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# TERESTRIČKO LASERSKO SKENIRANJE I MODELIRANJE VETROGENERATORA

# TERRESTRIAL LASER SCANNING AND 3D MODELING OF A WIND TURBINE GENERATOR

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*Rastući trend reverznog inženjerstva, posebno u oblasti građevine, gde je akcenat na obnovljivim izvorima energije, neposredno prati aktuelna rešenja mernih instурmenata, kao i softvera za procesuiranje dobijenih podataka, gde je neophodan precizan rezultat snimanja objekta. Terestričko lasersko skeniranje (TLS) i fotogrametrija kao savremene merne metode, daju vrlo precizne podatke o objektu, koji su baza za izradu tehničke dokumentacije, kreiranje 3D virtuelnih prototipova i njihove animacije, 3D štampe, provere geometrije, nosivosti, osunčanosti i drugih vrsta analiza. U ovom radu je dat prikaz rezultata geometrijskih analiza stubova vetrogeneratora i 3D modelovanja sa animacijom, koji su dobijeni na osnovu podataka TLS i fotogrametrije, uz poređenje preciznosti, sprovedenog tokom 2018. godine na lokalitetu Alibunar u Srbiji.*

***Ključne reči:*** *Vetrogeneratori, geometrijske analize, terestričko lasersko skeniranje, fotogrametrija, tehnička dokumentacija, 3D modelovanje.*

*Reverse engineering growing trend, particularly in the domain of civil engineering, additionally focused on renewable energy resources, actively follows technological improvements of measuring instruments, as well as processing software solutions, both necessary for an accurate objects' survey. Terrestrial laser scanning (TLS) and photogrammetric methods are contemporary standard for obtaining very accurate point cloud data, as a base for technical documentation, creation of 3D virtual prototypes and their animation, 3D printing, geometry inspection, loads, insolation or other analyzes. This paper presents results of geometric analysis of wind turbine tower, its 3D modeling with animation, based on TLS and photogrammetric data, obtained during 2018 at Alibunar in Serbia.*

*Key words: geometric analysis; terrestrial laser scanning; photogrammetry; technical documentation; 3D modeling; wind turbine tower*

## 1 Introduction

Energy efficiency and environment protection streamline initiated the development of variety of alternative energy resources. Among them significant role has the wind energy. In the areas where continuous air flow exists, wind-turbine generator parks are installed (especially on the territories of Germany, Denmark, Spain, USA, Australia, India, etc.) [1]. Moderately air flow conditions are characteristics of Serbian climate. Several wind-turbine generator parks (Kula, Vršac-Zagajica, Vršac-"Košava", Kruščica and Alibunar) are installed (or currently under construction) in our country, where wind generators have diverse energy performances (2-3 MW).

Wind turbine generators have variety of impacts on their nearest environment. In accordance, diverse analysis are required for project documentation preparation and approval [2]. Manufacturers of wind turbine generators make calculations for their design, which is usually aided by software solu-

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tions, where wind characteristics play determining role. The other issue is creation of 3D models, which could be used for diverse types of analyses, such as: the influence of shadows of wind turbine generators, mechanical analysis forces which occurs in working conditions, etc. In accordance to growing trends of reverse engineering, this paper deals with 3D modelling of wind turbine generator, based on laser scanning and photogrammetric processing of image data performed on the site Alibunar. Potential use of the model will be presented.

## 2 Location

The object of our scanning process are wind turbines located in municipality of Alibunar (Figure 1) in the wind farm, opened on September 11th 2018. Road distance of Alibunar from Belgrade is 56km, with aerial distance of 52km [3]. Wind farm "Alibunar" is built on agricultural soil belonging to the land register of Alibunar and the land register of Vladimirovac, located on the left turn from 53km, 300m to 55km, 900m from IA state road no.3 Belgrade-Vršac (by old classification, M 1.9). Location of the wind farm was selected based on detailed measurements of the wind and the terrain morphology [4].

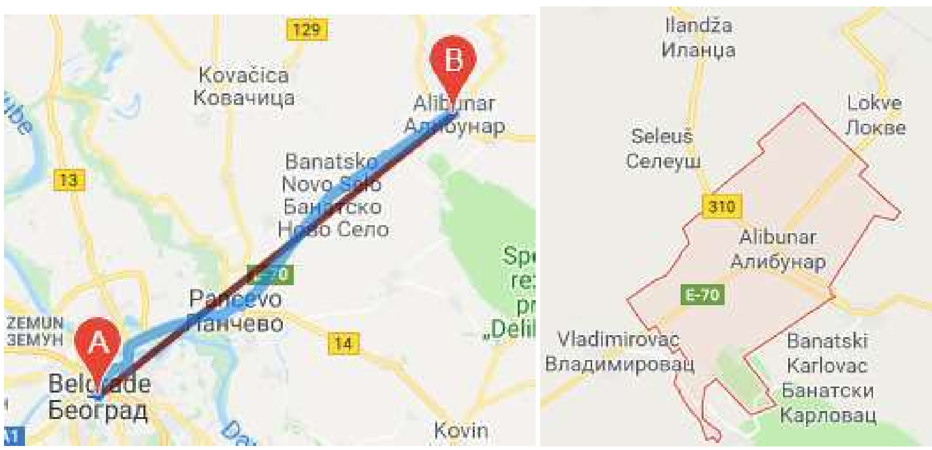


*Figure 1: Location of the wind farm „Alibunar"[1]*

*Figure 2 : Wind generators in „Alibunar" wind farm [3]*

*Figure 3 : Rotor blades and rotor hub*

Wind farm "Alibunar" is consisted of 21 wind turbines of individual power of 2 MW which develop full power at wind speeds greater than 11m/s [4]. In optimal conditions wind park can generate 42 MW of power. Wind turbines are identical, with one from another minimal distance of 400m, laid out in three rows by seven columns.

Wind-turbine generators have the specific geometry design (depending on the manufacturer) for each part of the structure: tower, nacelle structure enclosing the power generator, three rotor blades, rotor hub and ground equipment station (Fig.3). The foundation is the only part which has to be built directly on the site [5].

## 3 Measuring instruments and equipment


*Figure 4 : FARO® Laser Scanner Focus3D*

Laser scanner FARO® Laser Scanner Focus$^{3D}$ (Fig. 4 ) was used for scanning procedure. This is a device that uses high technology for terrain data collection with high time efficiency. IIt enables discretization of complex objects and environments with high geometry definition [6]. The basic features of the instrument

*Table 1: Features of Faro Laser Scanner Focus 3D*

| Characteristics | Values |
|---|---|
| Wavelength | 905 nm |
| Laser power | 20 mW |
| Measurement speed | 976000 |
| Maximal range | 120 m |
| Ranging error (10 m to 25 m distance) | ±2 mm |
| Working temperature | +5°C do +40 °C |
| Field of view (horizontal/vertical) | 360° /305° |

Camera used for photogrammetry reconstruction was NIKON Coolpix S9300, 16 Mpix resolution, optical zoom of 18x, and 1/2.3" (6.16 x 4.62mm) CMOS sensor [7].

## 4 Methodology

### *4.1 Scanning procedure*

Scanning procedure with FARO Focus 3D scanner was performed at Alibunar site in September 2018:

- The terrain is examined and 6 markers are placed (Faro Focus 3D scanner uses spheres as markers for further alignment of the scans);
- The instrument is placed at previously 5 planned station positions, in order to capture the shape of the whole object;
- Scan parameters are adopted: scan resolution was set for 3mm ranging error at the distance of 10m, which required 20-30 min of scan duration;
- The field of vision is defined for each particular station and both angles (horizontal and vertical); It varied from 90 to 210 degrees;
- Five scans were obtained with varying amount of data.

Weather conditions during scanning procedure varied from extremely sunny to cloudy weather. These conditions affected scanning results.

Some important issues were followed during markers setting:

1. The overlap of the two neighbor scenes contained minimum three common markers. In order to obtain accuracy of a 3D model and to enable determination of unknown transformation parameters, common markers were set in such overlapping manner.

2. In order to enable sufficient visibility of the markers (centre points of the spheres) and their precise recognition during scan registration, markers were set at the distance much closer (3-5m) than 20m (which is maximal distance set by manufacturer) .
3. Regular positioning of markers regarding depth variation was adopted in order to achieve registration accuracy.

Scanning result is set of 3D points, i.e. point cloud, where each point has four attributes: three spatial coordinates and information about intensity of the returned radiation (depending on the reflectivity of the scanned object) [8].

### *4.2 Photogrammetry procedure*

Photogrammetry methods commonly require more than 20 photographs from different locations around the object. In order to create a model from images it is prefered to know the information about the position where each image is taken [9]. The simplest approach is to use camera with built-in GPS. Photogrammetry method interprets photographic images and patterns to obtain reliable information about physical objects and the environment.

In the case of Alibunar project, 28 photo images were taken for two different wind generators. The unstable weather conditions and slight movements of the blades (due to the wind conditions) affected on image quality. NIKON Coolpix S9300 camera was used for obtaining photos. Images were imported into *Autodesk Recap* software, in order to obtain point cloud results.

### *4.3 Geometry camera matching*

This method uses still images. GPS location is extracted from EXIF data from the photographs, establishing geographical coordinates of shooting positions, focal length and camera's sensor size. Using mentioned intrinsic parameters, manual and automatic perspective matching and camera orientation matching is performed -resulting in extrinsic parameters which are orientation and position of the cameras within newly generated reference system [10].

## 5 Modeling procedure

Process of acquiring 3D data from the site follows this procedure:

1. Using FARO Focus 3D laser scanner and obtaining 3D point cloud data of a maximum distance scanner can reach, which is 120m from the position of the measuring instrument, but only 40m from ground level of wind turbine tower was successfully scanned due to the scanning conditions.
2. Each scan obtained with FARO Focus 3D laser scanner had a lot of unnecessary data that were taken from wind-turbine environment, such as ground, grass and other plants (Fig. 5). In order to acquire best result from scanned data scans were manually cleaned. All these unnecessary points increased file size and processing time which is needed to obtain 3D model. Only points that left after cleaning are from wind-turbine and spheres (figure 6).

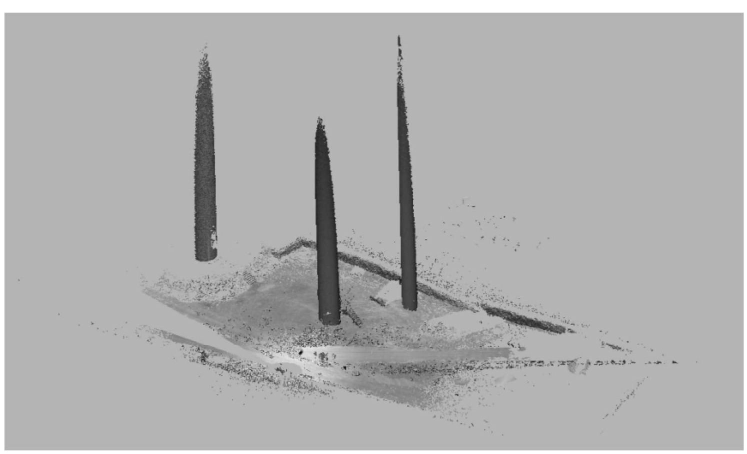

*Figure 5 : Scanned data from FARO® Laser Scanner.*

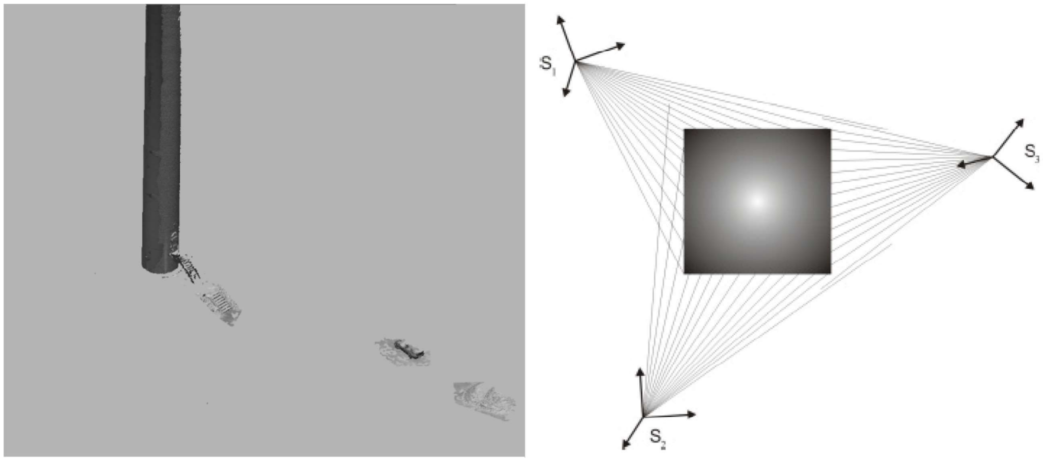


*Figure 6 : Cleaned point cloud (Left), Point cloud registration (Right).*

3. In order to obtain the scan results, registration of the point clouds was required. Registration involved 3D transformation of 5 point clouds into one (based on markers-spheres), within single coordinate system (Figure 6 - right).
4. After the completion of sphere registration all point clouds are combined into one, which is then converted into mesh (figure 7).

*Figure 7 : Combined point cloud (left), Solid Model created from mesh (right).*

5. 3D solid model is created from obtained mesh, but because wind-turbine is too high, only lower parts of the turbine pilar were scanned, up to 40m from ground level.
6. To fill in the missing parts of a point cloud, it was approached with photogrammetry method. Bad weather conditions resulted in slightly blurred photographs due to the long exposure times and slight rotation of the blades, which disrupted requirements of photogramme-

try method to utilize images with still elements in the frame. This approach did not provide sufficient data.

7. Supplementary method of geometry camera matching was applied as final alternative. Outlines of the subject from the photos are protruded trough recovered views back to the reference coordinate system and using multiple views, 3d shape is reconstructed in Blender, 3D open-source software. Reconstructed polygonal mesh is presented in Fig. 8.

*Figure 8 Reconstructed polygonal mesh*

8. Final result is translated back from the polygonal mesh to the point cloud, in order to combine it with the point cloud from steps 1-7 (Figure 9.), ensuring this reconstruction method is used only where the first two methods failed to provide satisfactory result.

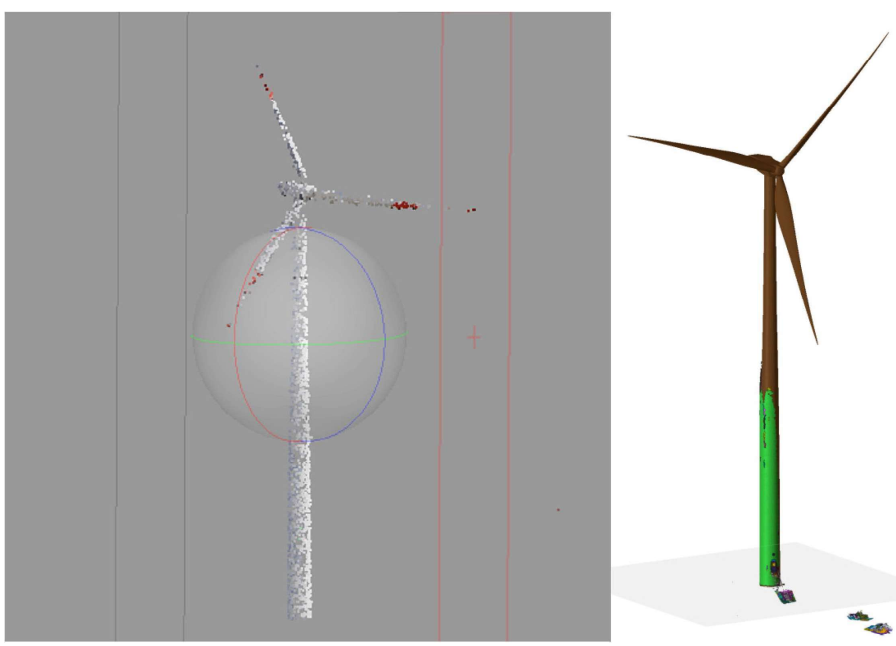

*Figure 9: Point cloud data from step 8.(left), Final result (right)*

## 6 Results and conclusion

This paper presents two models obtained by by using the 3D scanning and Geometry camera matching , two models were obtained. The 3D solid model of a lower part of a the turbine's tower (from ground level up to 40m) was created in SolidWorks 3D environment, based on the data collected by Faro 3D scene scanner . This model is partial because of the limited range of the scanning device, and non optimal scanning conditions.

*Figure 10. Final Model.*

Using the geometry camera matching geometric shape of the upper structural parts of the wind turbine was obtained (Fig.10). The complete 3D model was created by adjusting geometry and dimensions of the two partial models (dimensions of structural parts were available from project documentation). Length accuracy of final the model is approximately 90%.

FARO Focus 3D scanner has limited performance for this type of tall objects due to its short range and high reflectivity of the object's surface which interferes with laser measuring system. FARO Focus 3D scanner would be useful to test in different weather conditions, preferably on overcast day with higher resolution.

This model can be used for shadow analysis, to assess the impact on the environment, for urban planning, for cartography and usage in numeric simulations.

## 7 Acknowledgment

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