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ORIGINAL ARTICLE

Headframe modelling accuracy for finite element method analysis purposes

Damian Biel[1*] and Tomasz Lipecki[1]

[1]Department of Mining Areas Protection, Geoinformatics and Mining Surveying, Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, 30 Mickiewicza av., 30-059, Cracow, Poland

[*]biel@agh.edu.pl

Abstract

Nowadays, the growing popularity of terrestrial laser scanners (TLS) allows to obtain a point cloud of many industrial objects along with classic surveying. However, the quality and model's accuracy in comparison to a real shape seem to be a question, that must be further researched. It is crucial especially for Finite Element Method (FEM) analysis, which, being a part of technical design, estimate the values of construction's dislocation and deformation. The article describes objects such as headgear with steel support and 4-post headframe with steel sheers. Both supports and sheers were modelled basing on point clouds. All the models were compared to the point cloud. The differences in models' shape were calculated and the maximal values were determined. The results' usefulness in FEM analysis was described.

Key words: 3D modelling, TLS, headgear, headframe, finite element method

1 Introduction

Since the beginning of 21st century the growing popularity of Terrestrial Laser Scanning in objects deformation monitoring has been noticed. It became easier to conduct a monitoring of constructions, that are likely to suffer damage while exploited, usually due to the nearby mining activity or environmental loads. Thanks to TLS the obtained data describe the object in quasi-continuous way and allow to determine all geometric values. The examples of such use are chimney inclination analysis (Lipecki et al., 2017) and headgear monitoring, that is to check their geometric compliance with polish law. Scanning gives an opportunity to implement the Finite Element Method (FEM) into shape and construction deformation analysis, considering for example environmental loads. Obtained results of FEM analysis, like position of object axis, might be further compared to reality. Any difference would mean, that either some analysis conditions were false, or some environmental influences were not taken into consideration. On the other hand, there is a possibility, that the simplification of a real shape model was far too big and a comparison to proper FEM model leads to wrong conclusions. To avoid such situation in future, some basic research on modelling accuracy was conducted and described in this paper. It is planned to carry out similar FEM analysis determining the difference in results due to analysis conditions change.

2 Analysed objects

Two objects were analysed: headgear with 4 supports and headframe with 4 sheers. Headframe is 53 m height, made of steel, placed on concrete foundation. It has four pulley wheels on two levels. The sheers are plate girder, consolidated with truss, 42 m height (Fig. 1a). The headgear is also made of steel, upper part is covered with corrugated metal, 70 m height. Supports are cylindrical, consolidated with truss and plate girder, 41 m height (Fig. 1a). Both supports and sheers are inclined. Objects were scanned using FARO Focus X330. Headgear was scanned from 5 positions, while headframe from 10, as it was scanned together with some nearby infrastructure. Registration was made in Cyclone using combination of cloud-to-cloud method

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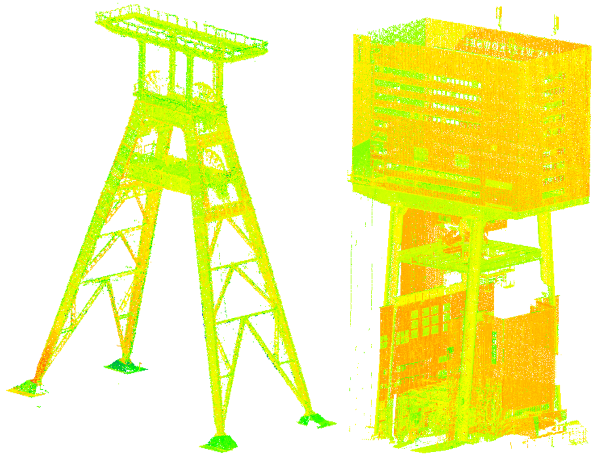


(a) headframe **(b)** headgear

Figure 1. Analysed objects

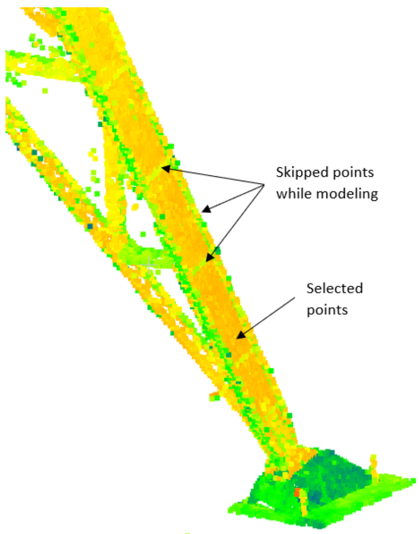


Figure 2. Sheer pointset selection

and targets. The mean absolute error for enabled constraints was ±7 mm for headframe and ±10 mm for headgear. The original point cloud density was set to 7 mm per 10 m, but to improve the analysing process, it was lowered. All false points generated on supports and sheers edges were deleted manually in Cloud Compare programme, to preserve the realistic shape of the elements. Any filter algorithms like SOR filter in Cloud Compare caused a removal of valuable points.

3 Elements modelling

The analysis of different shape modelling methods was conducted by creating a few, varying models of one object. All models were created using Rhino 6. Models vary from each other by selected points they were based on and the surface creation method. All the surfaces were transformed into mesh for better results presentation. In case of headframe there were two proposed modelling methods: plane fitting and section loft. CAD model on point cloud data is estimated to be more accurate than automated meshing (Korumaz et al., 2017). Automated meshing may also leave holes in model structure (Campana et al., 2009).

Plane fitting was conducted using two different selections of points. First, it was a simple fit into all points representing sheer. No selection was carried out. In a second way plane was fit only into selected points (Fig. 2). The preparation was conducted and some points representing plate girder were skipped.

Second method basing on 1 m interval section loft also varied by way of preparation. The first variety was selection of points: sections were fit into either whole pointset of sheer or only selected group (Fig. 2). Thanks to that, it was possible to determine the value of gross error in order to make a comparison. In addition, two options of loft creation were used. First option, "normal" forced the model creation to contain all the sections it was based on. Second option called "loose" fits the surface basing on selected sections, not forcing algorithm to contain them. Eventually, six different models were accepted for further analysis. The list of models and choice explanation can be found in chapter 4.1. All created surfaces were transformed into triangular mesh with minimal edge length of 0.5 m.

In case of headgear, models varied by sections interval: 1 m, 5 m and simplified model, which is just a loft of two sections: one on a top and one in the bottom of the point cloud. The curvature of construction in this case is lost, as the obtained model is just a cylinder. As in case of headframe, two methods of loft creation were conducted: loose and normal. Eventually, four models were accepted for further analysis. The list of models can be found in chapter 4.1. All created surfaces were transformed into triangular and quadrilateral mesh with edge length of 5 - 35 cm due to the cylindric shape.

4 Results of shape comparison analysis

Shape comparison analysis were carried out using "cloud-to-mesh distance" algorithm (Cloud Compare user manual, 2015). For every single point in point cloud algorithm searches for nearby reference mesh triangle elements. All perpendicular distances from point to triangles are calculated and the shortest is chosen. The result is saved as a point attribute so that further result visualization can be prepared. Comparison was carried out for models in reference to the original point cloud of either headframe or headgear - with normal loft or two different interval sections.

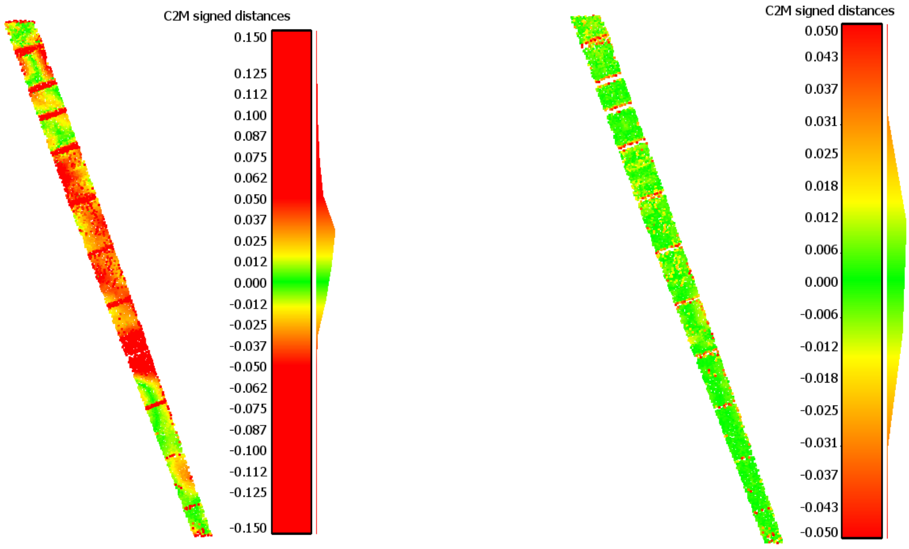
4.1 Headframe

Following models of headframe sheer were created:

- loose loft based on sections created from the whole pointset,
- loose loft based on sections created from the selected points.
- normal loft based on sections created from the whole pointset,
- normal loft based on sections created from the selected points,
- plane fit into the whole pointset,
- plane fit into selected points of the point cloud,

The value of differences in shape between loose- and normal loft (Fig. 5b) is up to 6 mm. It means, that models are almost identical. Due to that it was decided not to create any models or describe any further analysis with normal loft, as the loose loft is to be better for modelling because of its attributes and creation algorithm.

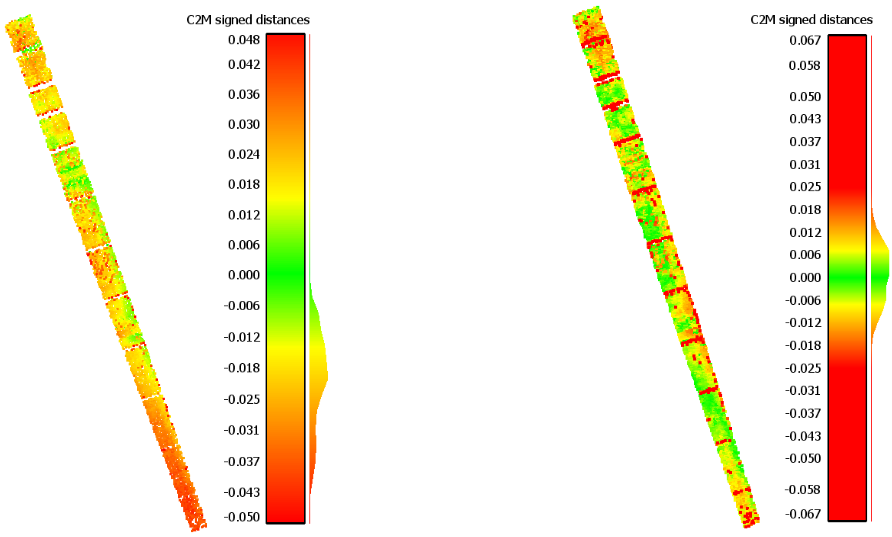
Models comparison to the point cloud (Fig. 3, Fig. 4a–4b) shows, that models shape prepared with different methods seems to vary from original point cloud up to 10 cm. Such difference was achieved with loose loft model without point selection (sections created from the whole point cloud) (Fig. 3a). The origin of such gross error is an incorrect section fitting.



(a) loose loft without point selection

(b) loose loft with point selection

Figure 3. Section loft comparison to the point cloud



(a) without point selection

(b) with point selection

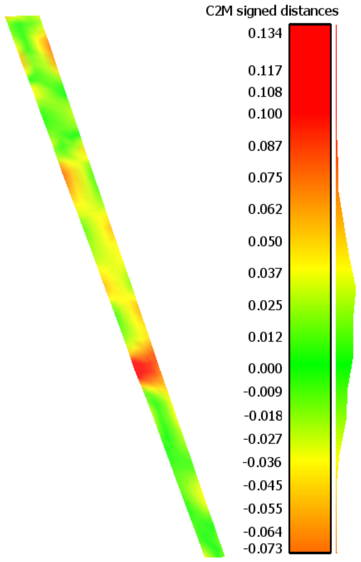
Figure 4. Plane fitting comparison to the point cloud

Point cloud, that was not prepared for modelling, caused a shape falsification of a surface. This example points out the need of proper points selection, as the omission of this step may lead to false conclusions and research failure.

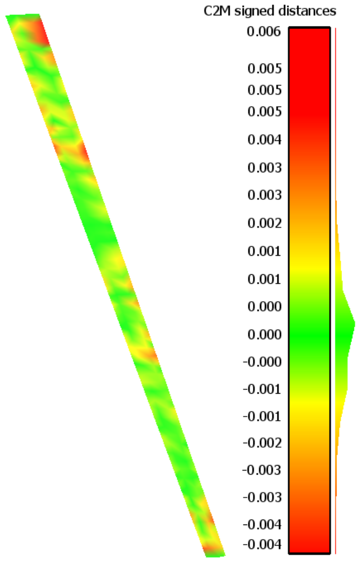
Maximal shape deviation between point cloud and loose loft (selected points) model was estimated at 1 cm (Fig. 3b). Any higher values noticed on a figure are points registered on stiffeners. The difference between this model and previously described loose loft without point selection is up to 10 cm (Fig. 5a). Yet is it another confirmation of the importance of point cloud preparation. The shape of plate girder has been faked.

In case of plane fitting into pointset (Fig. 4a–4b) maximal deviation has been estimated at 5 cm (no point selection) and 2.5 cm (with pTLSoint selection). Additional comparison made between both plane models showed, that the maximal difference in shapes is 3 cm in lower part. However, both models lean away from point cloud in lower and upper part. Such observation allows to suspect, that sheer arches because of some environmental or internal loads. Finding the origin of such bending requires finite element method analysis. Different constructions may cause even bigger displacements.

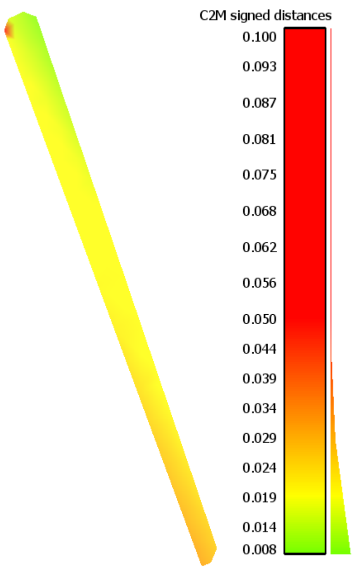
Aside from the described comparison to point cloud (Fig. 3a–3b, Fig. 4a–4b), there were also analysis between two models' shapes. First one was loose sections lofts from selected pointset and from the whole point cloud (Fig. 5a). The difference is up to 9 cm, because of gross error. Second one is loose and normal sections lofts from selected pointset (Fig. 5b), which already were described to be almost identical. Third analysis consisted two planes (selected points and full pointset) (Fig. 5c). The last comparison was made between loose loft and plane fitting, both with previous points selection (Fig. 5d). The analysis showed, that loose loft model bends from the plane model in lower and upper part. There are also some minor deviations in $^{1}/_{3}$ of the sheer height. The value of deviation is 1.5 cm in upper and lower and 0.7 cm in middle part.



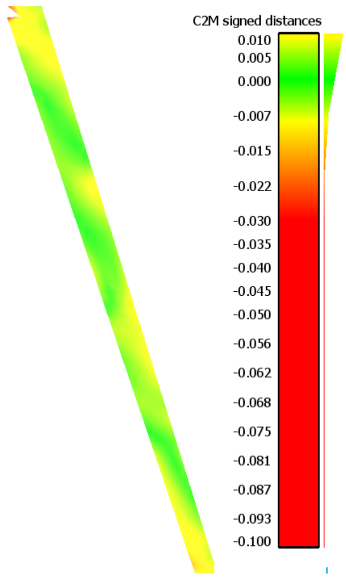
(a) loose lofts with and without point selection



(b) loose- and normal loft with point selection

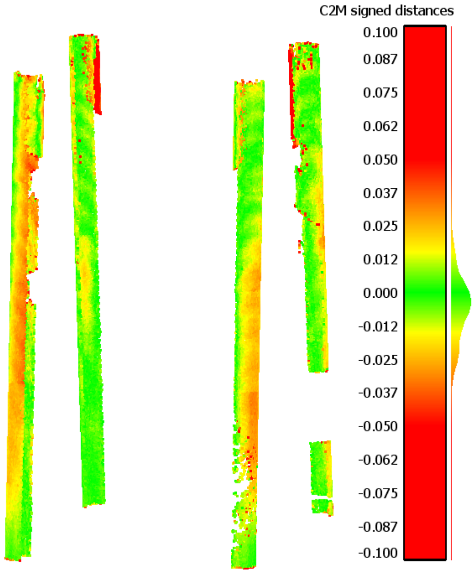


(c) plane fitting with and without point selection

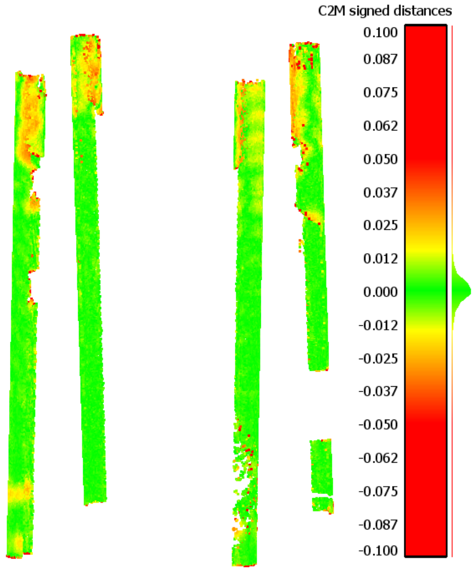


(d) plane fitting and loose loft with point selection

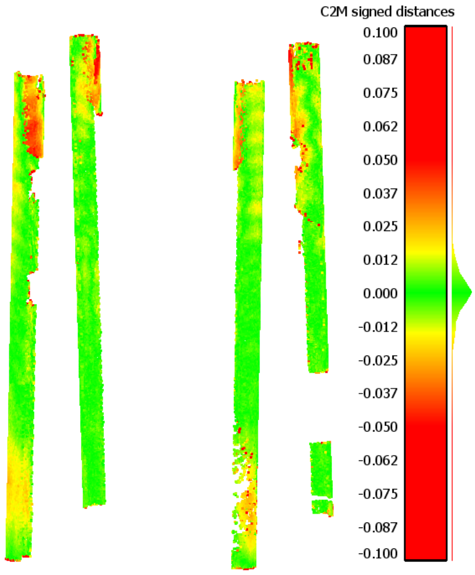
Figure 5. Models shape comparison



(a) simplified loft

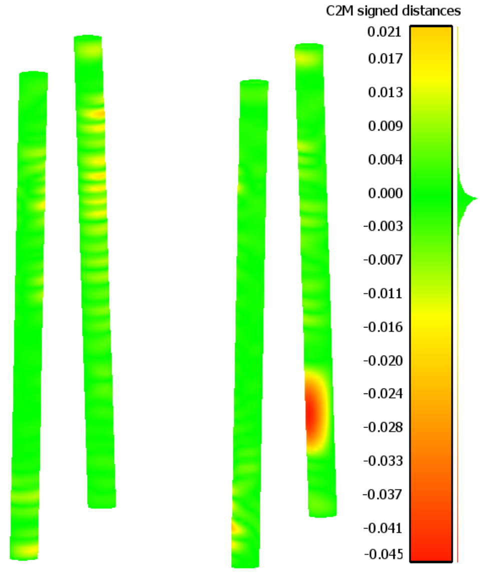


(b) loose loft with 1 m sections

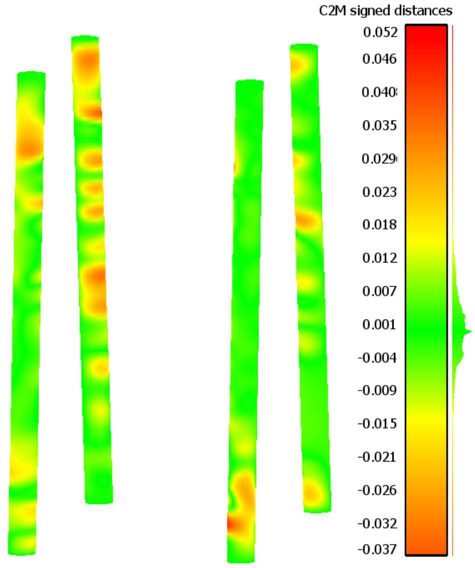


(c) loose loft with 5 m sections

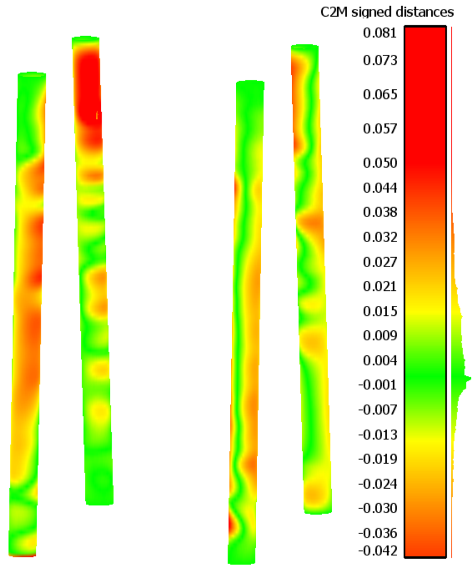
Figure 6. Models shape comparison to the point cloud



(a) loose- and normal loft



(b) 1 m and 5 m section loft



(c) simplified- and 1m section loose- loft

Figure 7. Models shape comparison

4.2 Headgear

The following supports models were prepared for a comparison:

- simplified loft,
- loose loft with 1m section,
- normal loft with 1m section.
- loose loft with 5m section,

Just as by headframe, the maximal differences in loose and normal lofts shapes are minor: about 1 cm (Fig. 7a). There is just one significant deviation on one of the supports with a value of 4 cm. However, the reason of such estimation might be incorrect circle fitting due to the incomplete point cloud in this area. It was decided, as by headframe, to describe only analysis with normal loft.

Simplified loft deviates from registered point cloud up to 4 cm , mainly in the middle part (Fig. 6a). Loose loft 1 m model do not lean away from the point cloud more than 1 cm (Fig. 6b), while the estimated deviation of the loose loft 5 m model is about 1.5 cm (Fig. 6c). Such analyses show how the curvature of construction is lost by model simplification.

Aside from model to point cloud comparison (Fig. 6a–6c), the following comparisons has been carried out: loose and normal loft with 1 m sections (Fig. 7a), loose lofts with 1 m and 5 m section (Fig. 7b), simplified and loose loft (Fig. 7c). Analysis of loose lofts with 1 m and 5 m sections shows the shape differences of 2 cm. Higher density of sections makes model more realistic. It is confirmed by comparison to point cloud, where denser model fits better (Fig. 6b–6c). The very last analysis was to compare the shape of simplified and loose loft with 1 m sections. As expected, a significant deviation in the upper and middle part has been determined. The value of deviation is up to 4 cm. Simplification may lead to some shape falsifications and some deformations may be skipped. Such shape changes can be determined only through more accurate modelling, using section lofts. Similar situation is common when a simple cylinder is fit to the pointset of tower or chimney (Pandžić et al., 2016). Environmental loads may cause major shape deformations and non-linear course of the object axis. In such situation simplified plane or cylinder fitting should be avoided, as the deformation (bending) may not be determined. Nowadays, it is common to use section lofts to analyse the axis of slender objects (Ćwiąkała and Jabłoński, 2016; Muszynski and Milczarek, 2017).

5 Conclusions

Analysis, that were carried out, estimated the values of shape differences between multiple models based on the same point

Obtained results need to be analyzed deeply using FEM. When working with more deformed objects inappropriate modelling may lead to false conclusions. The question is if such simplification causes a different result of comparison analysis between FEM model and a real shape. A further research needs to be carried out. It is planned to prepare a three-dimensional

cloud. All the models were created using plane fitting and surface loft (CAD point cloud modelling). Results confirmed how important it is to prepare and filter the point cloud before model creation. Incorrect data preparation may lead to the shape deviations of up to 10 cm. Such error will fake the model shape and make it unrealistic. Additionally, it was determined, that some simplifications through plane fitting instead of section lofts also cause visible shape differences up to 3-4 cm. The density of sections also leads to different results – the value of deviation was estimated at 2 cm. Such difference has minor influence on simple modelling problem.
model of the headgear, created with beam and bar elements. Analysis will be programmed to contain influences, that are typical for mining area like of subsidence of supports. By manipulating the analysis conditions, the shape differences will be obtained and an importance of 3D modelling will be determined.

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