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Modeling 3D Objects for Navigation Purposes Using Laser Scanning

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ABSTRACT: The paper discusses the creation of 3d models and their applications in navigation. It contains a review of available methods and geometric data sources, focusing mostly on terrestrial laser scanning. It presents detailed description, from field survey to numerical elaboration, how to construct accurate model of a typical few storey building as a hypothetical reference in complex building navigation. Hence, the paper presents fields where 3d models are being used and their potential new applications.

1 INTRODUCTION

The main feature of maritime, air and land navigation, as well as surveying is the extensive use of 2D mapping imaging [28, 29, 16, 5, 21]. One of their characteristics is the use of specific signs and abbreviations [3, 18] that significantly limit the range of users to professionals in the areas of activity requiring the use of maps. At the end of the last century, thanks to the development of GNSS systems, there was a very dynamic growth in the number of people using unprofessionally a variety of mapping imaging. The increase in accuracy of the location positioning while using the GPS system up to 13 meters (p=0.95) [25] has enabled the precise positioning of vehicles (within a single lane) - the effect was the development of systems of mapping imaging for public navigation [23] most frequently connected with geolocation and vehicle navigation

The main limitation of 2D mapping imaging is no possibility of drawing up a map without distortions (angular, distance and area) [7, 10, 13]. It makes spatial orientation difficult for unprofessional people associated with navigation. Therefore it can be concluded that the ideal navigation map would represent a 3D visualization of the surrounding world, from which all the imperfections of 2D maps have been removed. Perhaps this is one of the factors that caused at the beginning of the twenty-first century intensive work on the development of 3D imaging for all types of navigation.

The paper presents and compares the methods for creating 3D models of objects [2] for navigation applications. It presents an example of modeling objects with the use of: technical documentation, direct measurement with a handheld rangefinder, photogrammetric methods, and laser scanning of a two-storey building measuring 30.8m × 11.6m, located at the University of Warmia and Mazury in Olsztyn. The hence developed vector 3D model includes external and internal part of the building without objects on the roof.

2 MODELING 3D OBJECTS WITH PUBLICLY AVAILABLE METHODS

The simplest, available virtually for everyone method of developing 3D models is a short-range photogrammetry. Pictures taken from a distance of several to tens of meters from different angles are obtained using hand-held cameras, optionally placed on tripods. A prerequisite is to provide partial coverage of adjacent photographs. Characteristic points appearing in both images are adopted to carry out the mutual orientation of the images. Determination of the position of the camera at each photo is not necessary. The three-dimensional coordinates are obtained from the constructed photogrammetric model [27]. The method of a short-range photogrammetry is widely used in high-precision industrial measurements, to create three-dimensional models and orthogonal projections of objects. Presented in Fig. 1. the model of the main building of Gdynia Maritime University was carried out only with the use of images posted on the Internet, with the support of imagining from Google Earth.

Figure 1. 3D Model of the main building of Gdynia Maritime University developed with the use of photogrammetric techniques [source: own study]

An alternative approach was used in the paper [22], which shows two ways to produce 3D models of objects. The first used the direct measurement (inventory) using optical methods, while the second was based on the existing technical documentation. Figure 2 shows a model of the Faculty of Navigation of Gdynia Maritime University made using a handheld laser rangefinder. The measurements were supplemented with images shot with a camera – they helped to acquire the texture of individual parts of the building as well as some architectural details which were incorporated into the realized 3D solid object. It can be assumed that the completed inventory assured accuracy no worse than 10 cm.

Figure 2. Selected architectural details of the Faculty of Navigation of Gdynia Maritime University building [22]

A different approach was used when creating 3D models of characters of navigation aids on the approach to Nowy Port in Gdansk [22]. In this case the possibility of making direct measurements is virtually impossible, so the optimal method is to use the technical documentation of individual characters of navigational aids, which was obtained from the Maritime Office in Gdynia. Marking of the navigational approach to Nowy Port in Gdansk are now old buoys PM-2 and PM-3 and the new buoys with the articulated structure and signs of entrance/input heads. Figure 3 presents the technical documentation and a 3D model developed on its basis.

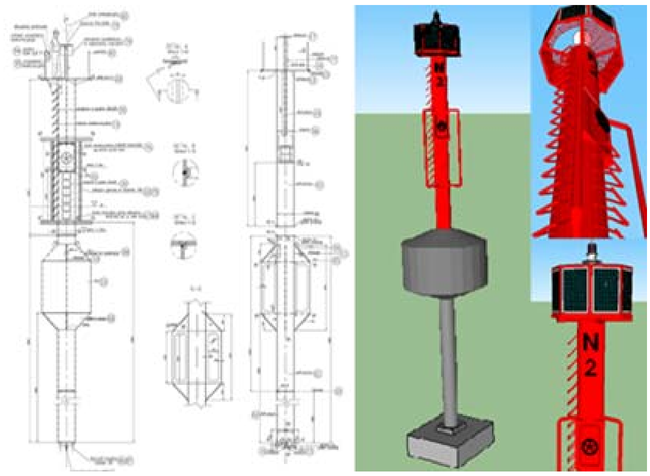

Figure 3. Technical documentation and made on its basis model of an articulated structure buoy of the approach route to Nowy Port in Gdańsk [22]

3 TERRESTRIAL LASER SCANNING AS A METHOD OF OBTAINING GEO-SPATIAL DATA

Terrestrial laser scanning is a method of obtaining spatial coordinates of objects, in which through the laser distance measurement (laser scanner - object) and the angular orientation of the device are achieved ortho-Cartesian coordinates of the measured points in the local coordinate system of the instrument. The laser scanner is equipped with mechanisms for emission of a beam horizontally and vertically. The laser beam sets on a rotating at a high speed optical element, which by rotation around the horizontal axis causes its reflection at a given angle [26]. In this way the measurement of points lying in the same vertical plane is taken. Next, a second mechanism rotates the instrument by a small angular interval in a horizontal plane around the vertical axis of the instrument and the measurement is repeated [1]. This process is carried out in a defined angular range including the object of measurement. The speed of obtained data is very large [4] and may be up to 1 million points per second.

The scanning technology was created in the 60's of the 20th century. The exact scanning of the object was a very laborious process due to technological difficulties. The introduction of computer processing of results has enabled the creation of accurate and complex object models. In 1994 there was created the first accurate and fast scanner to measure small objects using a linear laser beam. In 1996 they constructed a manually operated scanner that in addition to geometric data obtained information about the degree of reflection of the laser beam on the measured surface [8]. These scanners worked in desktop stationary mode. The measurement was taken in laboratory environment. First scanners working outdoors, placed on tripods, appeared in 1997. These were massive pulse scanners with external power supply and data storage modules. In 2003, the first phase scanners arrived. Still they used external measuring modules, but measurements were realized much faster. In scanners produced since 2007 was initiated the integration of memory modules and internal power supply. There were introduced solutions used in conventional measurement methods. The latest generation of scanners, which appeared first in 2009, are instruments with integrated memory and power supply modules, as well as a connected camera, which again improved the functional parameters of the scanner. Some scanners have the ability to measure multiple reflection of the same laser beam [19] which affects accuracy.

Today, in the terrestrial laser scanning, depending on the form of the measurement signal, are used two types of these devices – pulse scanners (Time of Flight - TOF) and phase scanners (PhaseShift - PS). The result of measurement is a cloud of points (Fig. 4) constituting a set of points with associated spatial coordinates and values of intensity of reflection [20]. The number of points obtained during the measurement of a typical object often reaches millions in numbers.

The scan speed of pulse scanners ranges from 5,000 to 125,000 points/sec in the latest models [14, 24]. Pulse scanners are characterized by a greater maximum scanning range than phase scanners [14]. However, the greater range of pulse scanners is obtained at the expense of speed of data acquisition. The phase measurement is definitely faster. The scanning speed of a pulse scanner ranges from 120,000 to 976,000 points/sec [14, 24].

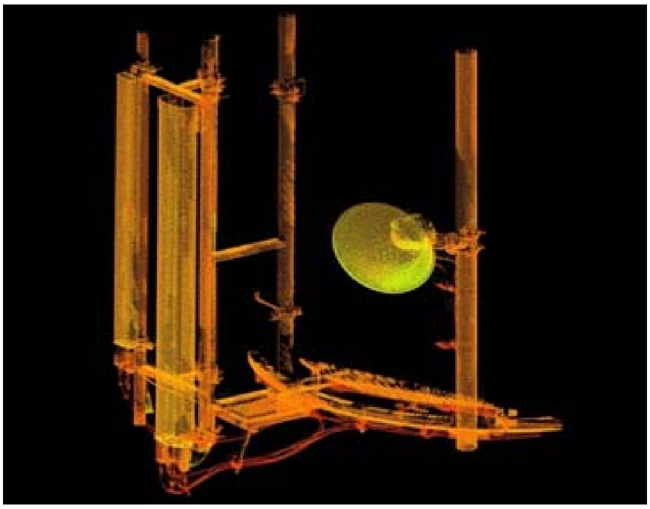

Figure 4. Example of a cloud of points resulting from laser scanning – a fragment of GSM mast

The most advanced laser scanner solution is its mobile version designed for gathering data for 3D modeling of large areas. Its essential elements are: the sensor consisting of several laser heads oscillating in the range of 360 degrees (Fig. 5, left), a GNSS positioning system based typically on active surveying networks along with the radio line RTK (GPRS) and the IMU inertial unit. Optionally, the system is complemented with an odometer recording information on a car wheel rotation, which allows to increase the accuracy of positioning of the vehicle at the stage of post-processing. The mobile scanner is complemented with the high resolution (2MP) panoramic camera system allowing the acquisition of images with more than 80% coverage of the sphere. This system allows full synchronization of acquired images, giving them geo-referencing and scanning frequency of 20 Hz at a speed of each of the heads of 36,000 points/sec. The inertial unit (IMU) supports positioning at the frequency of 200 Hz, ensuring accuracy of 13-24 cm at 1 minute loss of tracking GNSS signals. The latest development in the field of laser scanning is a hand scanner. This is a handy tool able to raise the point cloud at the speed of 43200 points/sec with a range of approx. 30 m, with a point accuracy of 30 mm. A special feature of this scanner is the ability to implement measurements without geo-referencing, which predestines it to create 3D models inside objects (Fig. 5, right).

Figure 5. Mobile (left) and handheld (right) laser scanner from Trimble

A laser scanner measuring accuracy depends on a variety of factors. Of key importance here are angular measurement accuracies: horizontal and vertical, as well as distances. Another factor is the resolution, which is a derivative of the laser spot size and the angular interval of a measurement being made. This parameter determines the ability of the instrument to detect and measure small objects. The surface from which the laser is reflected also has an impact on measurement accuracy. The color and texture of an object affect the level of intensity of the reflected signal. Studies carried out have demonstrated better parameters of reflecting signals by bright surfaces [6, 12]. Equally important, from the point of view of the reflected signal level, is the material from which the object is made [1, 9]. The accuracy of the measurement, the measuring range, and the recorded number of points are also affected by weather conditions [11]. Another additional factor influencing the quality and accuracy of scanning is the shape of the object being measured. These factors may cause the point cloud noise, distortion at the edges and other interference. The test of comprehensive and standardized verification of these factors was carried out at the Institute for Spatial Information and Measurement Technology at the University of Applied Sciences in Mainz [4]. They constructed a special research laboratory and analyzed several models of laser scanners. Similar comparisons were presented in other publications [15, 24].

4 3D OBJECT MODELING USING DATA FROM THE LASER SCANNER

Measurement data of the modeled object were obtained by the pulse laser scanner Leica ScanStation. Additional information concerning the distribution of the rooms was obtained from the technical documentation of the building made available for scientific and research purposes by the Department of Exploitation of the University of Warmia and Mazury in Olsztyn. Processing of the results of measurement was performed using the LeicaCyclone software. Plans and sections of the building were made in the LibreCAD software. For 3D modeling was used the TrimbleSketchUp software. Basics of using the program and the feasibility of the 3D model performance is presented in detail in the paper [17]. Finally, the constructed model was compared with the source point cloud using the CloudCompare software.

Field work began with the development of plan of the measurement. 4 locations of measuring stations were determined, ensuring the appropriate resolution of a point cloud. On selected elements of technical infrastructure were set rotary target plates enabling subsequent registration (joining) process of point clouds measured from individual stations. These plates have very good laser beam reflection parameters. At the same time was prepared a sketch showing the location and identifiers of individual plates. The measurement at each station included scanning the object and target plates. At the end of field operations was drawn photographic documentation of the object with the camera.

The next step was to combine all scans into a single object, namely registration. All point clouds were indicated and a system of coordinates of one of them was selected as a global system for which all the others were transformed. As points of adjustment of the three-dimensional point clouds transformation they used previously designated centers of target plates. Unification of point clouds was conducted, in which process the repetitive points were removed, filtered to the desired resolution and the numeric recording of the point cloud was optimized. Subsequently, the cloud of points was limited by selecting the fragment of space that contained the considered building (Fig. 6), next the planes of walls and cross-sections of the characteristic points were generated and exported to raster files.

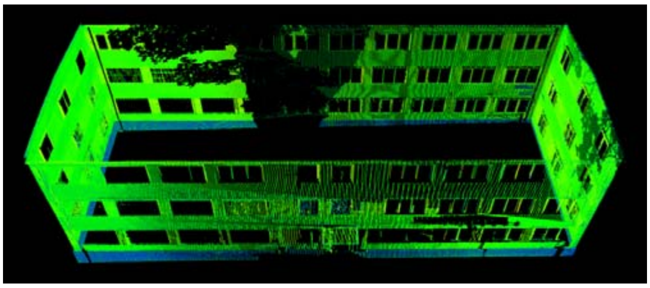

Figure 6. Point cloud of the building facade in perspective view (CloudCompare) [source: own study]

Further work was carried out in LibreCAD (Fig. 7). Distribution of rooms and corridors were obtained from the technical documentation of the building. The internal accuracy and consistency of all components were ensured.

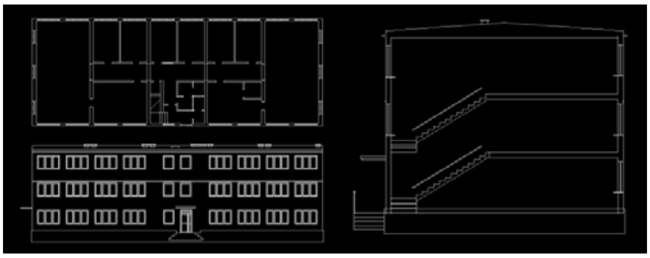

Figure 7. Examples of projections and cross-sections of the building (LibreCAD) [source: own study]

The target stage of work was to develop a 3D model of the building in TrimbleSketchUp. Elevation projections and cross-sections of the building were imported, which then were precisely arranged in the program space (Fig. 8).

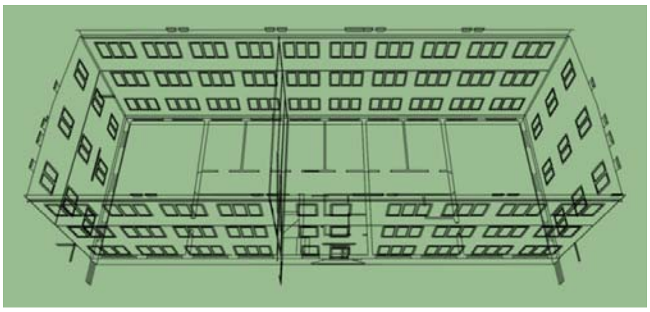

Figure 8. Plans and cross-sections of the building (Trimble SketchUp) [source: own study]

Then, based on the geometry of the vector projections and cross-sections was prepared a three-dimensional model of the building (Fig. 9). The model includes approximately 5200 linear and surface elements. The colors of individual pieces have been provided on the basis of photographic documentation.

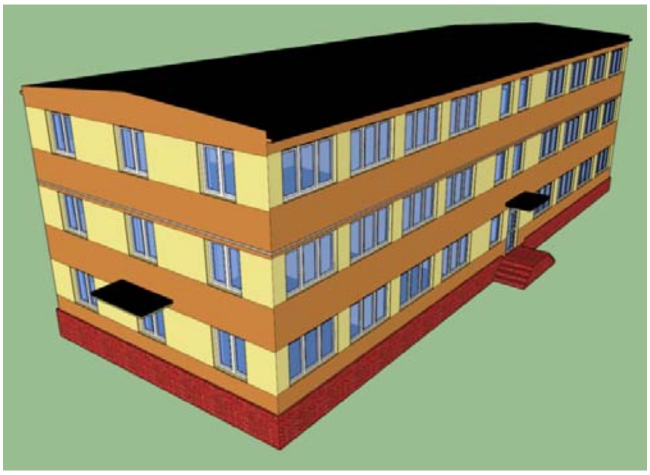

Figure 9. 3D model of the building (TrimbleSketchUp) [source: own study]

The figure below presents selected elements of the 3D model of the modeled object interior.

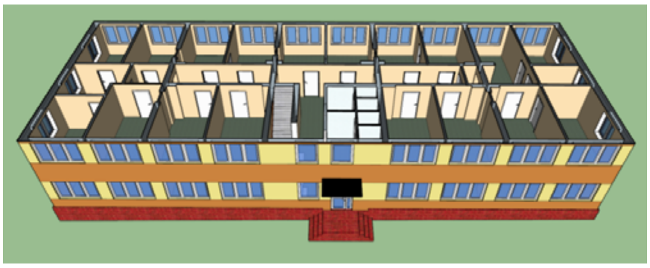

Figure 10. Selected elements of the building interior (TrimbleSketchUp) [source: own study]

In order to assess the accuracy of the 3D model they compared the constructed three-dimensional model of the object (external facade) from the source point cloud measured by a laser scanner. The analysis was carried out in CloudCompare (Fig. 11). The results are presented in the form of a histogram of matching errors (Fig. 11, right) that were applied in the form of colors on the model of the object (Fig. 11, left).

Assuming that the cloud of points is the most faithful discrete representation of the building geometry it can be assumed that the error of the developed facade model is below 5 cm.

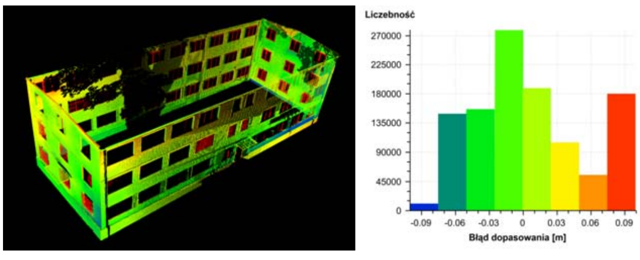

Figure 11. Evaluation of the accuracy of the model of the building facade from a point cloud (CloudComapre) [source: own study]

5 CONCLUSIONS

The process of navigation can be carried out both outdoors as well as inside objects. The development of modern mobile devices and their applications make it possible in the near future to have a very rapid development of positioning systems, also in the buildings, and the presentation of objects of the navigation infrastructure will be widely implemented in 3D.

The article presents several methods of implementation of 3D models of objects using various sources of information and commonly available software. The paper also shows a method of modeling the interior of a typical object with dimensions of 30.8m × 11.6m, located at the University of Warmia and Mazury in Olsztyn. There is no doubt that such projects will be in the future used in navigation systems operating both inside buildings, as well as they will complement the database of objects in the navigation systems working outdoors.

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