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COMPARISON OF TRANSFORMATION 3D SCANS

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Purpose. The purpose of this study is to determine the reliability of the results obtained using a fully automatic method for orienting scans. The results are determined in two different common software tools and compared with the results of scanning scans by combining common points using special marks – 3D spheres. **Methodology**. A technique is proposed based on the creation of several scanning stations at a short distance and one at a relatively larger distance. One of the distant from the scanned stations will be determined by the basic. This station should cover all the reference points and objects, which will be used to register the scans, as well as most of the scanned object. The control of the obtained results will be carried out by modeling the surface of 3D spheres and their comparatively. **Results**. In 2015, during archaeological excavations at the corner of Krakow-Armenian streets, the task was to fix the boulders of historical buildings. These residues were a wall with a length of about 24 m. To ensure the completeness of the information, a terrestrial laser scanning was used as an optimal method for 3D surveying of long complex structures in the structure of objects. For a minimal effect of the orientation error of scans and a reduction in the preparatory work for scanning, the baseline scan method with a high overlap level was used and the results of the scanning orientation were investigated. **Originality**. The proposed technique for performing terrestrail laser scanning provides an iterative method of searching for the closest point. The way to monitor the results obtained is the most reliable from a practical point of view, because it is based on comparison of the location of point groups and 3D modeling. **Practical significance**. The use of the applied methods makes it possible to significantly shorten the time for conducting field work on laser scanning, to obtain data with minimal influence of the misleading registration of scans.

Key words: terrestrial laser scanning; methods for 3D scans registration; iterative closest point; scan registration error.

Introduction

In most cases, 3D scanning requires measurements from many stations. This ensures the completeness of the collected data for surface modeling. As a result, at the initial stage of treating 3D scans, there is a problem of the transformation of measurements from different scanning stations into a single coordinate system. This process is called registration [Dorozhynskyy, 2014]. The purpose of the registration is to find the mutual location and orientation of one scene of the scene on the other with the most accurate combination of areas of overlap [Tsapko, Omelyanyuk, 2014]. In the process of scanning orientation, there is an error registering cloud points in a single point model, which should be attributed to methodological errors [Seredovich, 2009]. Therefore, the process of registering scans is a very important stage of the scan, because it ensures the correctness of the source data from scanning for further processing.

To register scans can identify two groups of methods of registration of scans: field and cameral (Fig. 1). Field scan registration specifies that point clouds are oriented while the scanner is being scanned at the scanning station, and the cameral – after processing with specialized software. The main disadvantages and advantages of these registration methods are given in [Schultz, 2009] and [Ismail Abd El Hamid Mohamed el Khrachy, 2008].

Field scanning methods are available when using only certain scanner models, which include the possibility of centering the device, setting the initial direction. Cameral scans registration methods are more versatile, they can be used to orient scans from any 3D scaners.

Recent versions of 3D scanner software have started to support the the iterative closest point (ICP). When carrying out practical work using the iterative method of finding the nearest point, it was discovered that the use of different versions of the same software product gives different indexes for the registration of the same scans. Taking into account different settings and changing the number of iterations for scan orientation, we can conclude that the result of registrations are not reliable.

Objective

The method of controlling the results of scan registration by the method of iterative closest point remains relevant [Pechenin, 2015]. The purpose of this study is the practical determination of the reliability of the results obtained using a fully automatic method of orienting the scans. The results are determined in two commonly used software tools and compared with the scan registration results by the method of combining common points using special stamps – 3D spheres.

Method

To obtain good results registered by iterative closest point method, must be met two conditions:

– high level of overlap between scans (according to [Chow, Ebeling, Teskey, 2010] not less than 30%);

– high level of complexity of the scanning surface, which provides the search for characteristic contours [Autodesk knowledge network].

A methodology based on the establishment of several scanning stations at short distances and one at a relatively greater distance is proposed for realization of the set task. One of the distances from the station scanning object will be determined by the base. This station should cover all the reference points and objects that will be scanned, as well as most of the scanned object. The rest of the scans will be tied to this station, the results of which will produce a point model in the coordinate system of the basic scan. This will allow the registration of scans without accumulation of errors in determining the center of reference points and objects by two methods:

– a method of combining common points (objects) with defined common characteristic points and / or brands;

– iterative closest point.

Scanning from the base station should be made with parameters that ensure accurate recognition of all reference points and objects. The rest of the scanning stations should provide a detailed measured of the object. For this, the scanner is installed at a distance from the scanned surface, which can provide a small scan step with minimal time consuming.

To ensure high scan registration rates by combining common points (objects), from the station of the device on short-distance scans, at least three supporting spheres must be clearly visible [Björn, Quintero, Lerma, 2008]. The number of short-distance station depends on the length of the object. The use of flat brands will be complicated by the sharp drop in laser beam from adjacent scans – for these reasons, there will be additional error in determining the center of the mark. Therefore, it is optimal to use 3D spheres that have the same visibility from different viewing angles [Lei Fan, 2015], [Mengmi Zhang, 2015] (Fig. 2).

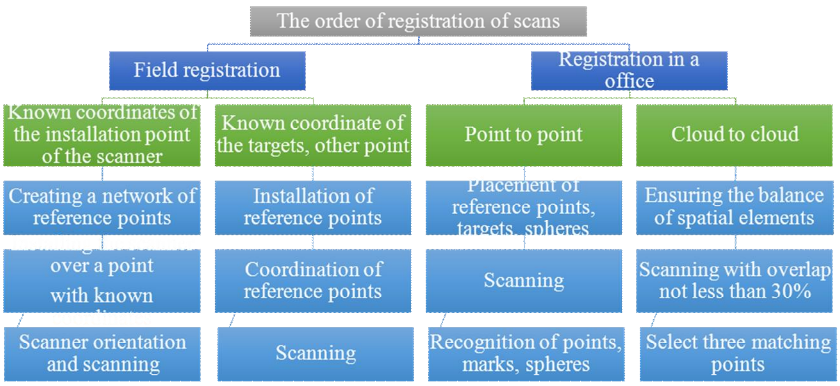


Fig. 1. Point model of 3D spher

Fig. 2. Point model of 3D spher

To determine the parameters of the transformation of scans, we need to find the points of the mark of the mark. At these points a model of a ball of the specified size is constructed. In this case, the minimum values of the function should be found [Franaszek, 2009], [Scene 6.2 User Manual, September 2016]:

$$E(x_c, y_c, z_c) = \arg\min \sum_{i=1}^{m} (R_i - r),$$

where x_c, y_c, z_c – coordinates of the center of the sphere; m – the total number of points on which the location of the sphere is determined; r – specified sphere radius; R – distance from the center of the sphere to the point [Van Genechten Björn, 2008].

So, the accuracy of scans registration depends on the accuracy of the recognition of the spheres themselves. The accuracy of spheres recognition depends on the number and quality of the markings on the surface of the mark. Accordingly, precisely from the scan mode (resolution and measurement accuracy), the accuracy of scan registration.

The advantage of the automatic mode of scanning registration is the iterative method of finding the closest point to save time in field and office conditions. This is achieved due to the fact that registration of scans occurs without the participation of supporting elements (marks, sphers), but with a high level of overlapping scans and diverse geometry of objects scanned.

Result

When scanning the remnants of historical development at the corner of the streets of Krakow-Armenian in Lviv (Fig. 3), was created one base (scan number 22), 6 auxiliary scan stations (scans no. 24, 26, 28, 30, 32) (rice .4). At the same time, a wall was scanned from 7 stations with a length of 24.2 m and a height of 1.5 to 3 meters [Malitskyy, 2016].

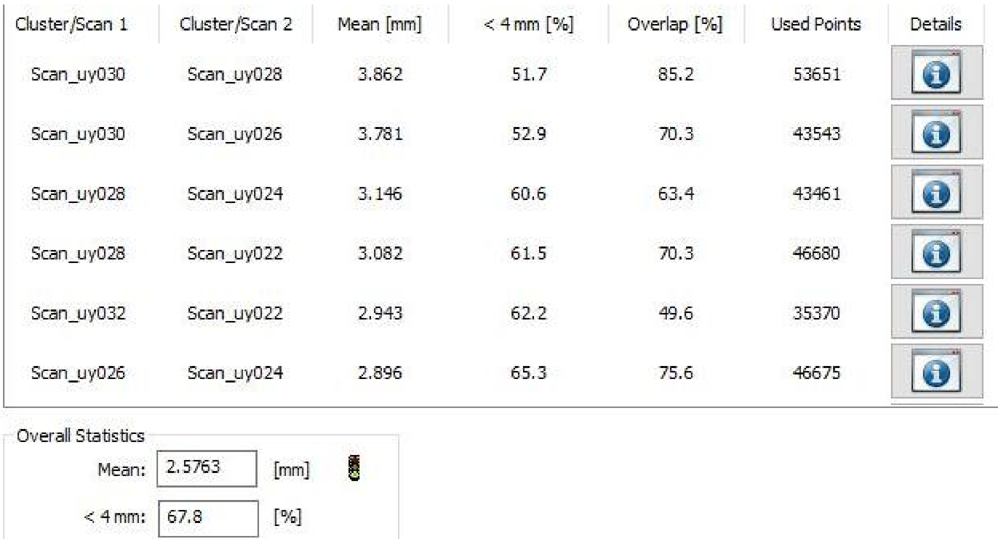
Fig. 3. Facility of work

Fig. 4. Scheme of terrestrial laser scanning

Table 1

The scanning settings of historic buildings

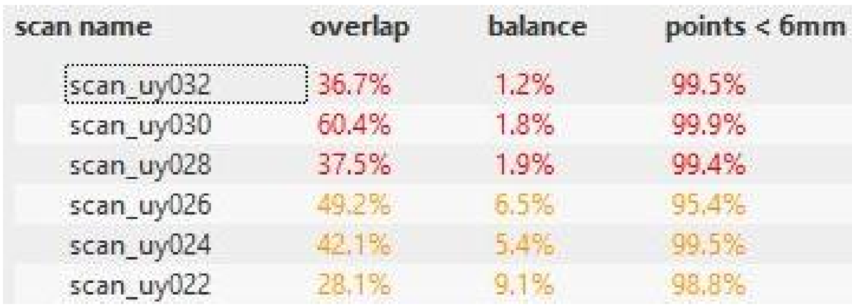
Scan #	Scan step, mm / 10m	Distance from the wall, m	The step of scanning on the wall, mm	Quality parameter	Scan speed, point / sec	Number of control elements
022	6,14	5,7	3,50	4x	122000	6
024	7,67	5	3,84	4x	122000	6
026	7,67	3,6	2,76	4x	122000	5
028	7,67	4,2	3,22	4x	122000	5
030	7,67	3,4	2,61	4x	122000	4
032	6,14	–	–	4x	122000	3



Cluster/Scan 1	Cluster/Scan 2	Mean [mm]	< 4 mm [%]	Overlap [%]	Used Points	Details
Scan_uy030	Scan_uy028	3.862	51.7	85.2	53651	
Scan_uy030	Scan_uy026	3.781	52.9	70.3	43543	
Scan_uy028	Scan_uy024	3.146	60.6	63.4	43461	
Scan_uy028	Scan_uy022	3.082	61.5	70.3	46680	
Scan_uy032	Scan_uy022	2.943	62.2	49.6	35370	
Scan_uy026	Scan_uy024	2.896	65.3	75.6	46675	

Overall Statistics
Mean: 2.5763 [mm]
< 4 mm: 67.8 [%]

Fig. 5. Result of iterative closest point method scans registration (Faro Scene)



scan name	overlap	balance	points < 6mm
scan_uy032	36.7%	1.2%	99.5%
scan_uy030	60.4%	1.8%	99.9%
scan_uy028	37.5%	1.9%	99.4%
scan_uy026	49.2%	6.5%	95.4%
scan_uy024	42.1%	5.4%	99.5%
scan_uy022	28.1%	9.1%	98.8%

Fig. 6. Result of iterative closest point method scans registration (Autodesk Recap)

The step of scanning auxiliary scans is 7.67 mm at a distance of 10 m, and the base – 6.14 mm (Table 1). Given the distance to the remnants of the wall, the minimum step of scanning the wall is 2.6 mm on the scan number 30, and the largest – 3.8 mm on the scan number 24.

These scanning options provide:

– detection and fixing on the base scan of the six supporting elements that will be used to register the scans by combining the reference points (objects);

– high level of overlapping of the basic scan with auxiliary scans;

– reproduction of all the characteristic elements of the surface of the wall, which will be used as reference points on short-distance scans when registering scans by an iterative method for finding the closest point.

According to the methodology used, the basic scan number 22 covered almost the entire scan area. This means that the adjacent scans have a certain overlap between each other, which allows you to use an iterative method to find the nearest point. It should be noted that for registration scan number 32 used 7 reference mark, and scan number 32 does not contain data scanning of the studied part of the remnants of development. In this case, the base scan has a low degree of overlap with scanner 32, and the 7th mark is undefined on it.

The use of the iterative method in Faro Scene 6.2.4.30 software was preceded by a scan listing based on the top view based registration, and then by the search for the nearest point (cloud to cloud registration).

Scan registration results are shown in Fig. 5.

Despite the low balance of indicators, the visual inspection of the scan results did not reveal any obvious registration errors.

To evaluate the results of registration, the fields built on the base scan number 22 will be considered as supporting. Models of spheres built on the remaining scans will transform the coordinate system of these scans into the coordinate system of the base scan. To determine mistakes in orientation of scans, or rather, deviations from the basic scan, the following methodology is used, in the following sequence:

1. After orienting the scans, the points of adjacent scans, when correctly guided, must form the surface of the sphere with slight deviations within the accuracy of the scanner. On the received cloud of points the areas, which belong to the surface of spheres are allocated. On these points, models of spheres are constructed. In this case, the radius of the sphere is not set. As a result of building spheres, the size of the marks and the position of their centers in two software tools is determined (Table 2, 3).

When constructing spherical models, the selection of points was done manually. The quality of the sample is indicated by an external deviation – the maximum deviation of the point from the built sphere. Indicator of the internal slope mainly points to the noise in the scan points, so it is usually much smaller than the external slope. The quality of cross-linking scans is indicated by the average deviation. This indicator reflects the typical offset (without direct dependence) among scan points relative to the brand's built model. According to the results, the average slope is placed within the limits of the accuracy of the laser scanner used to measure – the phase-based terrestrial scanner Faro Focus 3D 120. This determines the correctness of the orientation of scans.

Table 2

The centers of reference marks, icp registration method (Faro Scene)

#	Coordinates of the Sphere Center			Number of point	R sphers, m	Inside error, mm	Outside error, mm	Average error, mm
	X, m	Y, m	Z, m					
1	-1.261	-7.103	-2.277	1716	0.144	-7.2	4.0	0.9
2	1.500	-5.586	-0.904	1943	0.142	-5.6	25.9	2.0
3	-7.396	-9.419	-0.780	2493	0.146	-4.0	7.0	1.1
4	-10.182	-9.510	-1.842	4045	0.145	-4.2	8.2	0.9
5	-3.911	-7.897	-0.813	2188	0.145	-4.9	13.4	0.9
6	-4.255	-6.468	-2.670	2972	0.145	-3.6	4.8	0.9
7	-12.713	-11.662	-2.061	5049	0.146	-5.5	8.9	1.6

Table 3

The centers of reference marks, icp registration method (Autodesk ReCap)

#	Coordinates of the Sphere Center			Numb er of point	R sphers, m	Inside error, mm	Outside error, mm	Average error, mm X, m
	X, m	Y, m	Z, m					
1	-1.260	-7.104	-2.278	1750	0.144	-6.5	22.6	2.6
2	1.501	-5.587	-0.904	1918	0.144	-6.6	6.0	1.0
3	-7.397	-9.419	-0.784	2493	0.145	-6.4	6.7	1.2
4	-10.183	-9.510	-1.846	4051	0.145	-7.2	9.7	1.4
5	-3.912	-7.897	-0.816	2216	0.146	-7.6	16.0	1.7
6	-4.254	-6.470	-2.674	3047	0.147	-7.3	8.0	1.8
7	-12.714	-11.662	-2.064	5014	0.145	-7.3	5.5	1.6

Table 4

Coordinates of the centers of spheres

№	22 base scan				24 scan				26 scan			
	X	Y	Z	n point	X	Y	Z	n point	X	Y	Z	n point
1	**-1.261**	**-7.102**	**-2.277**	376	***-1.261***	***-7.102***	***-2.276***	***753***	-1.261	-7.102	-2.275	178
2	***1.501***	***-5.586***	***-0.904***	***691***	1.501	-5.586	-0.904	550	1.501	-5.586	-0.902	460
3	**-7.395**	**-9.417**	**-0.780**	148	-7.395	-9.417	-0.780	334	-7.395	-9.417	-0.779	33
4	**-10.182**	**-9.508**	**-1.842**	105	-10.182	-9.508	-1.843	257	-	-	-	
5	**-3.911**	**-7.896**	**-0.813**	291	***-3.911***	***-7.896***	***-0.813***	***717***	-3.912	-7.896	-0.816	71
6	**-4.255**	**-6.466**	**-2.670**	359	***-4.255***	***-6.467***	***-2.669***	***1253***	-4.255	-6.467	-2.669	104
7	–	–	–		–	–	–		–	–	–	

№	28 scan				30 scan				32 scan			
	X	Y	Z	n point	X	Y	Z	n point	X	Y	Z	n point
1	-1.262	-7.102	-2.277	347	–	–	–		–	–	–	
2	–	–	–		–	–	–		–	–	–	
3	***-7.395***	***-9.417***	***-0.780***	***822***	-7.396	-9.417	-0.781	469	-7.396	-9.418	-0.780	705
4	-10.182	-9.508	-1.843	1038	***-10.182***	***-9.508***	***-1.843***	***1553***	-10.183	-9.507	-1.844	1060
5	-3.911	-7.896	-0.813	584	-3.911	-7.896	-0.813	219	-3.911	-7.896	-0.813	304
6	-4.255	-6.467	-2.669	955	-4.255	-6.467	-2.670	175	–	–	–	
7	-12.717	-11.659	-2.062	388	-12.716	-11.659	-2.061	1615	***-12.712***	***-11.658***	***-2.062***	3134

The selection of points influenced the construction of the sphere model. However, due to the uniformity of spotting in two cases, the fluctuation in the size of the respective spheres when registering scans with the software Faro Scene and Autodesk ReCap fluctuates within 2mm. The maximum deviation in the position of the center of the spheres is observed in the coordinate Z and reaches 4mm.

2. To determine the starting position of the spheres, the scans were recorded by combining the common points with the Faro Scene 6.2.4.30 program tool. In this case, the diameter of all spheres indicated the same and equal to 0.14m. Given that the centers of the spheres are used as reference points, the accuracy of registration of scans depends on the difference in the coordinates of the centers of the fields of adjacent scans. Table 4. the coordinates of the centers of the spheres of the basic scan and coordinates of the same spheres, which are defined at the maximum number of points on other scans, are selected. Differences in coordinates lie within 1mm.

According to the presented results, the greatest fluctuations in the results of registration of scans are observed in height (Table 5).

Table 5

The difference coordinates

# sphers	ΔX, mm	ΔY, mm	ΔZ, mm
1	-1.1	-0.8	-1.6
2	-0.2	-0.1	-2.4
3	-1.4	-1.0	-1.5
4	-0.9	-0.9	-1.4
5	-1.4	-0.9	-3.3
6	-0.6	-0.8	-0.9
7	-4.7	-1.0	-1.0

Table 6

Mean squared error

# sphers	M_{Recap} mm	M_{Scene}, mm
1	2.5	0.2
2	0.6	0.9
3	4.6	2.0
4	4.5	2.5
5	3.4	1.0
6	5.1	2.0
7	4.4	3.9

When comparing the centers of the spheres obtained by the results of the iterative search of the nearest point and the combination of common points, the slightest deviations are observed when scanning the orientation of the Faro Scene software (Table 6).

Scientific novelty and practical significance

The peculiarities of conducting field works from ground laser scanning are proposed and tested in order to ensure the orientation of scans by the automatic method of iterative search of the nearest point. Using a basic scan with the specified coordinates of the reference marks on it allows to reduce the error of orientation of scans.

After analyzing scans using various methods using different software, the analysis of the results was carried out.

The prospect of further research is to independently determine the position of spheres' centers through the use of special sphers and total station

Conclusions

When analyzing the quality of iterative closest point scans registration, to be oriented to the indexes of registration is impossible, since these indicators are not reliable. They may vary significantly depending on the software used, the number of scans to process, and so on.

In order to evaluate the scan results, a comparison of scan registration results with the method of an iterative search of the nearest point with the method of combining common points was performed. It is found that the average square error of the deviation of coordinates using the base scan, according to the proposed fieldwork, is 2.5 mm in the Faro Scene and 4.6 mm in Autodesk ReCap. The last scan was recorded with insufficient floor level and one of the marks was not defined on the base scan. This led to the largest fluctuations in the coordinates of the center of the spheres defined under different conditions for 3D scanning.

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ПОРІВНЯННЯ РЕЗУЛЬТАТІВ ТРАНСФОРМАЦІЇ 3D СКАНІВ

Мета. Метою цього дослідження є практичне визначення достовірності одержаних результатів з використанням повністю автоматичного методу орієнтування сканів. Одержані результати визначаються в двох різних програмних засобах. Одержані результати порівнюються з результатами орієнтування сканів методом суміщення спільних точок з використанням спеціальних марок – 3D-сфер. **Методика**. Запропоновано методику, яка ґрунтується на створенні декількох станцій сканування на короткій відстані та однієї на відносно більшій відстані. Одна з дальних від об’єкта сканування станцій визначатиметься базисною. Ця станція має охопити усі опорні точки та об’єкти, по яких проводитиметься реєстрація сканів, а також більшу частину сканованого об’єкта. Контроль одержаних результатів проводитиметься шляхом моделювання поверхні 3D-сфер та їхнім порівнянням. **Результати.** У 2015 році під час археологічних розкопок на розі вулиць Краківська–Вірменська постала задача зафіксувати залишки історичної забудови. Ці залишки становили стіну протяжністю приблизно 24 м. Для забезпечення повноти відомостей використано наземне лазерне сканування, як оптимальний метод 3D-знімання протяжних складних у будові об’єктів. Для мінімального впливу помилки орієнтування сканів та зменшення підготовчих робіт зі сканування використано методику базисного скану з високим рівнем перекриття та досліджено результати орієнтування сканів. **Наукова новизна**. Запропонована методика проведення наземного лазерного сканування забезпечує виконання ітеративного методу пошуку найближчої точки. Спосіб контролю одержаних результатів є найдостовірнішим з практичного погляду, адже ґрунтується на порівнянні розміщення груп точок та 3D-моделювання. **Практична значущість**. Використання застосованих методів дає змогу значно скоротити час на проведення польових робіт з наземного лазерного сканування, одержати дані з мінімальним впливом помилки реєстрації сканів.

Ключові слова: наземне лазерне сканування; методи реєстрації 3D-сканів; ітеративний метод пошуку найближчої точки; помилка реєстрації сканів.

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