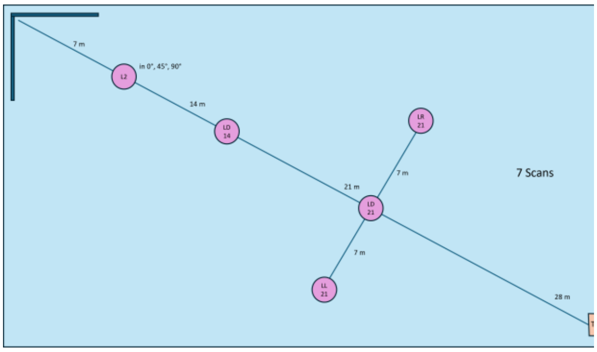

Figure 5. Experimental setup for the investigation of the distance dependence between TLS (pink circles) and total station (orange square), as well as orientation of the EOD in relation to the axis ROI (blue angle segment) - total station

4 Preliminary results

In the georeferenced point clouds, the 7 black and white targets were then automatically detected with the manufacturer's software from the previous 41 setups and the coordinates were output for further comparison with the target coordinates.

Table 1 shows the coordinate differences of the black and white targets between the reference coordinates from the network observation and the georeferencing from our approach using EOD for a selected measurement. The distance between scanner and ROI was 7.5m and the distance to the total station was 14.5m. The axis of the EOD was perpendicular to the target axis of the total station

Table 1. Comparison between reference coordinates of the black and white targets with the automatically derived coordinates from georeferencing using EOD

Target	Δx [m]	Δy [m]	Δz [m]
21	-0,0029	-0,0014	0,0032
22	-0,0042	-0,0027	0,0033
23	-0,0030	-0,0037	0,0026
24	-0,0030	-0,0051	0,0032
25	-0,0029	-0,0016	0,0034
26	-0,0019	-0,0010	0,0031
27	-0,0035	-0,0014	0,0031

It can be seen that our approach results in an average 3D deviation of 5mm in a point-by-point comparison, with 3mm systematically coming from the z-component, which we cannot yet explain. Compared to the network simulation for the OBJ point, we are 2 times worse in this example, although the distance between TLS and OBJ was only half the distance from the simulation.

If we compare this georeferenced point cloud with the original point cloud (Figure 6), which was georeferenced using the 7 black-and-white TLS markers, we can derive an average deviation between the data sets of 2.3 mm in a cloud-to-cloud comparison.

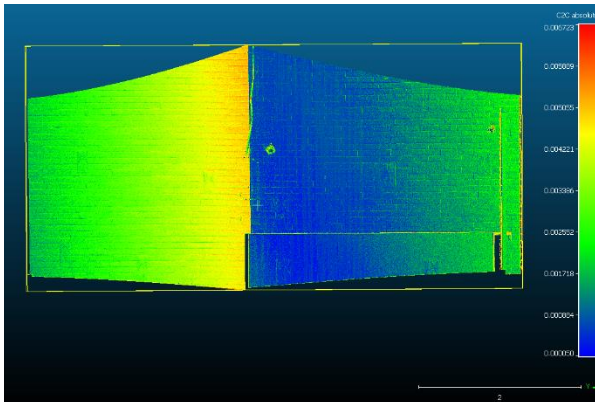

Figure 6. Comparison of the identical point cloud from georeferencing with EOD and with georeferencing using black-and-white targets. The colour scale shows the deviation of the two point clouds with a maximum of 6.7 mm in red and a minimum of better than 1 mm in blue.

These initial tests and investigations also show that there is a slight distance dependency with regard to the distance between the TLS and total station on the positioning of the TLS. The distance from 7m to 21m between the two sensors was investigated and the positioning accuracy improved with increasing distance to the total station. We attribute this to the uncertainty in the determination of the offset parameters, which is included in the coordinate calculation. On the other hand, we assume that with increasing distance of the TLS to the ROI the uncertainty also increases due to the mentioned orientation error. With regard to the orientation of the EOD, it was found that aiming at the EOD aligned perpendicular to the target axis improved the derived direction angle by a factor of 3.

5 Conclusion and Outlook

As already described, these are the first investigations into direct, external georeferencing of the laser scanner point cloud. These initial tests have already shown that the approach we have chosen is promising and that accuracies for georeferencing in the mm range are possible.

The final analyses of the point cloud comparisons from different viewpoints are still missing in our analysis; so far this has only been done on the basis of the reference marks.

Initial tests to determine surface changes using this georeferencing approach have already been carried out, but have not yet been finally analysed.

Ultimately, a corresponding test setup must also be developed for the investigations with the SLS with EOD, as we are dealing with a smaller measurement volume or ROI here. Due to the high measurement accuracy of the SLS, a more precise determination of the parameters must also be guaranteed when determining the offset parameters for the EOD, as we can see from the approach presented here that we still have residual effects in the mm range.

Acknowledgements

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