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QUALITY CONTROL OF CONSTRUCTED MODELS USING 3D POINT CLOUD

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Abstract. *Over the last decade, the technology of constructing buildings has been dramatically developed especially with the huge growth of CAD tools that help in modeling buildings, bridges, roads and other construction objects. Often quality control and size accuracy in the factory or on construction site are based on manual measurements of discrete points. These measured points of the realized object or a part of it will be compared with the points of the corresponding CAD model to see whether and where the construction element fits into the respective CAD model. This process is very complicated and difficult even when using modern measuring technology. This is due to the complicated shape of the components, the large amount of manually detected measured data and the high cost of manual processing of measured values. However, by using a modern 3D scanner one gets information of the whole constructed object and one can make a complete comparison against the CAD model. It gives an idea about quality of objects on the whole. In this paper, we present a case study of controlling the quality of measurement during the constructing phase of a steel bridge by using 3D point cloud technology. Preliminary results show that an early detection of mismatching between real element and CAD model could save a lot of time, efforts and obviously expenses.*

1 INTRODUCTION

The tremendous technological advances affect our present social and professional life. This includes machines that have high computational power and software that help people to achieve their tasks quickly and efficiently. From an engineering point of view, this applies to the use of CAD tools that help engineers to model buildings, bridges and other civil engineering structures. The question that comes to the mind is how to check whether the object is produced exactly like the CAD model?

Due to the complexity of some structures such as steel bridges or large industrial plants, is difficult to be combined with the tolerances in the factory and on site (Figure 1). The assembly of large structures made of steel, mainly by welding or bolts, requires observance with relatively small tolerances (in the range of ±2 mm to ±5 mm) for components with dimensions of up to several 100 m [1].

(a) In factory

(b) On site

Figure 1: Construction process of a steel bridge

There exists a way to check the accuracy of the comparison process between constructed objects and the modeled CAD object. It uses a Total Station (TS) for manually measuring discrete points, see Figure 2. Later on, the coordinates of the measured points (e.g. corner points) are compared against the respective coordinates of the modeled geometry.

Based on this, one can derive further information of the object, i.e. the distance between measured coordinates to check length, width and height or the absolute position of the coordinates w.r.t. the reference coordinate system, etc.

This way of measuring works well for simple and small construction objects. However, for huge and complicated objects, it can be very inefficient. This is mainly due to the complicated shape of components, the large amount of manually detected measured data, the high cost of manual processing of measured values and the cost of time of the technician who is taking the measurements [2].

A promising method for acquiring the geometry of a 3D object is Terrestrial Laser Scanning (TLS) [3]. By using TLS the complete surface of an object can be measured in short time and with high accuracy [4]. The result of the scanner is generating a cloud of 3D points containing primarily the three dimensional coordinates with additional measuring values, such as the

Figure 2: Quality control by measuring discrete points with total station

reflectance value or the color value of each measured point. There are a lot of concepts to evaluate a 3D point cloud. For instance, this can be done by automated recognition of 3D CAD model objects in the point cloud [5] or by using the Iterative Closest Point (ICP) algorithm to register 3D point cloud against each other or against a CAD model [6, 7]. In our case, CAD model exists, therefore we can immediately use the information of the modeled CAD objects to analyse the scanned data. The gathered scanned data includes information of the geometry (length, width and height), material properties (steel, wood, glass, etc.) or properties of the surface (roughness, reflection, etc.). This paper presents a new strategy of controlling the quality and accuracy of the real geometry by employing 3D laser scanner in collecting data of the constructed objects. This is an alternative method based on the most recent TLS technology of the quality control of large engineering structures that replaces the classical method of measuring discrete points that uses a total station.

2 CONCEPT AND METHODOLOGY

By using TLS the surveyor gathers a big data file of point cloud which describes the surface of an object by a high density of measured 3D points. The distribution of points on the surface depends on the used scan resolution, i.e. the angle increments of the rotating laser. Consequently, there are no directly measured edges or corner points in the data. To get an information about the geometric deviations of the measured object against the target state (CAD model) it is necessary to reconstruct the corner points and edges from the point cloud data. This methodology of measurement which uses TLS is illustrated in the following steps:

2.1 Starting point

At the beginning we have a CAD model and a point cloud that represents the constructed objects from a scanning process with TLS. This point cloud is registered in the coordinate system of CAD model (see [6, 7, 8]) and filtered to remove fake points which come from reflections or multipath effects. The number of 3D scanned points depends on the resolution which is a defined parameter in the scanner, it could be set before starting the scan. It is obvious that the scan resolution plays a vital role in identifying the object as accurate as possible.

2.2 Data representation

Many research and commercial CAD tools are used to deal with point cloud. We are using FreeCAD 0.13 [9]. FreeCAD is an open source parametric 3D modeler. It facilitates modeling and designing CAD objects and it is completely modular. FreeCAD reads and writes many open file formats and runs under all commonly used operating systems. In the first step the user loads CAD model as well as the registered point cloud of the object into the software that uses certain data structure and algorithms. The point cloud is represented by using a data structure called octree [10]. The advantage of using an octree is that the time complexity of building the tree and searching operations in it is efficient. Generally, the time complexity of building the tree is $O(Nlog(N))$. Meanwhile, the searching operation requires (for the best case) greater than or equal to $O(log(N))$. However, this is not an absolute evaluation of Octree performance. The search performance strongly depends on the distribution of points in the point cloud.

2.3 Comparing the scanned object against their CAD model

Once the CAD model is viewed in FreeCAD, the user chooses a geometric primitive which he wants to make a comparison between CAD model and the measured data (point cloud). Currently, this can be a corner point, an edge or a plane or any object. Thereby the selection of the geometric primitive happens on the CAD model. Navigating and working in a 3D point cloud requires a good spatial sense and a good sense of direction. Especially for inexperienced users working in a point cloud is often confusing. Therefore, the engineer is working with CAD which is the technical language he understands. The selection of 3D points to be used and the realization of the comparison are running automatically in the following way: The identification of a corner point or an edge is based on the computation of the intersected planes. The output of intersection could be determined upon to the number of independent planes. i.e. lines (at 2 planes) or points (at 3 planes). With this approach, the algorithm uses the information of all relevant surrounding points of the intersection point or the edge. With the information (coordinates) of the selected part of the CAD model (corner point, edge, or a plane) we search at first for the corresponding planes in the point cloud. To get this, we use adapted bounding box algorithms based on octree data representation of the point cloud [11].

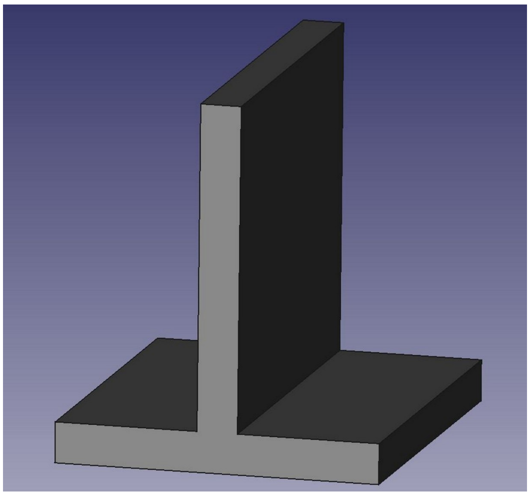
The resulting point cloud subset form the input data set of an Least-Squares Algorithm which computes a plane with its parameters (x, y, z, d). Calculating plane parameters and their standard deviation is done respectively by [12] along with data snooping [13] to localize and eliminate points that do not belong to the plane. This way is applied for every plane, which is localized by the starting information of the chosen part of CAD model. Finally, the software we developed in FreeCAD for this solution generates a report with information about the reconstructed planes and results of the intersection point(s). From that, the coordinates of a selected corner point can be compared with the corresponding point in the CAD model.

3 CASE STUDY: STEEL BRIDGE

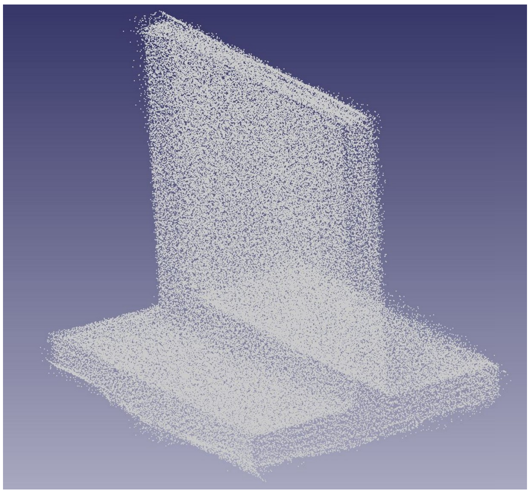
The 3D scanner gives millions of 3D points from different views. For research purposes, we produce a little piece of a steel bridge (T-beam). It is modeled in FreeCAD and scanned with the laser scanner IMAGER 5010 [4]. The T-beam is also measured with a total station, so we have the real (free of errors) coordinates of the corner points out of it. Figure 3 shows the laboratory setting with the testing object made of steel along with the laser scanner and the total station.

Figure 3: Laboratory setting: T-beam (left), total station (middle) and laser scanner (right)

The modeled T-beam and the scanned point cloud are shown in FreeCAD tool as in figure 4.



(a) CAD model of a T-beam

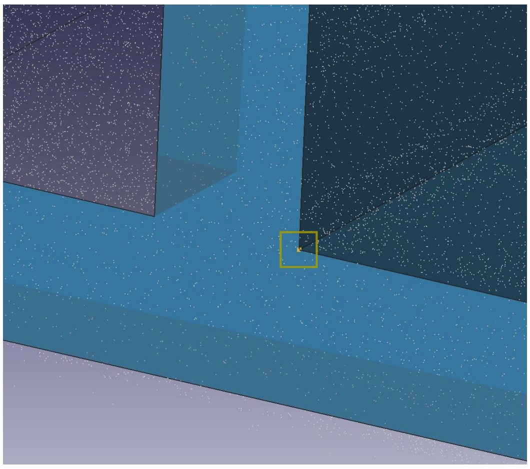


(b) Constructed T-beam out of points cloud

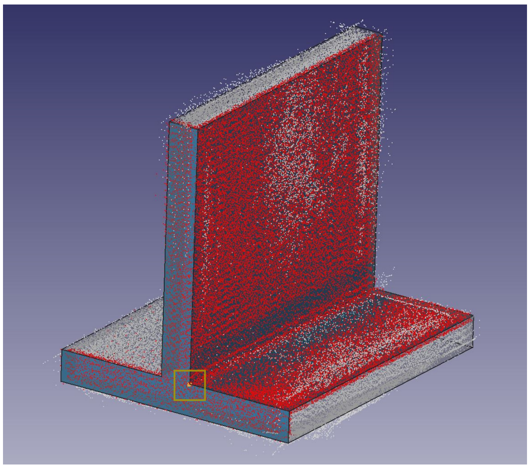
Figure 4: T-beam in CAD and constructed view

The coordinate systems of the CAD model and the scanned objects are identical. To measure the quality of the constructed T-beam, we used a scenario of searching a corner point in the CAD model and compute its corresponding point regarding the mentioned steps in section 2 based on the point cloud.

Figure 5 demonstrats the chosen corner point (yellow box) of the CAD model and the automatically located points of the 3 corresponding planes in red.



(a) Chosen corner point of CAD model



(b) Extracting sub point cloud of the 3 corresponding planes of the corner point

Figure 5: Examplary chosen corner point

With this subset of points, the calculation algorithm starts. At the end we obtain a report file which includes the parameters of the 3 calculated planes (alternative 2 or 1 plane by choosing an edge or a plane) and the comparison between the calculated (scan based) and modeled (reference) coordinates of the corner point (alternative the comparison between scan based and reference edge or plane). Figure 6 depicts the calculation results of the first plane.

Corresponding_Face_ID		T_Traeger_ID_00_Vertex29_corrFace_0	
Punktanzahl N_{total} / N_{inlier} / $N_{outlier}$		13723 / 13412 / 311	
Iterationen / Fehlerschranke / Zeit		311 / max $\lvert\hat{v}\rvert < 2.5$ mm / 0.3 s	
Ebenenparameter (Standardabweichung)	n_x (σ_{n_x})	-0.02401 mm	(0.00026 mm)
	n_y (σ_{n_y})	-0.99971 mm	(1e-05 mm)
	n_z (σ_{n_z})	-4e-05 mm	(0.00015 mm)
	d (σ_d)	-1419.56379 mm	(1.59328 mm)

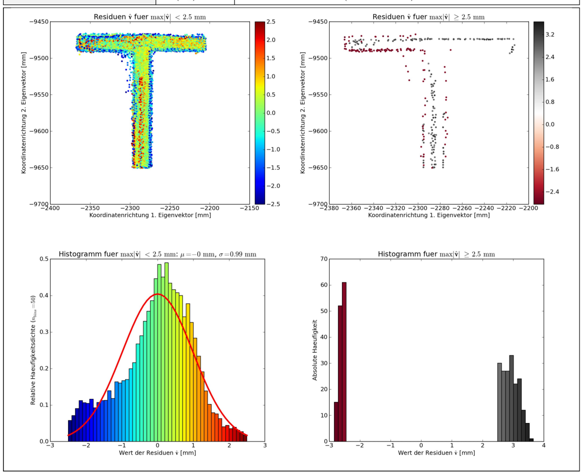


Figure 6: Results of one of the calculated plane (front of T-beam)

Figure 6 contains the most important parameters of the plane fitting, this information is:

- number of points inside (N_{inlier}),

- calculation time,
- parameters of the normal vector (n_x , n_y, n_z and d) and
- their standard deviation (σ_{n_x} , σ_{n_y} , σ_{n_z} and σ_d).

Furthermore, the 4 sub-figures presented in Figure 6 show the distribution of the used and eliminated scanned points. The distribution of the used points is normal and regular and the standard deviation is low, that is why it is a good representation of this plane.

Table 1 shows the results of determining compatibility of the coordinates of the chosen corner point.

		Reference point $P_{CAD}[mm]$	Scan-based point $P_{scan}[mm]$	$\triangle_{mm}$
Point coordinates (Standard deviation)	$x_p(\sigma_{x_p})$	773.25 (−)	774.21 (1.94)	0.96
	$y_p(\sigma_{y_p})$	1356.67 (−)	1357.05 (1.64)	0.38
	$z_p(\sigma_{z_p})$	9511.23 (−)	9511.20 (1.25)	−0.03

Table 1: Coordinates of a corner point from CAD and scan-based calculation

As we see in table 1 that the difference $\triangle$ between the coordinates of the reference and calculated scan-based of the studied point P is less than 1 mm. These are very promising results calculated from the algorithms which we are developing. Realistically, these are not optimal results and there are some small errors, these errors could come out of different resources, i.e. the production line, reflections on the steel surface, the coordinate transformation of the point cloud into the reference system (CAD system), etc. This difference is allowed in the construction calculation as it is already taken in consideration. The standard deviations are a bit pessimistic, this is due to the impact of the calculation process.

To check if there are errors coming from the production line, the corner points of the T-beam are measured with a total station with an accuracy of less than 0.1 mm. Table 2 shows the results of the comparison between the scan based and the real coordinates of the chosen corner point.

		Real point $P_{Real}[mm]$	Scan -based point $P_{scan}[mm]$	$\triangle_{mm}$
Point coordinates	x_p	773.86	774.21	0.35
	y_p	1356.78	1357.05	0.27
	z_p	9511.79	9511.20	−0.59

Table 2: Coordinates of a corner point from total station and scan-based calculation

The results shown in table 2 validate the calculation process. The difference $\triangle$ between the coordinates is also less than 1 mm. There is no significant serious error coming from the calculation process. The overall number of points we have calculated and compared in this way is 12 points of 2 T-beams. We confirm that more than 80% of the difference values $\triangle$ are less than 1 mm.

4 CONCLUSION AND FUTURE WORK

In this paper we have presented a strategy of quality control of constructed models using 3D point clouds. The solution is based on 3D laser scanning. We have shown the work flow of the solution in an applicable way (not mathematics or analytic presentation). The study was conducted with a case study which is an example of how to measure a selected CAD point and its correspondent in the TLS point cloud. The proposed solution demonstrates that it is an efficient and faster way than the traditional one which uses a total station. The advantage of using the laser scanning combined with our application is that the user works only on the CAD model and gather information on the quality of the built object on the whole object. Therefore, the geometry of the object is known from the production line over the construction till the working time.

A rapid detection, comprehensive analysis and reliable evaluation of the construction process is used to improve assembly quality and for reducing essential rework and installation time. In the future and from a perspective view point, we can use it for deformation based monitoring. The measured deformations allow direct determination of injury. To the best of our knowledge, this is the first step of using the information (geometry) of CAD model to evaluate a point cloud of the constructed object. Our another perspective is to continue investigating more searching, selecting and segmentation algorithms that we want to bring to the 3D laser scanning during the real time scan to obtain a better informative point cloud.

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