Comparison on Commercial and Free Software for Point Cloud Processing

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http://doi.org/10.29227/IM-2024-01-57

Submission date: *4.2.2023* | Review date: *8.3.2023*

Abstract

Terrestrial laser scanning technology is becoming increasingly common for automated spatial data acquisition and digitization in the fields of surveying, civil engineering and architecture. The data from measurements made with terrestrial laser scanners are a huge array of points in space, called a point cloud, which describes the captured surface of the object under study. The point cloud processing is performed in specialized software products for handling measurements from laser scanners, which provide different possibilities for manipulating the point cloud and forming different results. The software available on the market differs according to its data processing capabilities and functionalities, application areas, methods used, manufacturer and cost. To be able to perform spatial data processing and analysis correctly and with high quality, it is important to understand the available functionalities of the different software products and their advantages and disadvantages compared to others. A comparison is made for three software packages for point cloud processing - Autodesk ReCap Pro, CloudCompare and Trimble RealWorks. The different functionalities available in the products are described and presented on small building measurements along with their performance accuracy and efficiency. The strengths and weaknesses of the different software products are identified through the comparison performed. The first section describes the basic principles of the terrestrial laser scanning method. In section two, the different point cloud processing software products on the market are presented, together with a description of the different file formats for data exchange and a theoretical section on point cloud registration, filtering, and modelling. The third section contains a presentation of the main functions and processing capabilities in Autodesk ReCap Pro, CloudCompare and Trimble RealWorks software. The fourth section describes the data used for the study, the measurements performed, their processing and results in the three software, together with an assessment of accuracy by control measurements. Section five contains conclusions and implications.

Keywords: comparison, commercial and free software, point cloud processing, terrestrial laser scanning

Introduction

Nowadays Terrestrial laser scanning (TLS) is applied for the generation of highly detailed 3D city models from ground-based views. In the context of such applications, large scale city models at a limited level of detail are already available for many cities from airborne Digital Elevation Models. Additional data from TLS are needed to generate accurate 3D model of buildings inside. Obviously, the airborne acquisition of 3D building models does not provide detailed geometry for the facades of the building. This information, which is for example required to generate virtual views from pedestrian perspectives, has to be captured by ground-based approaches like TLS. The resulting point clouds from TLS require further processing to be able to obtain the desired results in city mapping and creating Digital Twins.

Terrestrial laser scanning allows to capture large amounts of measurements, with high accuracy and in a short period of time, enabling the collection of a large volume of 3D data in real time, regardless of lighting conditions. As a result, we create a highly detailed spatial image of the object. The application of various types of processing and analysis on the output data allows the creation of high-precision spatial models that actually describe the state of the object under study at the time of capture, and the solution of tasks related to the documentation and restoration of architectural objects, determination of deformations of engineering structures, documentation of the condition and performance of construction projects and the creation of up-to-date information models of buildings. Proper processing of the data, obtained from ground-based laser scanner measurements, is of great importance to achieve quality and reliable final results that enable the solution of these problems.

The object of the study is a comparison of the capabilities, advantages and disadvantages of point cloud processing software products. Software products in the scope of the research are Autodesk ReCap Pro (Offered by a CAD software manufacturer), CloudCompare (Open sourse software) and Trimble RealWorks (Offered by a н instrument manufacturer). For the comparison, the different functionalities available in the products are described and presented on measurements of a small building, along with their accuracy of operation and efficiency. As a result, the advantages and disadvantages of the different software products are determined. The software versions used are ReCap Pro 2019, RealWorks 12.0, and CloudCompare 2.6.3.

Terrestrial Laser Scanning

Terrestrial laser scanning is a modern technology performed by specialized instruments called terrestrial laser scanners, which measure the distance to the imaged surface by emitting laser pulses and receiving the reflected signal, which is registered as a 3D point. The spatial position of the measured point is determined by its spatial coordinates (X, Y, Z) in the local coordinate system of the instrument, together with the received signal strength - the intensity (I). Each point is saved in the instrument memory in the

format {X, Y, Z, I}. Some scanners also have a digital camera to capture the object. The resulting digital image displays information about the color of the captured point, in RGB color format, where the actual color represented by the values of the individual color channels {R,G,B} is added to the recording. Processing and analyzing the point clouds can be performed with the help of specialized software to derive the necessary data for the object under study.

Software Products for Laser Scanning Data Processing

The processing of a point cloud is carried out in specialized software products that allow the manipulation of this type of spatial data, such as merging individual clouds of points into a common coordinate system (registration and georeferencing), extracting specific parts of the set of data (filtering), creating a 3D model (modeling), etc., as well as shaping them into a single product, satisfying the needs of the user.

Overview of Commercially Available Software Products

There are many software products for processing cloud from points, each of which differs according to its ability to work with laser scanner measurements, field of application, price and manufacturer. Some of these specialized programs are offered by manufacturers of laser measurement instruments (FARO, RIEGL, Leica, Trimble and others), with a focus on providing a common system between the customer, tool and software, allowing an easy and hassle-free workflow - from making the measurements themselves to processing and shaping them consistently. Another part of the manufacturers (Autodesk, ArchiCAD, Bentley, PointCab and others) are focused on creating software packages that allow the processing of point clouds regardless of their source or structure, giving the ability to jointly process data from different tools. The latest category is software like CloudCompare, which provides a free platform for processing cloud points without the requirement of a license, ensuring accessibility for everyone.

Due to the different capabilities, standards, resources, needs and requirements of individual manufacturers and the market itself, each of these platforms differs in its capabilities such as supported formats, available functions for processing clouds, their analysis and output results of the processing performed. Some of the software products available on the market are presented below.

Autodesk® ReCap™ Pro is a software for point clouds processing that allows filtering, registration, georeferencing and cutting of point clouds, as well as their visualization by various properties such as colors (RGB gamma), height and intensity. In addition, photo images can be georeferenced in a single general image and measurements of lengths, angles, areas and coordinates of points on the cloud can be performed. The software also provides basic capabilities to create 3D models from a cloud of points and as part of Autodesk products, ReCap Pro allows the output of data on point clouds in formats supported by the company's other products, such as Civil 3D, Revit and Navisworks, to create drawings or further modeling, processing and analysis [1].

CloudCompare is a free software that allows complex analyses, processing point clouds and working with irregular surfaces. The program contains tools allowing registration and georeferencing of point clouds, calculation of projections, comparisons between cloud to cloud and cloud to model, as well as the measurement of lengths, angles, areas and coordinates of points in the cloud. Other capabilities of the software are statistical and geometric calculations and analyses such as normals, curvatures and density and the creation of surfaces from a point cloud for TIN modeling. CloudCompare also contains various extensions for filtering and modeling point clouds, further increasing the functionality of the software [2].

Trimble RealWorks™ is a fully functional software for logging, visualizing, analyzing and manipulating data from point clouds and creating 2D and 3D results for immediate output or export to other CAD programs [3]. In addition to the previously described functions, this platform allows many additional capabilities for the processing and analysis of point clouds. Cloud and surface analysis functions allow the determination of gaps and deformations in the research object, and the classifiers for outdoor and indoor environment allow for automatic recognition of terrain, buildings, pillars, vegetation and other objects from the point cloud. Automatic brand recognition is also possible. RealWorks also provides opportunities for modeling surfaces and primitives, as well as automatic modeling of stairs, tanks, pipes, steel beams along various profiles, ladder cells and railings by set parameters or from existing catalogs.

The ability to select individual modules for work, provided by different manufacturers, gives flexibility to the market model they apply and gives the ability to perform quality processing of point clouds without the need for the purchase of additional software products by the customer. In addition, with the expansion of the fields of application of laser scanning, the need for compatibility between the different software platforms to ensure the correct and quality implementation of architectural, construction, cartographic and other types of investment projects arise.

Functionalities of Point Cloud Processing Software

Input and output of data

Each of these software has its own supported file formats, which they can import or export, and which are selected or specially created by the manufacturer according to their needs. As a result of the orientation of different companies towards the use of formats that are related and compatible with their software and / or hardware products, a lack of standardization or a commonly used format is created, which leads to a lack of interconnection or the ability to exchange data between different software products. Even in cases of converting from one format to another, losses in translated information may occur, lowering the accuracy or damaging the file itself.

Due to this form of limitation in the exchange of data between different software products, it is of great importance to understand the individual formats for recording point clouds, their capabilities, limitations, characteristics and the software products with which they can be used.

Measurements with TLS may be subject to further processing in specialized software products, such as registration and georeferencing, filtering, 3D modeling and others, which can be transferred to other software for post-processing.

In order to be able to move a point cloud between different platforms, the software product is required to support file formats for different sources and their recording in commonly used or standardized formats for the exchange of point clouds, such as LAS and E57, RCP, RCS, OBJ, STL, etc. Table 1 presents the supported formats from the software products studied.

Registration and georeferencing

In the practice of performing measurements with terrestrial laser scanners, the objects usually studied are too large or complex in shape to allow their full scanning from a single station, so it is necessary to perform measurements at different locations [4]. As a result of these measurements, several point clouds are obtained, each created from a different station and with its own orientation of the coordinate system of the instrument. To form the full image for the given object and facilitate the subsequent work, pre-processing is carried out, consisting of the general orientation of the individual clouds and merging into a single cloud, in the local coordinate system of the instrument. This process of merging the individual clouds of points into a single coordinate system is called registration. It could be done by using plane-based registration or target-based registration.

Tab. 1. Supported file formats of ReCap Pro, CloudCompare and RealWorks

Software product	**Autodesk ReCap Pro**	**CloudCompare**	**Trimble RealWorks**
Input files	ASCII (TXT, XYB, XYZ) CL3, CLR (Topcon) **E57, LAS** FLS, FWS, LSPROJ (Faro) PRJ, PTG (Leica) PTS, PTX, RCS (ReCap) RDS (RIEGL) ZFS, ZFPRJ (Zoller+Fröhlich) DXF, DWG, PCG (Autodesk) JPEG	ASCII (TXT, ASC, NEU, XYB, XYZ) BIN (CloudCompare) DP DXF, FBX (Autodesk) E57, LAS, LAZ FLS, FWS (Faro) PTX (Leica) PLY, OBJ, STL, VTK (mesh) OFF OUT, JPEG, Ortho/.tif (GeoTIFF) SHP	ASCII (TXT, ASC, NEU, XYB, XYZ) CL3, CLR (Topcon) E57, LAS JXL FLS, FWS, LSPROJ (Faro) PRJ, PTG (Leica) RCS, DXF, PCG (Autodesk) RAW TZF, TZS, TSF (Trimble) JPEG
Output Files	E57 PTS **RCP**, RCS DXF, DWG, FBX, PCG OBJ RCM Ortho/.tif (GeoTIFF)	ASCII BIN (CloudCompare) DP DXF, FBX, SHP (Autodesk) E57, LAS, LAZ FLS, FWS (Faro) PTX (Leica) PLY, OBJ, STL, VTK (mesh) OFF Ortho/.tif (GeoTIFF) SHP	ASDI BSF E57, LAS, LAZ **DGN, DXF, DWG, FBX** KMZ LANDXML OBJ PTX PDMS POG RWV

Data filtering

In the process of ground-based laser scanning, the measurements provide data describing the surface of the captured objects as a set of points in space, but they also contain measurements of other objects that are not in the interest of the captured or additional data generated by "noise" in the environment. The availability of such additional and unnecessary data requires selecting the necessary parts of the resulting cloud of points and removing unnecessary ones, in a way that allows and facilitates additional cloud processing to achieve the desired results of the scanning. Reaching such a clear point cloud can be done by so called classification and segmentation. Filtering the cloud itself according to different set criteria, allowing the removal of unnecessary data and improving the quality of the final products.

Part of the filtering is classification of data I different criteria like indoor and outdoor classification. Classification functions allow automatic recognition of terrain, buildings, vegetation, poles, and road signs as well as automatic drawing of corners, edges and fences. Of the different methods of filtering point clouds, the most successful results for the correct recognition of different objects in a cloud were obtained in the application of surface filtration and segmentation methods [5].

Comparison of point clouds

Many problems as deformations monitoring, change detection, calculation of trenches and embankments are solved by comparison of point clouds. Different software packages give different instruments for that.

The CloudCompare software has features to perform cloud-to-cloud (C2C), cloud-to-model (C2M) and model-to-model comparisons (M2M), allowing the determination of spatial deviations, volume and deformations between individual objects or a uniform object over a period.

In addition to the features available in CloudCompare to compare clouds and models, RealWorks provides a wide range of tools for performing analysis and research on various sites, as well as determining earthworks:

•Determination of verticality and flatness of walls and floors.
•Deviations in the structure of tanks and pipes relative to factory parameters.
• Determination of deformations along the tunnels and ducts.
•Forming a diagram of specified deviations for documentation.
•Shaping deformation profiles for documentation.

Modelling

The process of creating digital models can be taken as the process of creating a digital mathematical image of an object in space, composed of multiple surfaces describing the geometry of the object Figure 1. The 3D model itself can be applied to achieve goals from a variety of fields, which include visualization of scanned objects, creation of digital terrain models (DTMs), creation of

3D models of architectural objects for restoration, performing control measurements to determine design deviations and deformations or documenting the condition of existing objects.

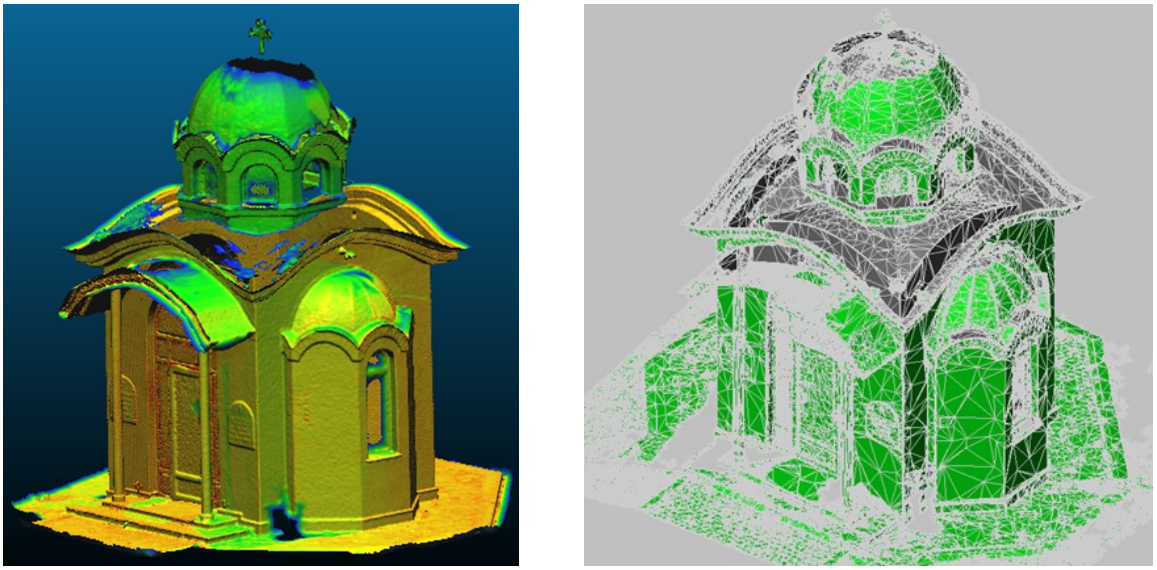

Fig. 1. Creating triangular irregular network (TIN) models from point cloud.

Additional functionalities

The calculation of volumes for embankment and excavation can be made between a scanned surface and a defined plane, or between two scanned surfaces.

Working with polylines

CloudCompare and RealWorks software products allow drawing and extracting polylines, contours and isolines from point clouds and saving them in DXF format for post-processing in CAD software.

Creation of sections and profiles

ReCap Pro allows the use of Limit Box for visual sections and the manual cropping of parts of the cloud to obtain sample profiles.

CloudCompare allows the extraction of one or several sections of a cloud of points, according to set parameters for size, spacing and direction, relative to the three coordinate axes.

Compared to previous software, RealWorks provides much more capabilities for creating sections and profiles. In addition to the mentioned methods, RealWorks has tools for the automatic creation of transverse and longitudinal profiles along a set polyline and parameters, allowing easy and quick exploration of linear objects such as tunnels and motorways.

Experimental Part

Description of the Object

The photographed object is the chapel "St. John Chrysostom" in Sofia, Lozenets district in Figure 2. The shape of the building is like an octagon, with the size of the side about 1 meter. The site covers an area of about 20 m2, with a height of about 8 meters and a structure consisting mainly of brick, metal and glass.

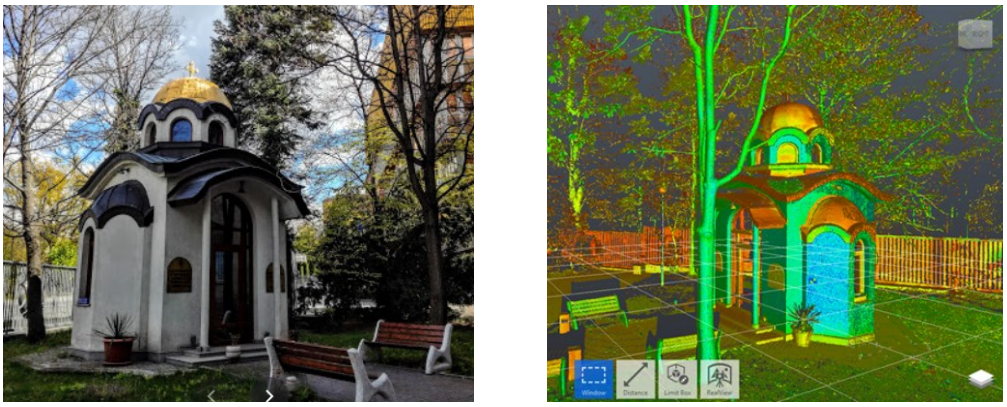

Fig. 2. Chapel "St. John Chrysostom" – original and scan view intensity coded.

Measurements

The measurements were made with the aim of presenting the terrestrial laser scanning technology and the possible processing of the resulting measurement data in the software products Autodesk ReCap Pro, CloudCompare and Trimble RealWorks.

After a preliminary inspection of the site, and during the actual laser scanning, the location of the individual stations around the site and their approximate acquisition range was determined. Additionally, marks located on and around the site were used to

ensure the quality of registration for the measurements (Figure 3). Due to the limitations caused by the location and shape of the site, existing vegetation and the environment itself, the full photographing of the dome part of the site was not carried out.

Fig. 3. Location of some of the used targets

The measurements were carried out with a ground-based laser scanner Trimble TX 6, with a scanning speed of 500,000 points per second and an accuracy of less than 2 mm. For the capture of the object, Grade 2 of the instrument was used, with a laser spot size of 11.3 mm for 30 meters, with a shooting time of 5 minutes and a cloud size of 138 million points. The object was scanned by 11 stations surrounding it completely, and to improve and ensure the accuracy of registration marks were located on and around the site – 6 black and white and 2 spherical (Figure 3).

As a result of the measurements, 11-point clouds were obtained, each about 138 million in size. points and occupying a memory of 3.48 GB, a total of about 1.3 billion points and 39 GB.

The measurements are preserved in the standard format used by Trimble tools – TZF, which are therefore reduced in size by filtration through 2 pixels and converted to the standard E57 format. Following this processing, the output point clouds are 35 million points in size and 826 MB of memory.

Workflow Comparison

The processing of point clouds was carried out in the three software products. As a result of the research, analysis and testing of real objects, a sample scheme of the workflow was drawn up in the three software products, which are shown in Figure 4.

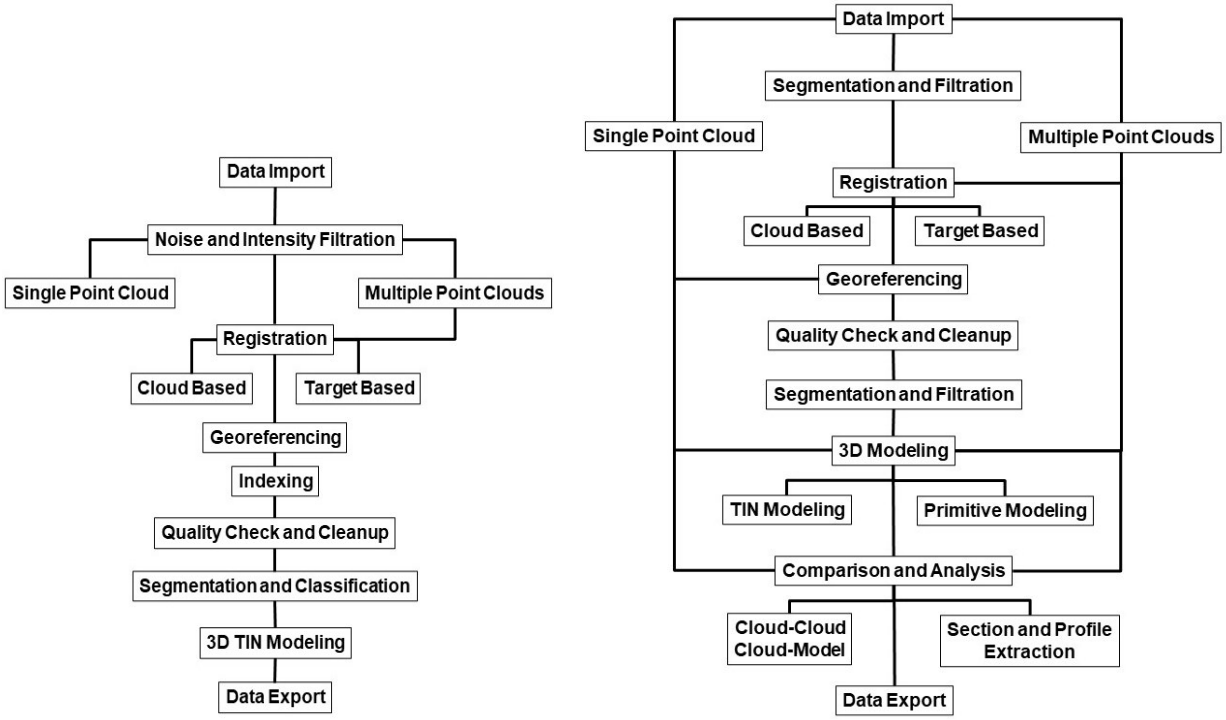

Fig. 4. Workflow in Autodesk ReCap Pro (left), in CloudCompare and Trimble RealWorks (right)

All three software products can make registration by clouds and targets. AutodeskRecap Pro outputs as a result a percentage of overlap between clouds and a percentage of points with a registration error below 6 mm. CloudCompare and Trimble RealWorks give the registration error in absolute terms Figure 5.

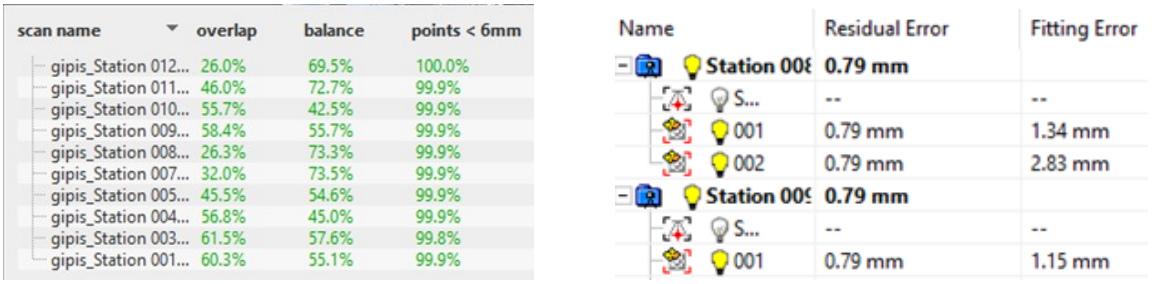

Fig. 5. Registration results from Autodesk Recap Pro (left) and Trimble RealWorks (right)

The results of the comparison of the basic functionalities in the software are presented in table 2.

Tab. 2. Comparison of the software products – Functions

Function	Autodesk ReCap Pro	Cloud Compare	Trimble RealWorks
Cloud-to-cloud registration	●	●	●
Target based registration	●	●	●
target recognition	●	●	●
Edit targets			●
Geo-reference	●	●	●
Filter "noise"	●	●	●
Classification of buildings			●
Classification of terrain			●
Classification of trees			●
Sample with details retention		●	●
Create a TIN model	●	●	●
Edit TIN Items			●
Improving tin model			●
Fill model gaps			●
Modeling of primitives		●	●
Modeling of pipes			●
Modeling stairs			●
Modeling of tanks			●
Modeling of beams			●
Modeling brands			●
Retrieving the DTM model		●	●

Function	Autodesk ReCap Pro	Cloud Compare	Trimble RealWorks
(Limit Box)	●	●	●
Sections	●	●	●
Multiple sections		●	●
Profiles			●
Cloud to cloud(C2C)		●	●
Cloud to model(C2M)		●	●
Model to model(M2M)		●	●
Working with polylines		●	●
Extract Contours		●	●
Extraction of conturs		●	●
Auto draw			●
Extraction of structural lines		●	●
Create animations		●	●
Обединяване на команди			●
Coordinates	●	●	●
Distances	●	●	●
Area	●	●	●
Volume		●	●
Corners	●	●	●

Conclusion

The registration methods used, between the compared software products, apply the same principle of solid-body transformation for the precise unification of point clouds. Of the approaches presented to registration, cloud to cloud and by brand, the highest accuracy is achieved in RealWorks, even when performing automatic registration. The shortcomings found in individual software mainly relate to the wrong recognition of black and white brands, which can be improved with the use of spherical, although the manual editing capabilities of brands in RealWorks and CloudCompare, allow the improvement of the quality of registration. A big disadvantage found in the process of merging clouds in ReCap Pro is the inability to determine the accuracy of the registration, but only its quality in cases where georeferencing is not carried out.

In the process of filtering data, all three software allow the removal of "noise", intensity filtering and performing manual segmentation for the clouds of points. In addition to these capabilities, RealWorks and CloudCompare provide features for remote sampling and with the preservation of details. Despite these common methods between software, the automatic classifiers for outdoor and indoor environments in RealWorks allow the highest level of functionality for the filtration of clouds from points, urban areas and enclosed spaces.

The available methods for the creation of a 3D model of point clouds in the studied software products are mainly based on the application of 2.5 TIN modeling, with a Delone condition, and the choice of a level of detail for the generated model is possible. Additional features of CloudCompare for data filtering, setting limits to the size of TIN elements model and model smoothing allow for greater modeling control over ReCap Pro. Compared to these features, RealWorks can automatically model pipes, tanks, ladders, steel beams and more, along with tools for creating and editing the individual elements of the model and its optimization, allowing full control over the structure and type of the final result.

All three software allow the creation of sections and simple profiles, but the capabilities of RealWorks and CloudCompare to automatically create multiple sections or profiles, according to set parameters, provide greater functionality in this regard.

A big disadvantage of the software product ReCap Pro, compared to RealWorks and CloudCompare, is the lack of functions for contour output, work with polylines and opportunities to make comparisons, cloud to cloud or model to cloud, which are available in the other two softwares, allowing the determination of object distortions and inconsistencies in project implementation. In addition, RealWorks provides specialized tools for carrying out tests related to the determination of discrepancies and deviations for buildings and engineering facilities, as well as the calculation of earthworks and their preparation for documentation.

Due to the shortcomings of ReCap Pro, the application of the software product is limited to the initial processing of aggregation and rough modeling of point clouds, which requires the provision of an additional platform if necessary to perform additional processing and analysis related to the structure of the studied object. The possibility for additional equipment are the software products of Autodesk - Civil 3D, Revit and other CAD softwareS with which ReCap Pro has full compatibility.

Despite the presented advantages by RealWorks, the software has the highest system requirements and license price, followed by ReCap Pro, which in terms of difficulty of use, provides the most intuitive workflow. Compared to them, CloudCompare has the advantage as free software and with relatively lower system requirements, making it more accessible than other software products on the market. Its biggest disadvantage is the lack of software support provided in case of technical problems.

Acknowledgments

The authorc express their gratitude to Research, Consultancy and Design Centre of UACEG on the financing of the project BN278/23, entitled “Terrestrial laser scanning of cultural heritage sites”.

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