GEODETIC METHODS FOR EFFICIENT SPATIAL DATA COLLECTION

GEODETICKÉ METÓDY PRE EFEKTÍVNY ZBER PRIESTOROVÝCH ÚDAJOV

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Abstract

The need to collect space geodetic data substantially increases. The cause lies in requirements of practice, but the scientific progress enabling detailed description of the position and shape of objects not only in 2D but also in 3D imaging was very stimulating. Geodetic surveying systems, such as laser 3D scanners, photogrammetry or GNSS systems offer very good results, nevertheless their actual contribution depends not only on the accuracy of the instrument itself, but also on the quality of operating personnel. Appropriate exploitation of geodetic methods and instruments depends on geodesist's knowledge – on his professionalism. Nowadays, we may observe that geodetic methods and instruments are used by lay personnel with the result that gained data are very often inaccurate and resulting conclusions are wrong. This paper aims therefore to inform shortly the professional community not directly specialized in space data collection and 3D modelling with technologies and methods serving this purpose.

Abstrakt

Potreba zberu priestorových dát zaznamenala v posledných rokoch dynamický nárast. Je to spôsobené požiadavkami praxe ale aj vedných disciplín na detailné zachytenie polohy a tvaru objektov nielen v 2D ale aj v 3D. Geodetické meračské systémy ako sú 3D laserové skenery, fotogrametria či GNSS systémy ponúkajú veľmi dobre výsledky avšak ich relevantnosť záleží nielen od presnosti prístroja, ale aj od kvality personálu, ktorí s nimi pracuje. Správne využívanie geodetických metód a prístrojov je podmienené znalosťami geodeta – špecialistu. Súčasná doba prináša fenomén využívania geodetických prístrojov a metód neodborníkmi čo spôsobuje, že získané dáta sú často nepresné a vyvodené závery nesprávne. Cieľom tohto príspevku je preto stručne oboznámiť odbornú verejnosť, ktorá sa profesionálne nevenuje zberu priestorových dát a 3D modelovaniu s technológiami a metódami k tomu určenými.

Keywords

surveying, 3D laser scanning, digital photogrammetry, GNSS, 3D data, modelling

Kľúčové slová

topografické mapovanie, snímanie, digitálna fotogrametria, GNSS, 3D-údaje, modelovanie

1 Introduction

Geodetic measurements belong to the most precise, but simultaneously to the most laborious procedures of space data gaining. Nowadays, very different requirements are posed for documenting and incorporating natural, but also anthropogenic objects into maps, and planimetric featuring sufficient till recently is no more acceptable now. Implementation of the third dimension – height – is substantially complicated than planimetric projection, because the nature terrain is very complicated as to its surface. We are facing this problem mainly in the modern engineering geodesy, e.g. building of transport communications, surprising interest in 3D documenting of nature artefacts arouse from archaeology, and the need of third coordinate appears also in documenting of nature phenomena and their 3D modelling for needs of geosciences. Definitely, this wide spectrum of applications of geodetic apparatuses and methods poses problems with wrong 3D objects localization, as well as problems in creation 3D models of geo-objects. Usually the cause is the unprofessional use of surveying technology, resp. of the modelling method. Therefore the challenge is whether such activities, like for example localization of phenomena by GNSS, or space bodies modelling and their volume calculations may be done by people without appropriate professional knowledge and skills.

2 Data collection methods

Space data on geo-objects can be gained from different sources and by different methods. Decisive step that we should carefully weight, the choice of technology aimed to receive three-spaced data is. Except economic aspects, we should take into account the efficiency of the method (instrument), as well as its accuracy.

According to the procedure of data collection, we may classify geodetic methods as follows:

a) Direct methods,

- *contact methods (levelling, tachymetry, GNSS),*
- *no-contact methods (laser scanning, radar, photogrammetry, remote sensing),*

b) Indirect methods (e.g. digitalization).

The difference between the two methods is: direct methods at geodetic measurements give primary data and indirect methods process already existing data, such as old maps, diaries of documentation, geodetic field books, and so on (these data may, but need not be digital) (www.1).

2.1 Direct methods of data collection

Measurement of height and inclination

Geodetic levelling from the centre (Fig. 1) is the proved method, allowing determining object heights (Z coordinate of the point) with high accuracy, but the problematic point of levelling is the determination of the position of the observed object (X, Y coordinate of the point). This problem is usually solved by using other geodetic method (tachymetry, GNSS). Levelling is mainly used for monitoring of changes in the position of objects in direction of the axis Z – elevation, resp. decline of the point. In practice it is commonly used for monitoring of active landslides, monitoring of the stability of various technical objects such as buildings, bridges, artificial dams, but also for monitoring of mine activities impact on the surface, etc. (Cebacauer et al., 1998).

The very precise levelling can reach mean error till ± 0.3 mm, what means that we are able to determine even slight decline or elevation of the point caused by natural or anthropogenic processes. Measurements of object banking can be done by optical apparatuses, theodolites, even online – in real time using special apparatus – till sensor (Fig. 2).It can be connected to central monitoring computer (monitoring system) which evaluates these movements continually. This way, for example dangerous active shifts or important technical objects (dams, buildings) are monitored in real time.

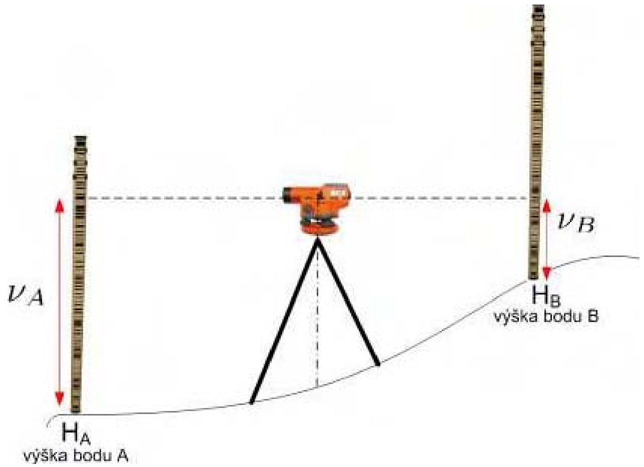

Fig. 1. Principle of levelling.

Fig. 2. Till sensor.

Fig. 3. Universal measuring station.

Tachymetry

Using tachymetry one can determine the height and position of the point (X, Y, and Z point coordinates) in the defined coordinate system. Principle lies in measurements of oblique length, horizontal and height (zenith) angle simultaneously by one instrument – universal measuring station (UMS – Fig. 3). The point which coordinate we want to determine is usually signalled in the terrain by a lining rod with reflecting prism. Modern laser instruments enable also measurement without prism and this way we are able to bear also inaccessible point – objects, and so determine their coordinates. This is great contribution of this technology, because it makes possible the realization till now technically impossible measurements (e.g. morphology of inaccessible rock massive, documentation of caves, etc.). USM station is basically an electronic tachymeter that measures directions using laser telemeter and angles by using electronic system on encoded circles. On the basis of these data, instrument will then calculate coordinates of the measured point (Cebacauer et al., 1998). Tachymetric accuracy at UMS use is sufficient also for needs of precise various geo-objects documentation (bearing of quarries, alignment of geophysical profiles or other geologic screening works in terrain, etc.). Grant to instruments with laser telemeter, the accuracy of length measurements onto prism by very precise instruments is app ±1 mm with ability to work till 3 500m! Measurements without prism are realizable with accuracy ± 2 mm with reach ability till 1000m (www.2).

GNSS

The use of GNSS method is nowadays increasing, mainly for space data collection (Fig. 4 and 5). The most spread GNSS system is NAVSTAR GPS operating in USA. The other, active system Russian GLONASS is which however does not have fully functioning satellite configuration. Substantial improvement of GNSS technology services, as well as the increase of its accuracy for civic purposes should bring the European system GALILEO. Its implementation is delayed because of technical and financial problems. Active operation of GALILEO system might start probably in 2015.

To determine object coordinates using GNSS several methods are used, they may be divided as methods static and kinematic. For special works with the highest required accuracy (regional geodynamics, observation of shifts and transformations), the static method needing a continual observation of several GNSS sets during several hours or days is used. This method, at use of post-process data treatment, reaches the accuracy approximately to ± 1 mm. Kinematic measurement method in real time (RTK) has at favourable ionosphere state and good satellite constellation the position accuracy approximately ±cm and height accuracy ± 4 cm. For GNSS measurements holds that horizontal coordinates (X, Y coordinates) are always determined with higher accuracy than vertical coordinate (Z coordinate). The accuracy of Z coordinate is influenced mainly by the number and constellation of satellites (Hefty, Husár, 2003; Pukanská, Weis, 2007).

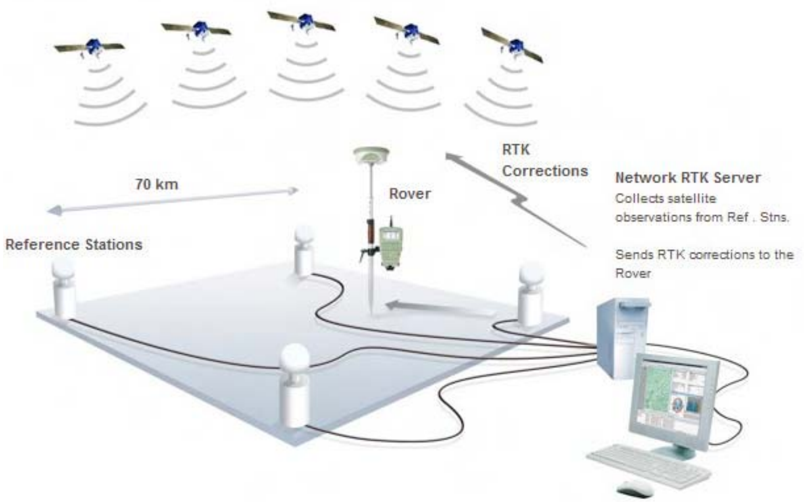

Fig. 4. GNSS principle.

Fig. 5. GNSS instrument (www.3).

Fig. 6. Terrestrial laser scanner (www.4).

Laser scanning systems

Nowadays there is a wide spectrum of laser scanning systems. They differ in their physical principles, technical parameters, purpose and fitting. Scanner systems may be fitted at satellites, planes (LIDAR, or on the Earth (terrestrial laser scanners – TLS). TLS systems (Fig. 6) offers at the present the most progressive and the most effective way of collecting a great amount of space data with the aim to create the digital 3D model of the terrain, objects or closed spaces. Measurement method is based on UMS principles, which mean that for the determination of the space point position (X, Y, Z coordinates) the polar method with a trigonometric height determination is used (Cebacauer at al., 1998). Maximal measurement speed is till 50 000 point per second. Reach ability of TLS system is till 300 m at 90% reflectivity of the object surface. Accuracy of the modelled surface is, after noise elimination, ± 2 mm (www.4).

The use of laser scanning systems for mapping different surface, but also underground objects received in last years great expansion. It is mainly because this technology enables detailed mapping of relatively large objects (inaccessible rocks, surface quarry, tunnels, mine work, building, etc.) in relatively short time (Pukanská et al., 2008).

Photogrammetry

Photogrammetry is old method that now has found large utilization grant for development of digital photography and digital picture processing. Advantage of photogrammetric methods is the use of common cameras. According to the number and picture configuration we define:

- *one-picture photogrammetry,*
- *multi-picture photogrammetry.*

Three-dimensional values we receive using multi-picture photogrammetry. When we use stereoscopic pictures, we speak about stereo-photogrammetry, when axes of shot are convergent; we deal with cross sectional photogrammetry (Fig. 7). Cross sectional photogrammetry grant to digital photography has been recently extensively used for 3D modelling of space objects (Bitterer, 2005). Accuracy of the method depends on the distance of the object, Picture definition and camera calibration. The accuracy of coordinate determination at the distance 20-30 meters is equal to the accuracy gained by using geodetic methods, e.g. very precise USM. Resulting accuracy is till 0.1 pixels.

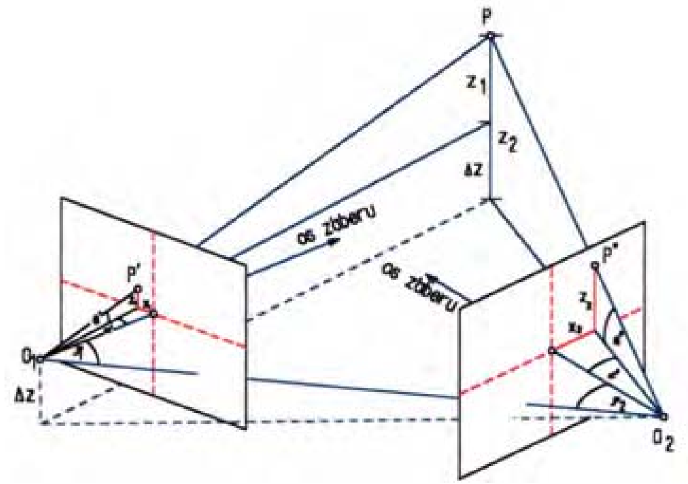

Fig. 7. Principle of cross sectional photogrammetry.

3 Example of the use of geodetic methods at space object bearing

Data collection, i.e. determination of coordinates, and resp. others attributes, is a demanding and responsible work, because errors that might occur during this period of the project solution are transferred into further phases of the project solving and will influence all results and conclusions. Therefore, the period of preparation for data collection (study of methods of data collection) and resulting choice of the method by which the data collection will be done. Correct choice of the data collection technology depends first of all at the specific task that should be solved. Decisive factors here are: how large the locality (object) going to be mapped is how the locality is accessible, which accuracy of data is required, but also how much time we have for data collection. The choice of the method should also ensue from good knowledge of properties and possibilities of specific technologies for data collection, of their strong and weak characteristics. And finally, we live in time when costs of every project are carefully evaluated, and the economic factor is in this case also one of main aspects of expedience of the chosen method.

Fig. 8. Stoneware stockyard in Sedlice quarry.

Fig. 9. Bearing by TLS.

Fig. 10. Bearing by UMS.

To document technical possibilities of selected geodetic methods we choose as a model example a stockyard of crushed stoneware in Sedlice quarry (Fig. 8). Surface of the stockyard is relatively irregular body sized 120 m (length) x 10 m (height). Its bearing is theoretically possible by every geodetic method (chapter 2). From technical and practical reasons following methods of its bearing were used:

- *GNSS,*
- *terrestrial laser scanning (Fig. 9),*
- *tachymetry by UMS (Fig. 10).*

Used methods can be mutually combined, what is very reasonable, because disadvantages of the one method are in the other method compensated by its pros. Other of mentioned methods, such as levelling or photogrammetry, would be not an ideal solution for bearing of such object. Levelling is unsuitable for bearing of such object, because the stockyard is loose and measurement would technically complicated, but we would also need additionally to determine also X and Y coordinates of each measured point, what would uselessly complicate the whole bearing. Appropriate bearing of the whole surface of object (height is app 10 m) by photogrammetric method the use of aerial photos would be needed, what is technically, but mainly economically demanding.

As was mentioned in previous chapters, the purpose of the realized research was to demonstrate technical possibilities of modern geodetic instruments, and prove possibilities of selected geodetic methods at space data collection with the aim to evaluate their suitability from different aspects. At measurements we evaluated:

- *measurement accuracy, given by the accuracy of the instrument used,*
- *speed of data collection and speed of data processing,*
- *economic aspect – global costs considering also the price of apparatus, ev. Of needed software equipment,*
- *efficiency of the method considering the area extent, that could be bearing by given method in the same time period of time.*

3.1 Collection and processing of data

Bearing the object – stoneware stockyard- was realized 12.3.2012 at ideal atmospheric conditions. The body of the stockyard was bearded by three mentioned methods using following instruments:

- *GNSS apparatus Leica GPS 900CS,*
- *Universal surveying station LeicaFlexLine TS 02,*
- *3D laser scanner Leica ScanStation C 10.*

Before the beginning of object measurement itself, a surveying net of detailed points was built, serving as instrument stations, or orientation. Points were stabilized in temporary modus and aligned by GNSS method and their coordinates were determined in the coordinate system S-JTSK and height system Bpv. The body of stockyard was gradually aligned by each of mentioned geodetic methods and gained results we subsequently processed software equipment Leica GEO Office, ev. in the program remarked as Trimble RealWorks. For the construction of the 3D model we aligned:

- *by GNSS method – 307 points,*
- *by tachymetry using UMS – 706 points,*
- *by method of terrestrial laser scanning – approx. 2 000 000 points.*

3.2 3D modelling and visualization

Models of different bodies are created using different special types of software (SW). Also here, choosing the type of the software we consider the extent of the order, the method of data collecting, but mainly the purpose of the model, and its further presentation. Basic and commonly used group includes CAD software (i.e. AutoCAD, MicroStation and others). Also the group of GIS software (i.e. ArcGIS with extension to visualization in 3D Arc-Scene) should be mentioned that has as to characteristics of GIS also other than visualizing tools. CAD (Computer Aided Design) or computer aided drawing and projecting is a large area of computer technology suitable for processing of space

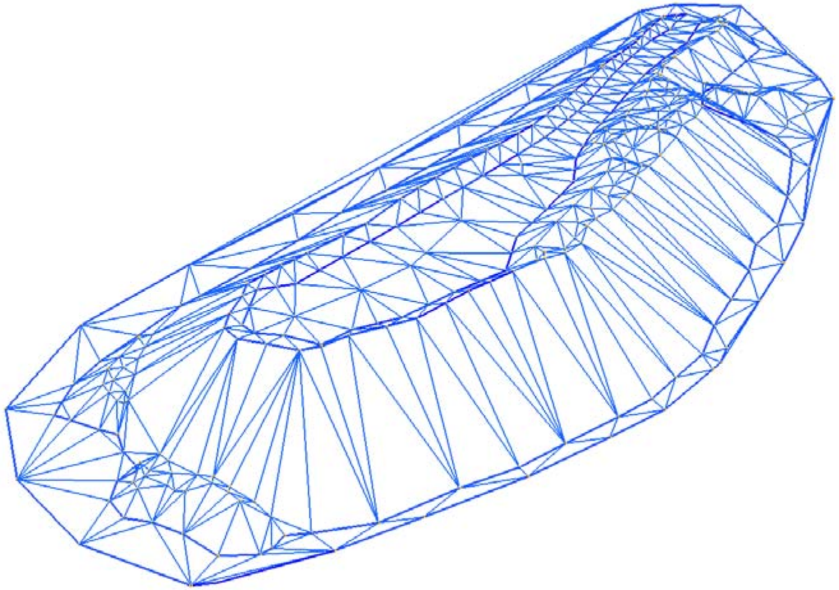

Fig. 11. 3D stockyard model in MicroStation.

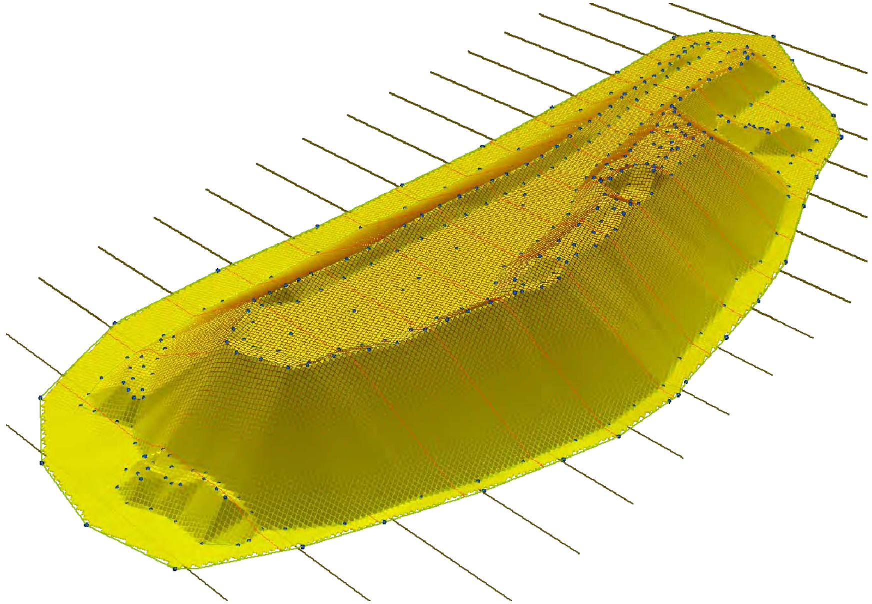

Fig. 12. 3D stockyard model visualized in ArcGIS.

data. This software operates in 2D, as well as in 3D dimension, and it is often specialized for one specific field (building industry, mechanical engineering, etc.).

Processing of geodetic measurement data is often done in 3D with resulting space models of objects, terrain, etc. In our case, results of terrain measurements were processed into the 3D model shape in the platform of CAD system MicroStation (Fig. 11) and visualized in GIS system ArcGIS (Fig. 12.). In this software except of model construction and visualization itself one can realize different over-operations (volume calculations, body sections, etc.) or add the databases and so present together with the object also its database information.

3.3 Evaluation of efficiency of methods used for data collection

Following calculations consider costs for task realization without other indirect costs – that is travel costs and wage of personnel etc.

GNSS

GNSS equipment can be basically classified in two groups: manual and geodetic. Manual equipment has compact dimensions and reaches usually lower accuracy than the geodetic one. The core use of manual GNSS instruments is data collecting for mapping in medium and small size and for the collection of GIS data; it means data where accuracy of point coordinates determination ± 0.5 till 30 m is sufficient. Classic geodetic equipments reach depending on the used method – static or kinematic, substantially better results. They are used for localization of objects, alignment of technical works, but also for 3D terrain models construction. Data collection by GNSS is relatively quick and relatively cheap way of 3D data collection.

The price of GNSS equipment, including processing software is about 10 000 Euro. Cost for one hour of operation of such equipment is estimated approximately on 5 Euro/hour. Our measurement lasted about 1 hour. Office processing of results is not demanding and lasts 3–5 hours, including 3D model construction in CAD system. In presented case we needed together 4 hours. When we price office works by average normative price 25 Euro/hour, then the total price for stockyard alignment and 3D model construction is approximately 105 Euro (Tab. 1).

Electronic tachymeter

By the use of universal surveying stations one can gain simultaneously very precise data on the position and height of determined points. Time demands of direct terrain measurements are usually higher than at GNSS. Using UMS, time of data collection consists of several parts:

- ***Point field construction*** (points of surveying net) – they differ in number of points that are necessary to be stabilized for object alignment and except of the shape and size of measured object, depend on complexity of the terrain, its vegetation, etc. The process of point field construction lasts approximately from one till several hours (depending on the number of needed points).
- ***Levelling and centring the instrument*** at stand point and orientation to known points. This process is influenced mainly by transfers of a helper and lasts usually minutes till decades of minutes.
- ***Alignment of detailed points.*** It depends on terrain configuration, number of measured points, generalization, number and experience of helpers. Measurement of one point lasts approximately 5 – 10 seconds, to them the time for transfer and horizontality of a reflective prism at following point must be added. Therefore we have to count decades of seconds per one point. In case of use the technology without prism, time is considerably shorter, and including aiming to the point lasts about 10 seconds.
- ***Measurement processing***. Modern UMS allow coordinate calculations directly in real time exploiting their incorporated calculation software – in that case, only transfer of coordinates to PC is realized. This process lasts only few minutes. Then the procedure of data processing in CAD software follows, which includes elaboration of the new CAD plan, tuning its parameters, import of coordinates, situation drawing on the basis of surveying sketch, 3D model construction using drawing tools of CAD. In the case of classic terrain model we use 3D modelling tools, like interpolation and surface generating. The result is model of the body, ev. area in 3D. The whole process lasts depending on the complexity of the body, ev. complexity of the terrain (given by the number of measured points) usually hours or decades of hours.

The price of efficient geodetic universal surveying station, including processing software is about 17 000 Euro. The price of one working hour of such equipment is estimated on about 9 Euro/hour. Measurement by UMS lasted approximately 2 hours. Office result processing is somewhat more demanding than processing of GNSS measurements, and lasts about 3-8 hours, including 3D object model construction in CAD system. Points gained from UMS should been corrected as to error data, and only then model construction may follow. The whole process lasted together 5 hours. Pricing office works by 25 Euro/hour, the total price for stockyard alignment in UMS and 3D model construction is about 143 Euro (Tab. 1).

Laser scanning systems

Laser scanning in one of most rapidly developing fields in last 5 years, and its utilization found wide application mainly in these geodetic tasks where detailed documenting of object surface or terrain surface is required. As to planimetric and height accuracy, results given by this method are sufficient enough for detailed documenting close bodies, where the error at short distances is about few mm. At distances of hundred of meters, the error is about few cm. Similarly as at UMS, using TLS time for data collection consists of:

- ***Point field construction.***
- ***Levelling and centring the apparatus.***
- ***Alignment of detailed points***. This process is considerably quicker than at UMS, because TLS realizes the process of alignment automatically. The whole process of alignment of the point cloud lasts only about few or decades of minutes, depending on the chosen density of point cloud.
- ***Measurement processing.*** The procedure of processing results of TLS measurement data is very demanding, and requires first of all good knowledge of the processing software. In this software a primary processing of data, their filtration and their export to output point set are realized. This process lasts till several hours. Then the procedure of data processing in professional CAD software able to process the point cloud consisting of million points ensues. This process again lasts several hours. The result is the realistic body model in 3D.

Tab 1. Evaluation of geodetic methods used for stoneware stockyard alignment as to costs for technologies, material and human sources.

Instrument	**Costs**		**Time requirements**		**Global expenses for stockyard alignment [Euro]**
	Measuring [Euro / hour]	**Office works [Euro / hour]**	**Terrain works [hour]**	**Office works [hour]**	
GNSS Leica GPS 900 CS	5	25	1	4	**105**
Tachymetry using UMS Leica FlexLine TS 02	9	25	2	5	**143**
Terrestrial laser scanning Leica ScanStation C 10	35	25	2	8	**270**

The whole procedure of TLS data processing lasts, depending on complexity of the body, few hours till decades of hours.

Laser scanner is one of the most expensive equipments, its price including the processing software is about 70 000 Euro. Its operating hour then is about 35 Euro/hour. Stockyard TLS alignment lasted about 2 hours. Further office works – result processing in professional software – consumed about 8 hours. The whole process lasted about 10 hours. The whole price of work for TLS stockyard alignment, including its model construction is then 270 Euro (Tab. 1).

Summarizing gained results supplemented by characteristics of two other mentioned methods – levelling and photogrammetry we reached a simple table, which expresses the efficiency of specific geodetic methods (Tab. 2). This efficiency was evaluated as to its accuracy, speed and price of each method considering the size of documented area. Results of analysis proved that the cheapest method, the method of GNSS is. Exactly GNSS method is nowadays the most used method for mass space data collection because of its relatively low costs and sufficient accuracy of gained space coordinates.

Tab. 2. Efficiency evaluation of specific geodetic methods.

Method	Accuracy	Speed	Price	Area size
Measurement of height and inclination	0.003 – 0.01 [m]	*	€€€€€	o
Tachymetry	0.002 – 0.05 [m]	**	€€€	oo
GNSS	0.01 – 0.1 [m]	***	€	O
Laser scanning systems	0.002 – 0.05 [m]	****	€€€€	oo
Photogrammetry	0.002 – 0.5 [m]	******	€ - €€€€	o – OO

Good results at object documenting also photogrammetry reaches, but it is unfortunately not suitable for object alignment by coordinates (alignment of borders, alignment of the position of surveyed work, etc.). Laser scanning is an ideal procedure for precise object shape documenting (building, rocks) and for monitoring of its transformations (deformations of bodies, erosion, etc.), but costs are very high and skills necessary for the works with scanner and processing software require an experienced expert. To classic methods, with the favourable ratio “price/performance”, digital tachymetry exploiting UMS belongs. The accuracy of this technology is considerably higher than GNSS, and its price is in the last years gradually decreasing. Modern robotized UMS are with their performance (granted to technology of length measurement without prism) approaching even to TLS, while their price comparing with TLS is considerably lower.

4 Conclusion

All presented methods have their unique advantages, but also outstanding disadvantages, and therefore one cannot label one of them as the best one. It is always necessary to consider several parameters that influence the decision on the choice of the method. Main criteria always are:

- *purpose for which resulting measurements will be used,*
- *accuracy and detail requirements of resulting model,*
- *time demands of measurements and results gaining,*
- *economic accessibility of technology,*
- *extent of documented area,*
- *own technical possibilities.*

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