Investigating the Applicability of Standard Software Packages for Laser Scanner based Deformation Analyses

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Key words: Terrestrial Laser Scanning, Deformation Analysis, Point Cloud Comparison, Water Dam, Global Test

SUMMARY

For analyzing area-based deformations based on terrestrial laser scans, several methods exist. If there is no information about the object's geometry, the deformations are analyzed in most cases based on point cloud differences revealed by scanning in two epochs. The point clouds are either compared directly, are previously meshed or they are filtered based on geometric conditions. Standard software packages include these methods. After a theoretical introduction of these point cloud comparisons, they are analyzed based on two examples: the shape deformation and the rigid body movement of a wooden plate and the shape deformation of a water dam. It is revealed that the methods are suited to analyze shape deformations and rigid body movements under certain restrictions. However, more important is the direction of deformation related to the observed surface: out-of-plane deformations are better detectable than in-plane ones. In all cases, the interpretation is only based on inspecting color-coded point cloud differences; a statistical test judging the differences between two epochs is not performed.

ZUSAMMENFASSUNG

Zur Analyse flächenhafter Deformationen auf Basis terrestrischer Laserscans stehen verschiedene Methoden zur Verfügung. Liegen keine Informationen über die Geometrie des gescannten Objekts vor, werden die gesuchten Deformationen oft über Vergleiche von Punktwolken, aufgenommen in zwei Epochen, herausgearbeitet. Diese Punktwolken werden entweder direkt verglichen, vorher vermascht oder aber geometrisch geglättet. Diese einzelnen Methoden sind in Standardsoftware zur Punktwolkenverarbeitung implementiert. Nach der theoretischen Betrachtung der Vergleiche werden sie anhand von zwei Beispielen näher analysiert: die Verformung und Starrkörperbewegung einer Holzplatte sowie die Verformung einer Staumauer. Es wird herausgearbeitet, dass die Punktwolkenvergleiche zur Analyse von Verformungen und Starrkörperbewegungen unter gewissen Umständen geeignet sind. Wichtig ist hierbei die Richtung der Deformation bezogen auf die Objektoberfläche: Deformationen quer zur Oberfläche sind wesentlicher besser aufdeckbar als Deformationen entlang der Oberfläche. Allgemein basiert die Interpretation der Ergebnisse allerdings jeweils nur auf einer subjektiven Betrachtung von farbig dargestellten Punktwolkendifferenzen, ein statistisch fundierter Zwei-Epochentest dieser Differenzen wird nicht angewendet.

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1. MOTIVATION

Terrestrial laser scanners (TLS) are now used for a variety of different deformation analyzes. Examples are the monitoring of bridges, locks, dams, towers, tunnels and radio telescopes. Neuner et al. (2016) and Mukupa et al. (2016) give a detailed overview of these different applications. While the procedure for the recording of the laser scans hardly varies between the different applications and authors, the strategy depends very heavily on the user. This is due to the fact that, in the analysis of laser scans for deformation analysis, the paradigm shift which has already been much condemned is carried out from point-to-point measurements to surface areas. There are no signalized individual points in two epochs whose difference can be checked for significance. Instead, the deformations are derived from two point clouds. Though each point cloud consists of individual points again, their position on the measured object is not settable. The described two-epoch test of identical measuring points described in Heunecke et al. (2013) is therefore not easily feasible. Rather, pre-processing and modelling of the point cloud produced is necessary in each case in order to produce point correspondences and, if necessary, to carry out a two-epoch test between points which are regarded as correspondingly in order to decide on the presence of a deformation. However, how this pre-processing and modelling has to be is only very application and user-specific to answer.

The basic procedure is illustrated in Fig. 1. Although all the shown processing steps are decisive for the meaningfulness and significance of a deformation analysis, most of them are not considered further below. Instead, the article focuses exclusively on the methods of point cloud comparison and its suitability for TLS-based deformation analysis.

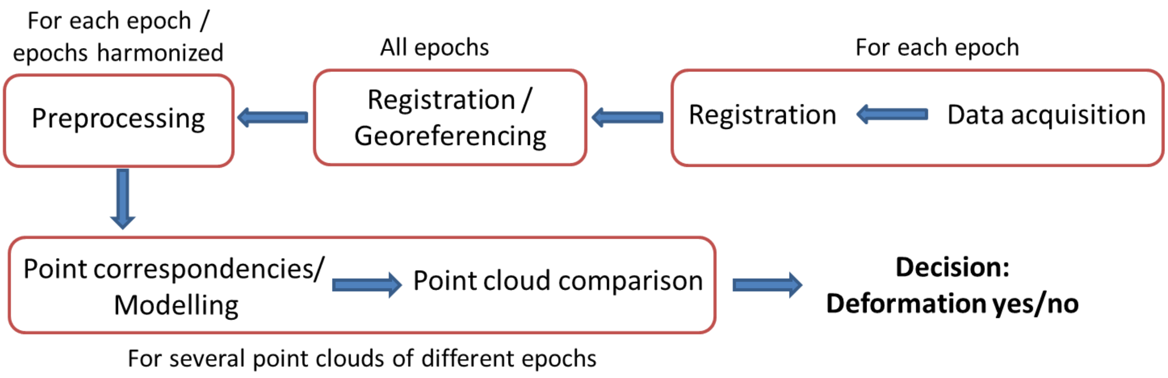


Fig. 1: General workflow for TLS-based deformation analyses

If a standard software is used for the analysis of the deformation, various possibilities are available to compare point clouds. Three common software packages for comparing two point clouds are

Geomagic Studio/Control (3DSystems), 3DReshaper (Hexagon Metrology) and the Open Source Freeware CloudCompare (www.danielgm.net/cc/). In all three packages, point clouds can be compared either directly or via a previous meshing or smoothing.
For TLS-based deformation analyses, a large number of methods are available, which are also implemented in software packages. The question therefore arises of the advantages and disadvantages of the individual methods and the extent to which they are capable of detecting the deformations of an object in a reliable manner, and possibly even statistically, as it is possible in the deformation analysis of individual points. This question is investigated in this article. It will be analyzed as to what extent rigid body movements and shape deformations of an object can be seen in point cloud comparisons and whether the magnitude of the deformation can (significantly) be derived there from. Examples of this are a deformed wooden plate as well as the Brucher water dam. The underlying methods are explained in chapter 2, chapters 3-4 discuss the examples and chapter 5 summarizes the results.

2. TLS-BASED DEFORMATION ANALYSIS AND POINT CLOUD COMPARISONS

In principle, the comparison of two point clouds is possible in five different deformation models, as categorized by Ohlmann-Lauber und Schäfer (2011) in Fig. 2. Point-based models can only be used if the laser scanner observes from an identical station in both epochs so that two points can be compared immediately. In point cloud-based models, relationships are established between two point clouds, e.g. by coordinate transformations. An example is the Iterative Closest Point Algorithm presented by Besl and Mc Kay (1992). Surface-based models process the point clouds to point grids via meshing or interpolation so that a comparison can be made. In geometry-based models, the point clouds are approximated with a geometric model and compared with a nominal shape or the other epoch in order to reveal large-scale differences. In parameter-based models, the estimated parameters are also used for the analysis of the deformations. These models are further classified and presented in Wunderlich et al. (2016) and Neuner et al. (2016) by giving examples.

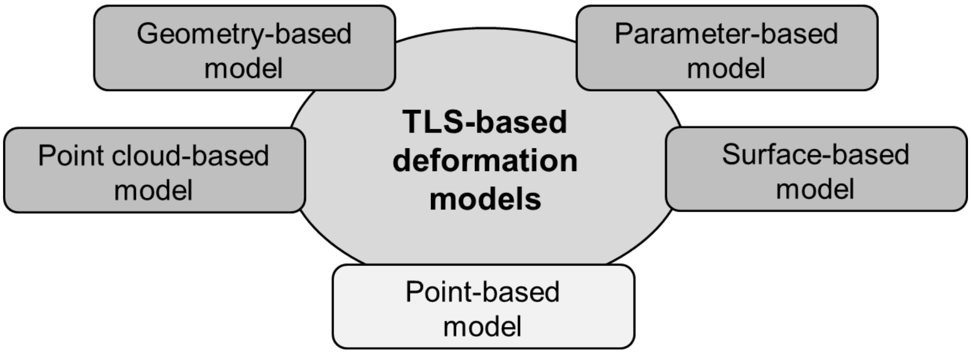


Fig. 2: TLS based deformation models according to Ohlmann-Lauber and Schäfer (2011)

From these descriptions it becomes clear that point-based models can be used only to a limited extent, and that geometrically as well as parameter-based models require preliminary information about the scanned object, the so-called model knowledge. Therefore, point cloud-based or surface-based models are used in many cases where no prior information about the geometry of the observed surface can or should be integrated.

For this reason, point cloud-based and surface-based models are implemented in most software packages; partly also geometry-based models, whereby on the basis of the above mentioned limitation they are no longer dealt with below. Point cloud-based models are based on a cloud-to-cloud (C2C) or multiscale model-to-model cloud comparison (M3C2), surface-based on a cloud-to-mesh (C2M) or mesh-to-mesh comparison (M2M).

In a C2C comparison, corresponding points between two points clouds are assigned and the distance between these corresponding points is calculated representing the point cloud differences. In C2M comparisons, one point cloud is meshed. Afterwards, the distance of this mesh to each point of the other point cloud is calculated (Cignoni et al., 1998). This approach is one of the most common for analyzing point clouds with software products and can be used particularly well on flat surfaces (Lague et al., 2013). As a variation on the C2M comparison, two meshes can be built and be compared directly with one another leading to the M2M comparison. In the M3C2 comparison, the number of points of one epoch is reduced by building core points that should represent the geometry of their neighbourhood of size D. They are gained by filtering. The difference to the other point cloud is then calculated along each core point’s normal vector regarding its neighbourhood d. Hence, two neighbourhoods of size D and d need to be specified for this point cloud comparison. For a more detailed explanation, see Barnhart and Crosby (2013), Holst et al. (2017) or Wujanz (2016).

For the TLS-based deformation analysis, three standard software packages are used in this study: 3DReshaper, CloudCompare and Geomagic Studio or Geomagic Control. The functions of Geomagic Studio and Geomagic Control of the investigations presented here are identical. When comparing these, the respective software is not the focus, but the methods used for the point cloud comparison. For these software packages, the point cloud comparisons listed in Tab. 1 are available. The approximation of geometric primitives in the geometric or parameter-based model, which can also be used to perform a deformation analysis, will not be discussed further here (e.g. Holst et al., 2015). It has to be noted that all point cloud comparisons most times go along with a smoothing of the data that is only partly traceable for the user.

Table 1: Possible point cloud comparisons in standard software

Software	C2C	C2M	M2M	M3C2	Approximation of geometric primitives
3DReshaper	X	X	X		X
CloudCompare	X	X	(X)	X	X
Geomagic Studio/Control		X	X		X

3. DEFORMATION ANALYSIS OF A WOODEN PANEL

The results of a TLS-based deformation analysis using standard software are discussed in the present study by giving an example: an untreated wooden panel with a dimension of 1.50 x 1.50 m (Fig. 3), which in turn is mounted on a white wooden panel, is scanned with a resolution of 6.3 mm @ 10 m with a Leica ScanStation P20 with a measuring distance of approx. 5 m in several epochs. The wooden panel is either not deformed or is deformed in the sense of a rigid body movement or a shape deformation. This wooden panel is not even, but has in its stress-free bearing already deformations in the range of -6 mm to +5 mm compared to a best-adapted plane. Therefore, it cannot be assumed in the deformation analysis that it is a plane whose parameters directly provide information on any deformations that may be present.

Fig. 3: Measurement configuration when scanning the wooden panel

The measurement and evaluation for the deformation analysis is carried out in three steps, where the latter two are explained in more detail in the following sections:

- Analysis of the significance range for the deformation analysis: The wooden panel is scanned two times without deforming it. Even without deformation, differences between the point clouds are expected due to the sampling density and the fact that the position of the scan points is not settable (Fig. 4). From theses repetitive measurements (not shown here, see Holst et al. 2017), the range of significance for the occurrence of deformations is set up to 2 mm. Thus, only larger deviations between two point clouds allow the conclusion of deformations.

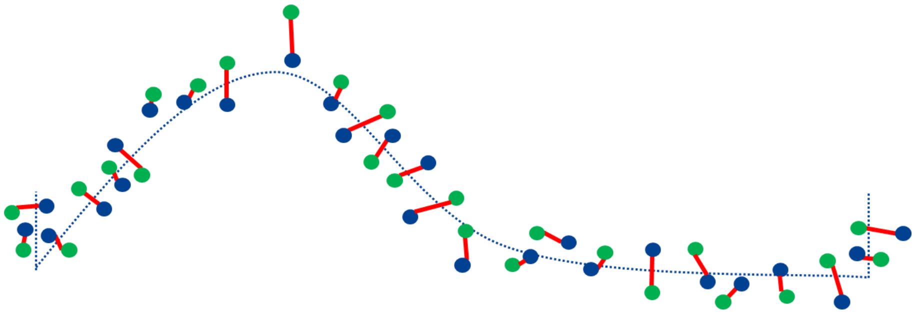


Fig. 4: Deviations (red) between the point cloud of epoch 1 (blue) and epoch 2 (green) when a surface (blue dotted line) is measured in two eras without deformation

- Examination of an out-of-plane shape deformation: The wooden panel is more curved, by locally increasing its distance from the wall without loosening the screw on the wall. Here, the wooden panel is scanned before and after the deformation from an identical station.
- Examination of an in-plane rigid body movement: The wooden panel is unscrewed and screwed again slightly offset. In this case, special care is taken to ensure that no significant

shape deformations are produced by a stress-free bearing. This could be verified with the aid of a measuring arm with laser line scanner with superior precision. Here too, the wooden panel is scanned from the same station in both epochs.

3.1 Out-of-plane shape deformation

For the deformation of the wooden plate, some wooden sticks are pushed between the wall and the plate so that the plate is under tension. The fixings on the substructure are not released, so there is no additional rigid body movement. This was confirmed by means of a measuring arm with superior accuracy. The effect on the point cloud comparison in this deformation is shown in Fig. 5 in accordance with Fig. 4. As can be seen in this sketch, large deviations occur mainly at positions of greatest deformation.

This theoretical consideration can be confirmed by experimental data: Fig. 6 shows the C2M comparison in Geomagic Control and Fig. 7 the M2M comparison in 3DReshaper. Since the result of the M3C2 comparison is similar to the one of the M2M approach, it is not shown here. The same applies for the C2C comparison being similar to the C2M comparison. All comparisons show the course of the surface deformations in a similar way, whereby the clarity between the software packages varies slightly. The significance range of 2 mm defined is shown in green.

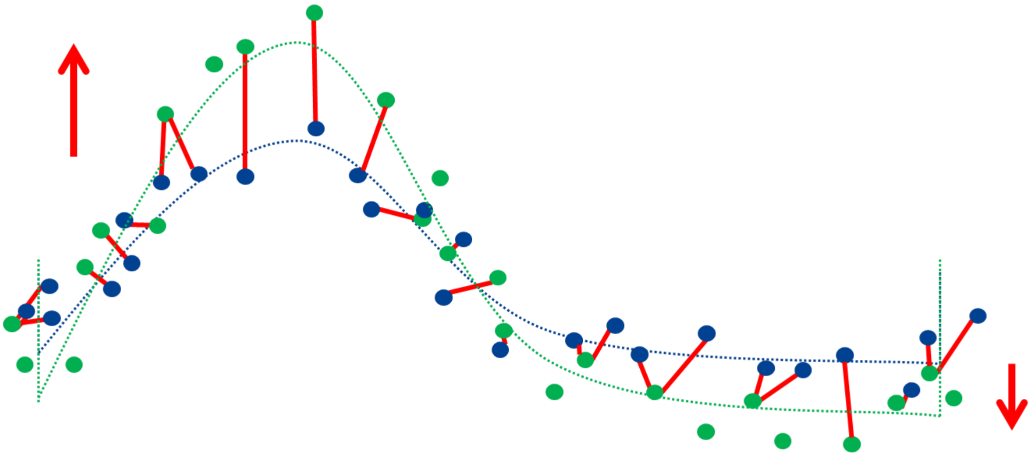
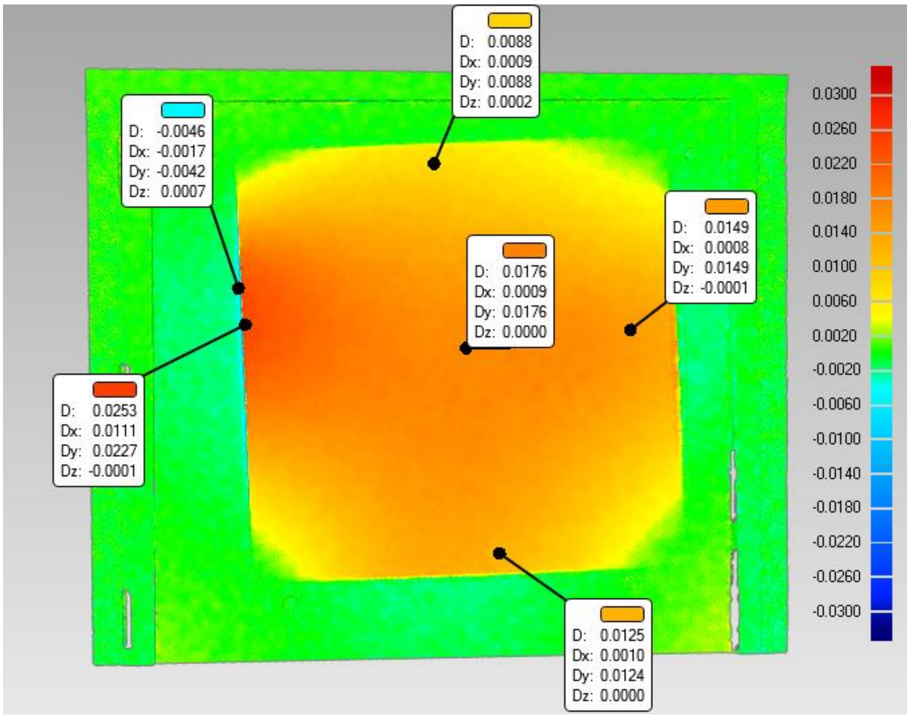


Fig. 5: Deviations (red) between the point cloud of epoch 1 (blue) and epoch 2 (green) when a surface (blue and green dotted line) is measured in two epochs before and after a shape deformation

The largest deformation occurs in the left central area of the wooden board, and decreases on all sides. This deformation has a value of approximately 25 mm (C2M, Geomagic Control), 23 mm (M2M, 3DReshaper) and 23 mm (M3C2, CloudCompare). The reference value determined with the measuring arm is 23 mm. These values were picked up point by point from the comparisons at the maximum deformation, so they are subject to a certain scatter. Nevertheless, it can be determined that the detected deformations lie within the range of the set point value.

The fact that a larger deviation is obtained in the C2M comparison can, however, be expected: the scattering and noise of the non-meshed point cloud directly impacts the comparison. In the case of M2M and M3C2 comparison, smoothing takes place in both point clouds.



D: 0.0088
Dx: 0.0009
Dy: 0.0088
Dz: 0.0002

D: -0.0046
Dx: -0.0017
Dy: -0.0042
Dz: 0.0007

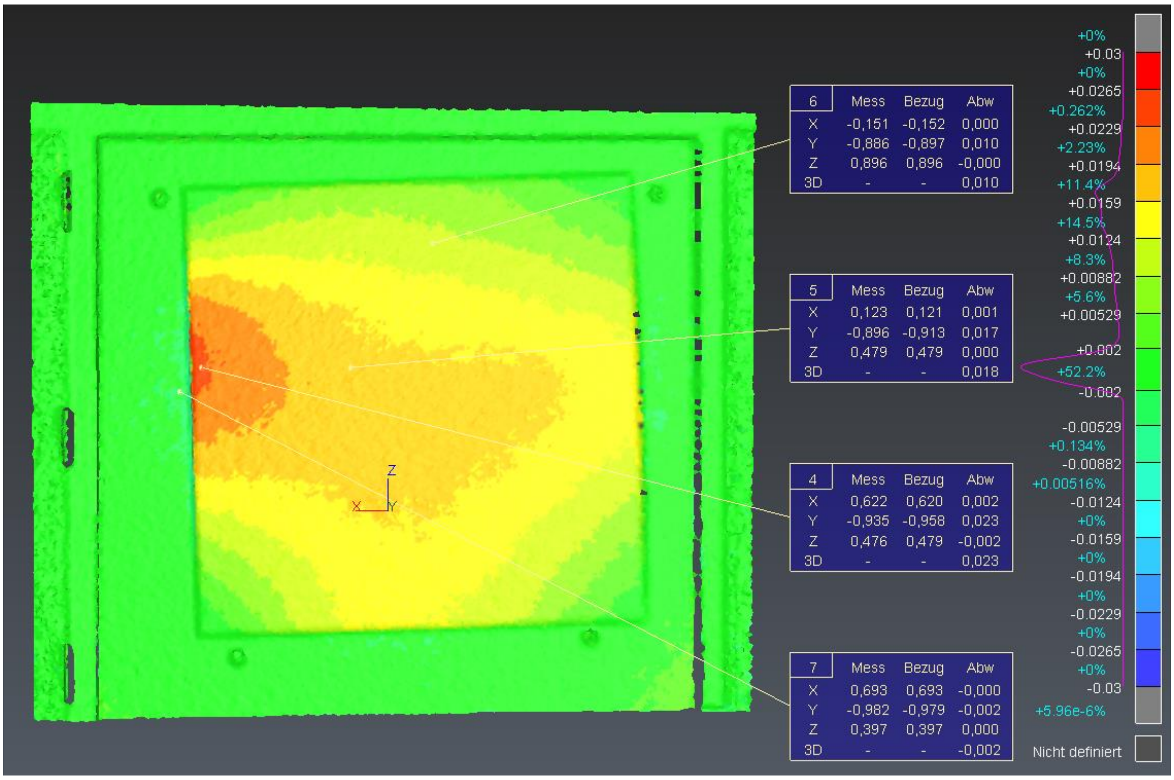
D: 0.0149
Dx: 0.0008
Dy: 0.0149
Dz: -0.0001

D: 0.0176
Dx: 0.0009
Dy: 0.0176
Dz: 0.0000

D: 0.0253
Dx: 0.0111
Dy: 0.0227
Dz: -0.0001

D: 0.0125
Dx: 0.0010
Dy: 0.0124
Dz: 0.0000

Fig. 6: C2M comparison [m] for a shape deformation (Geomagic Control)



6	Mess	Bezug	Abw
X	-0,151	-0,152	0,000
Y	-0,886	-0,897	0,010
Z	0,896	0,896	-0,000
3D	-	-	0,010

5	Mess	Bezug	Abw
X	0,123	0,121	0,001
Y	-0,896	-0,913	0,017
Z	0,479	0,479	0,000
3D	-	-	0,018

4	Mess	Bezug	Abw
X	0,622	0,620	0,002
Y	-0,935	-0,958	0,023
Z	0,476	0,479	-0,002
3D	-	-	0,023

7	Mess	Bezug	Abw
X	0,693	0,693	-0,000
Y	-0,982	-0,979	-0,002
Z	0,397	0,397	0,000
3D	-	-	-0,002

Fig. 7: M2M comparison [m] for a shape deformation (3DReshaper)

3.2 In-plane rigid body movement

For the analysis of rigid body movements using the standard software, the wooden plate is unscrewed from the substructure and moved a few centimetres to the left and turned slightly counter clockwise. Hence, it is moved in-plane regarding the surface's geometry. Since an additional shape deformation should be avoided, a further control measurement using the measuring arm in combination with a laser line scanner was conducted: there were no significant shape deformations. Thus, a rigid body movement can be sketched as in Fig. 8 according to Fig. 4: The shift of the surface in the second epoch creates new point assignments from the first epoch (blue) to the closest points in the second epoch (green) and new deviation vectors based on this. Larger distances result mainly in areas of large unevenness or surface curvature and at the beginning and end of the surface (in the 2D sketch: left and right). Areas with low curvature do not show any increased deviations in the sketch.

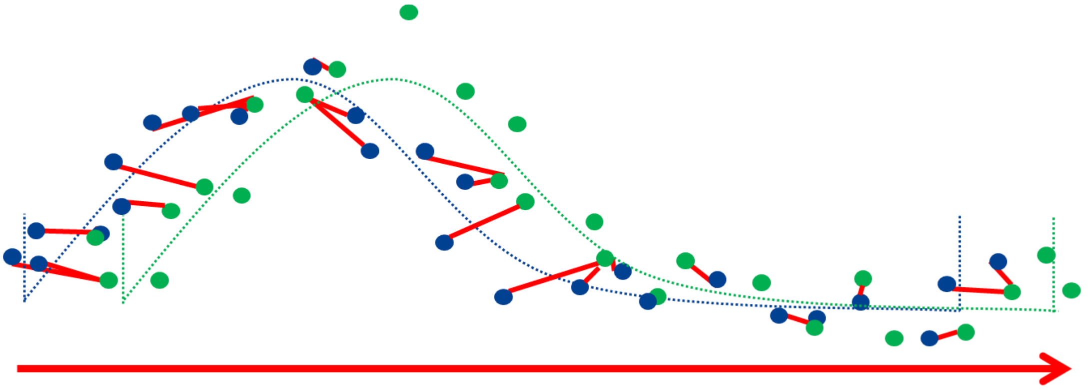


Fig. 8: Deviations (red) between the point cloud of epoch 1 (blue) and epoch 2 (green) when a surface (blue and green dotted line) is measured in two epochs before and after a rigid body movement

This theoretical consideration can also be confirmed by the M2M comparison in Fig. 9: The greatest deviations occur at the edge of the wooden panel. The dimension of 15 mm shows that the points of the first epoch are no longer assigned to the moved object, but to the non-moving background. This can be seen, since the wooden plate has a thickness of 8 mm and protrudes at most about 7 mm from the background. The measure of the maximum point cloud difference thus does not correlate with the actual amount of displacement of several centimetres due to an incorrect allocation of point correspondences.

In addition, deviations of several millimetres, i.e. outside the green significance range, occur in the area on the upper left of the plate and on the right at the bottom. With an increase in the shape of the wooden panel, it is clear that these areas are subject to large deviations due to the unevenness of the wooden panel of approximately -6 mm to +5 mm. Now differently curved regions of the plane are regarded as corresponding in the formation of point assignments. On the basis of these incorrect assignments, the wooden panel now appears to be deformed when compared in these regions, as already shown in Fig. 8.

From this analysis, it becomes clear that an in-plane rigid body movement is difficult to recognize as such with the aid of the point clouds. The magnitude of this displacement is even less apparent. The results rather appear to be a shape deformation and are therefore difficult to distinguish from this. The only point here is the sharp edge of increased point cloud differences that occur at the edge of the deformed object. Whether there is only a rigid body movement or a shape deformation in the middle region of the wooden panel, is, however, not apparent from Fig. 9. The C2C, C2M and M3C2 comparisons show similar results and are therefore not shown.

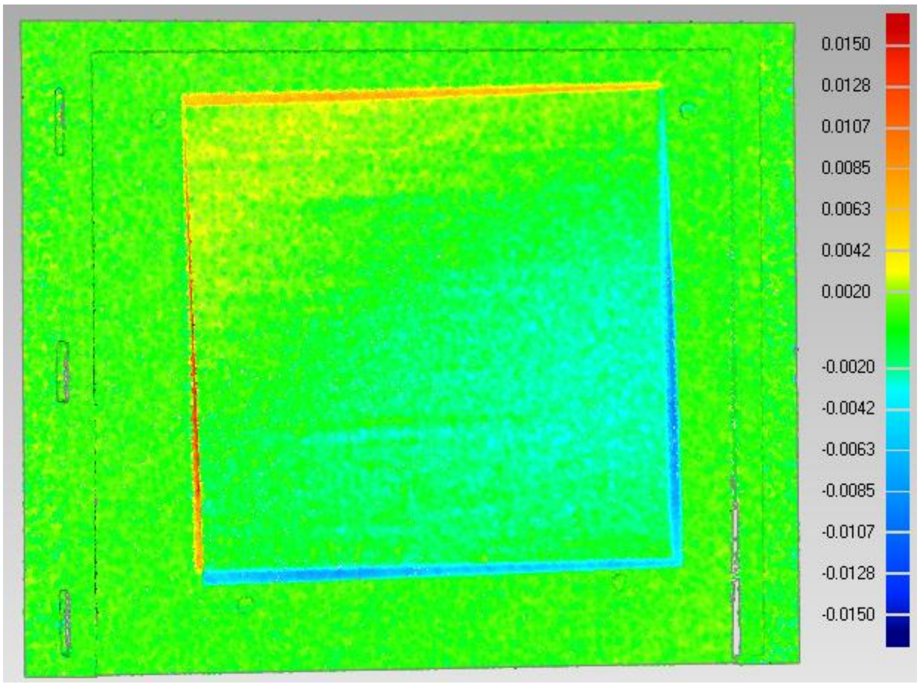


Fig. 9: M2M comparison [m] for a rigid body movement (Geomagic Control)

4. DEFORMATION ANALYSIS OF A WATER DAM

In order to verify the previous – rather synthetic – example with the help of a real example, an extensive deformation analysis of the Brucher dam is carried out. This is a gravity dam operated by the Wupperverband in North Rhine-Westphalia, which went into operation in 1913 and was renovated between 1990 and 1993 due to age-related damages and adapted to the current state of the art. The arc-shaped wall consists of gray rock stones and is now under monument protection (Fig. 10). The dam was installed for domestic hot water storage and flood protection. The dam has a crown length of 200 m, the height above the foundation bottom is 25 m, the sole width 17 m and the crown width 4, 50 m. The total volume is 3, 37 million qm (Wupperverband, 2012).

4.1 Setting up the measurement concept

This dam is examined for deformations every six months by the Department of Surveying / Planmanagement / CAD of the Wupperverband. The deformation analysis is based on a permanently installed network from which approx. 18 targets placed on the air side of the dam are measured by a total station. Thus, point shifts of the 18 targets can be detected after the stability of the fixed point network has been checked. Half-year point movements of more than 10 mm are observed on the basis of a classical geodetic, point-based deformation analysis. An additional levelling for detecting height changes of the dam crown supplements this deformation analysis.

Fig. 10: Brucher water dam from the air side (left) and partial view of a corresponding laser scan (right)

For the extensive deformation analysis, the surface of the dam on the air side was scanned in two epochs (March 2016, June 2016) from three different stations. Figure 10 (right) shows a partial view of a scan. Due to the length of the dam as well as the viewing conditions on site and the resulting measurement configuration, the occupation of three standpoints per epoch was necessary. The registration of these three stations was done target-based by marking the permanently installed measuring pillars, both epochal and interepochal.

Due to the temporal distance between the epochs of only three months, the surface is expected to deform by 5-10 mm. A rigid body movement can be excluded. Following the investigations in chapter 3, these deformations can be theoretically revealed on the basis of the presented methods. However, in contrast to the previous, synthetic example, there are aggravating circumstances which are similar in most applications:

- Several stations must be occupied and the point clouds have to be registered. This can lead to systematic registry errors. Even though the identical three positions have been occupied in both epochs, and therefore similar registry errors are expected in both epochs, this can lead to less interpretable results.
- The greywacke stones of the dam have edges and different reflective properties due to slight colour differences and varying surface structures (Fig. 10 right). This can lead to systematic errors and incorrect point assignments.
- The growth of plants on the surface was more pronounced in June than in March.
- In March, the water level was nearly the same, so that the middle section of the dam, below the overflow areas, was temporarily covered by running water.

4.2 Results of the deformation analysis

For the analysis of the deformations the different point clouds comparisons are used again. Fig. 11 shows the M2M comparison and Fig. 12 the M3C2 comparison. The green significance range was kept comparable between the methods, as before. It was empirically determined to be 3 mm. The C2C and C2M comparisons are not shown, since an interpretation is not effective because of the high noise in the point cloud difference.

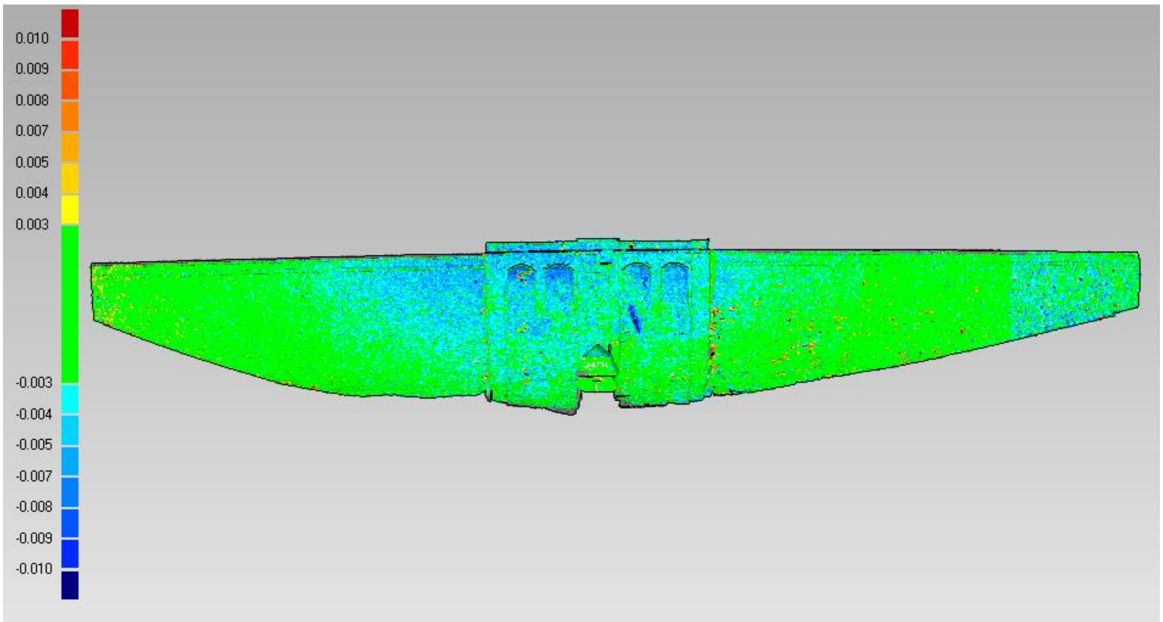


Fig. 11: M2M comparison [m] of the Brucher water dam (Geomagic Studio)

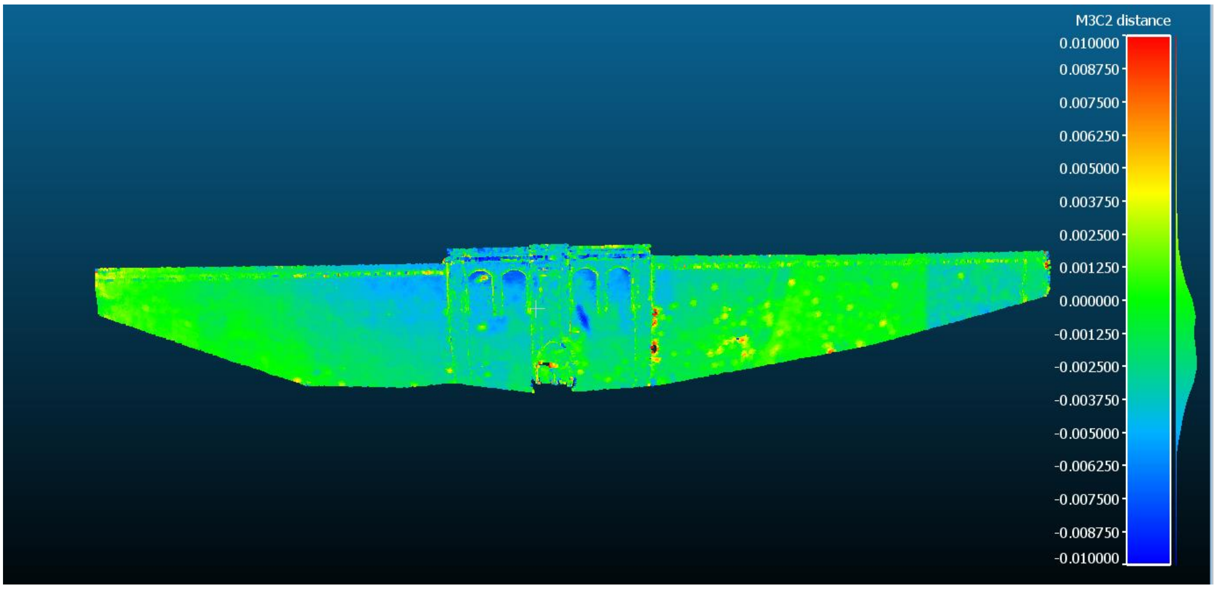


Fig. 12: M3C2 comparison [m] of the Brucher water dam (CloudCompare)

Both figures show that the largest coherent deviations are in the areas in the middle of the dam and from there to the left. The differences are of the order of -7 to -5 millimetres. This means that the dam has moved from March to June towards the water side. This deformation direction is justified by the lower water level in June.

In addition to these large-scale differences, small-scale deviations of both point clouds with positive and negative signs can also be seen in both illustrations:

- Positive deviations of about 10…11 mm: Growth of plants.
- Negative deviations of about -10 mm in the middle of the dam: at the moment of the measurement, a larger surge water has flowed along this overflow.
- Negative deviations of about -5 mm in the outer right part of the dam: abrupt sinking of the tripod due to frost.

These small-scale deviations are most evident in the M3C2 comparison (Figure 22). This is explained by the stronger filtering of the measured data due to the core point formation: measuring noise is thus reduced during the analysis, but local abnormalities are also overshadowed. The parameters are set to d = 1 m and D = 1 m here. If both parameters are selected to be smaller, the small-scale deviations have less effect on the final result, but the noise is also higher. So here a compromise must be reached.

5. CONCLUSION AND OUTLOOK

If two point clouds, taken in two epochs, are used to analyze surface deformations, there is a wealth of possible methods which can be assigned to the five TLS deformation models shown in Fig. 2. If there is no geometrical pre-information about the scanned surface, usually point cloud-based or surface-based models are used. These can be further subdivided into C2C, C2M, M2M and M3C2 comparisons. In this case, the two point clouds are either directly compared (C2C), meshed (C2M and M2M) or the point clouds are smoothed (M3C2) prior to the comparison, taking into account neighbourly structure. The individual methods are implemented in different software packages, whereby the standard packages 3DReshaper, CloudCompare and Geomagic Studio / Control are used in this article.

From a deformed wooden plate, different conclusions can be drawn:

- There are always differences between the point clouds. These can be assigned to measurement uncertainty, as is the case with point-by-point deformation analyzes. However, there are also deviations, since scan points from two epochs are not identical but have a distance depending on the measurement resolution. Therefore, it is difficult to judge if deviations are significant. For this reason, a two-epoch test is not feasible without subjective intervention on the basis of the methods shown for the examination of significant deviations, as is carried out with point-like deformations.
- If the identical station is occupied in both epochs, shading and systematic deviations will affect the measurements less than at two different stations. This leads to a simpler interpretation of the point cloud comparison.
- In the case of an out-of-plane shape deformation, the actual shape deformation and their magnitude can be elaborated with the help of all point cloud comparisons.
- This statement also holds for an out-of-plane rigid body movement (not shown here). Nevertheless, this would be hard to distinguish from an out-of-plane shape deformation

since the magnitude of the point cloud comparison will not be constant for the whole surface due to measurement and modelling errors.

- Large deviations are the result of an in-plane rigid body movement but these do not depend on the actual movement of the measuring object. Edges and curvature differences of the scanned surface rather lead to large deviations in the point cloud comparison, not the displacement amount and the direction of displacement. Hence, an in-plane rigid body movement cannot be revealed.
- This statement also holds for in-plane shape deformations (not shown here). However, this kind of deformation is rather seldom at building as it would equal a creeping or circulation.
- While these findings apply to all methods of point cloud comparison, the C2C comparison tends to be a greater uncertainty in the significance, since the scanning points are less smoothed. Here, too, the influence of the cloud resolution is greatest.
- (Optional) smoothing is performed for all comparisons. The smoothing of the M3C2 algorithm is geometrically comprehensible by the formation of the core points.
- Using the dam as an example, it is clear that the smoothing noise is minimized, but also that object details are blurred or small-scale systematic errors are highlighted, depending on the aggressiveness of the smoothing.

These results refer to the mentioned examples of the deformed wooden plate as well as the Brucher dam. While the first example appears to be quite docile because of a single station and the homogeneous surface, the requirements for the deformation analysis in the second example are higher: There is a more complex surface with edges and resulting data gaps as well as inhomogeneous surface properties (material, colour, reflective behaviour). It becomes apparent that, as also stated in Lague et al. (2013), the C2C and C2M comparison lose their significance. From the M2M comparison as well as the M3C2 comparison, the deformations of the dam are, however, easier to detect. Due to the integration of measurement uncertainty and the geometrical interpretability of the smoothing over core points and their uncertainty, the M3C2 comparison, however, still offers further advantages over the M2M comparison.

In general, it becomes clear from the present study that point-by-point deformation analyses cannot be simply converted into surface areas if the point cloud differences considered here are used: Rigid body movements can hardly be detected since no coherent object has been detected during the point cloud comparison. This results in incorrect point assignments for the difference formation of both point clouds. Furthermore, due to the lack of a stochastic model in point cloud comparisons, a strict significance test cannot be carried out for the assessment of relevant deviations. This has only been considered in the present article by means of point cloud resolution, but can also be carried out using inadequate knowledge about spatial correlations of laser scans as well as systematic measurement errors (Kauker et al. 2016; Holst und Kuhlmann, 2016; Holst et al. 2016).

Hence, we can logically conclude that for an effective analysis of point cloud differences metrological competence as well as object expertise is necessary. Otherwise, point cloud differences caused by registration errors, measurement errors, shading or object properties cannot be separated from actual deformations. The final representation of each point cloud comparison as previously shown cannot be interpreted without this knowledge and is thus almost worthless.

These explanations lead to the conclusion that the methods presented and used here do indeed permit a conclusion to the quantitative changes between two point clouds but cannot be regarded as a qualitative deformation analysis of an object. For this purpose, an object modelling as well as the elaboration of statistical statements, as known from the point-to-point deformation analysis, would be necessary (Heunecke et al. 2013). For the latter, a realistic stochastic model of laser scans has been missing so far, as already described. This drawback of extensive deformation analyses is currently being discussed and further analyzed in various geodetic engineering publications (Bureick et al. 2016; Holst et al. 2016; Kauker et al. 2016; Neuner et al. 2016; Wujanz et al. 2016; Wunderlich et al. 2016; Holst und Kuhlmann 2016), so that future developments can be assumed here.

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