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The Use of Surface Laser Scanning for Creation of a Three-Dimensional Digital Model of Monument

Irina Kuznetsova[a], Darya Kuznetsova[b,*], Xeniya Rakova[c]

[a]*Kazakh National Technical University after K.I. Satpaev, Satpaeva st.22, Almaty,480013 Republic of Kazakhstan*

[b,c]*St. Petersburg State Politechnical University, Politechnicheskaya st. 29, St. Petersburg, 195251, Russia*

Abstract

For architectural survey, the most important factor is to create a very believable drawing of the existing building, structure or monument (sculpture). In order to carry out such surveys, there can be used reflectorless tacheometers, phototheodolites, digital cameras and surface laser scanners. Nowadays, it is the most expeditious method of obtaining the detailed and reliable information concerning the particular object. With the help of laser scanning, it is possible to create the most accurate and detailed digital models of the whole environment in the shortest possible time. The information concerning the object in the form of a point cloud can be got in minutes. Thus, we have a unique opportunity for real-time monitoring of the processes, both natural and manmade character.

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Keywords: laser scanning; monument survey; scanner; digital model; three-dimensional model

1. Introduction

For architectural survey, the most important factor is to create a very believable drawing of the existing building, structure or monument (sculpture). In order to carry out such surveys, there can be used reflectorless tacheometers, phototheodolites, digital cameras and surface laser scanners [1].

* Corresponding author. Tel.: +7-963-322-35-22.
E-mail address: kuznetsova.darya@mail.ru

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The traditional survey methods do not allow achieving the required accuracy and efficiency, and they are not so effective, as nowadays, the majority of projects is performed in the three-dimensional environment.

A standard tacheometer with reflectorless range measuring system allows performing the survey of any building from some particular points (corners of the window frames, doors, double cusps of different parts of the building and so on). However, such tacheometer is useless, if the task involves the survey of rather difficult elements – such as the ruin of buildings, colonnades, jewelry, armorial elements and other parts of the building. Until recently, such elements could be drawn only with the help of rather expensive photogrammetric equipment, the cost of which sometimes can reach several hundred thousand dollars. At the same time, the result is highly dependent on the skills of a photogrammetrist [2].

Nowadays, surface laser scanning is the most effective method of obtaining the detailed and reliable information concerning the investigated object. With the help of laser scanning, it has become possible to create the most accurate and detailed 3D-models of any objects and the environment itself in the shortest time.

The automatic three-dimensional scanning process can be used in the manufacturing environments, as an alternative to the inspection and testing of various parts of machines and equipment, for example, a high-pressure valve or parts of the body. During the measurement, the scanner has been moved and positioned at the target points with the help of a robot [3,4].

3D-technology of laser scanning is successfully used for monitoring of the hillside, shoreline deformation. The scanning results allow modelling and predicting the areas, which are prone to landslides, and timely using protective actions [5,6,7].

Small objects, such as a 20-cent coin, a cup, a set of certain tools for drilling and other items can be used as scanning objects for the detection and reconstruction of 3D-surface and rating the surface defects with high accuracy (12-15 mkm). In some cases, a compact hand-held 3D-scanner can be used [8,9,10,11].

During the last period, there has been developed a great number of scanners of different purposes, parameters and accuracy. The speed of data acquisition and processing is becoming more important issue, which should be taken into account choosing the proper device for work implementation with the required accuracy [12]. First of all, the choice depends on the object size and its location, as well as the accuracy with which you have to perform the task. In order to use the devices in construction and architecture, the parameters of devices should be taken into account during the choice of laser scanner models, which allow scanning large areas with high accuracy. The received data can be used for the survey of the surface deformation of buildings and constructions, for the reconstruction and modernization of facades of regular and irregular forms [13].

The high resolution of the surface scanner images provides the detailed geometric information of the object state as well as other data, which could not be accurately obtained with the help of traditional geodesic activities. The method of 3D-laser scanning has become a very effective measure of traditional architecture and geodesy. The laser scanning technology has a great potential for the state assessment, in particular, for the damage assessment, and enables the research and quantitative estimate of the particular material damage using 3D LiDAR, including mass loss because of the collision of vehicles, reinforcement corrosion and surface erosion [14,15].

The technology essence, based on the use of surveying instruments - laser scanners, is to determine the exact spatial coordinates of the surface object points at high speed (several thousand measurements per second). Laser survey allows providing the higher density and accuracy of the laser points and, consequently, the higher level of the detailed survey, whereby it becomes possible to obtain a three-dimensional digital model of any object, whether it is a building, a monument, an industrial building with complex structural elements or an inaccessible underground structure [16,17,18].

The use of materials of the surface laser scanning in architecture and building constructions allows solving some problems concerning the measurement of building, constructions and monument parameters, as well as the creation and restoration of the asbuilt documents and engineering drawings. It makes it possible to carry out the design of monuments and architectural constructions, the restoration of facades, to create virtual models of the outward things in order to choose the best location for the monument or architectural construction, the review of the projected construction from the different points of view, taking into account the real data.

According to the results of such survey, it becomes possible to evaluate the condition of the observed object (vertical and horizontal deformation, rolling, cracks, etc.) [1].

2. Main part of the research

Regardless of the type of the laser scanner and the used software, the resulting data of the surface laser scanning and primary processing is the pixel array, in other words a “point cloud” with the known coordinates X, Y, Z [19,20].

The software plays an important role in the scanning process management, the data accumulation in computer, further processing and provision of the result of the whole work. As the measurement range is from a few tens of thousands to several hundred million points, the main load concerning the processing falls on the software. Cyclone is a widely used program for fast and efficient processing of the scan data.

The whole process of scanning can be divided into two parts. The first part is to perform the field survey, and the second one is to perform the office analysis. Speaking about the field survey, the surface laser scanning is most of all similar to the traditional phototheodolite survey, but a high degree of measurement automation and computerization of all the stages of work make the new method much more productive and efficient [21,22].

The object for scanning is the K.I.Satpayev monument in Almaty (Kazakhstan). Before starting the field survey, there have been carried out the reconnaissance operations, which have led to the choice of the scanner installation location for the measurements and the place for the mark installation (target), we should estimate the time required for the complete scope of work.

The location of marks can be chosen arbitrarily, and it is optional, all of them should have the known coordinates. In order to change the coordinates of the entire data array, it is sufficient to determine the coordinates of three targets in the necessary coordinate system. During the operation process, the scanner automatically recognizes these targets and determines the coordinates of their centers.

The places, from which there is the survey, have been chosen in such a way, that the surveyed subject can be seen from all the angles. At the same time, each station point, from which the survey is performed, should be removed in such a way, that the particular “images” have the overlapping (common details or parts of object details) [23]. .

The object scanning has been performed in two scanner and target stations. The targets have been set around the monument, so they fall into the area of overlapping of the neighbouring scans. After visual observation of the territory, it has been decided to place the scanner and the target in accordance with Figure 1.

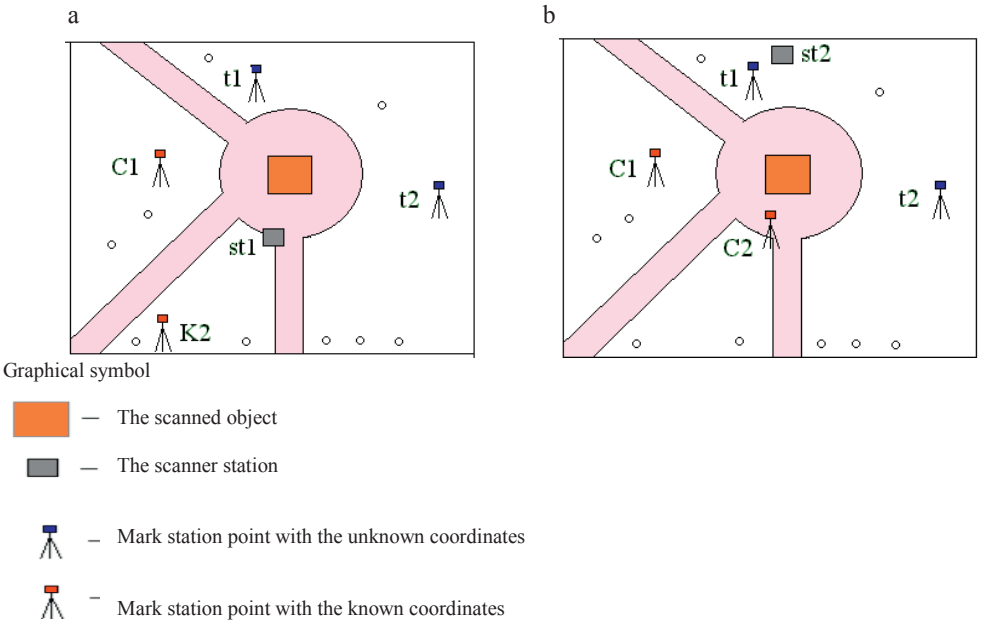

Fig. 1. Diagram of scanner and mark station points: (a) for the first position; (b) for the second position.

The coordinates of the targets have been determined with the help of GPS-receiver Leica GPS1200. GPS-receiver Leica GPS1200 operates on two frequencies, with the possibility of obtaining the millimeter accuracy. The coordinates of the points have been determined in the local coordinate system in RTK mode (Real Time Kinematics). GPS1200 can be used as a base and a mobile station in any of the operating modes from static to RTK [24].

After preparation and installation of the scanner and special targets on the selected places, we proceed directly to the object scanning. Before scanning, we should measure the instrument height. In order to do this, on the device body there is a special label.

All the processes of the device management are carried out with the help of a portable computer (laptop) and special program Cyclone.

Before scanning, there has been created a project using the command Configure - Databases, which then gets the name.

Then, it has been photographed with the help of the built-in camera, which allows "pointing" the device at the object and selecting the necessary scanning area. Making sure that the image quality is good, there has been carried out the repeated photography [25,26].

Figure 2 shows an image taken from the first scanner station point, and Figure 3 - from the second station point. The figures clearly show the "collected" spherical image of several images obtained during the process of photographing with the help of scanner Leica ScanStation.

The images show the monument from both sides.

Fig. 2. The image obtained during the process of object photographing from the first scanner station point.

In order to scan the object, there has been chosen the step between the survey points (the closer the points are, the more time it takes to make the scan), the distance to the scanned object.

During the scanning process, there has been controlled the process of obtaining the "point cloud" in the tab ModelSpace, in which there have been checked the "silent" zones. If such zones have appeared, there has been performed the additional scanning of the particular parts. After scanning, the scanner automatically recognizes the targets and specifies their location.

Finishing the work from the first station point, we have performed the scanning of the other part of the monument from the second point in the same sequence. In this case, one of the marks has been moved, as it has been invisible, and others have been within line of sight of new scanning task in order to ensure the continuity of point clouds.

Fig. 3. The image obtained during the process of object photographing from the second scanner station point.

There have been made two scanner stations. Figure 4 shows the “point cloud” obtained during the scanning process from the first scanner station point, and Figure 5 - from the second point.

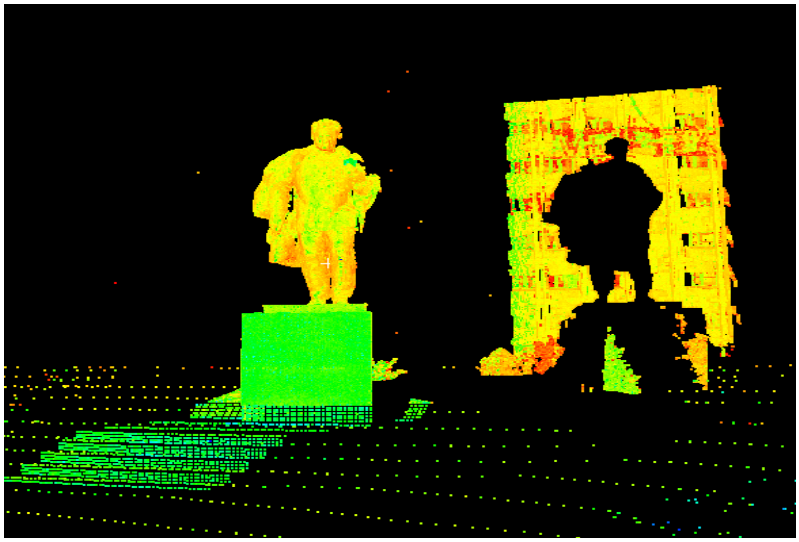

Fig. 4. “Point cloud” obtained during the scanning process from the first scanner station point.

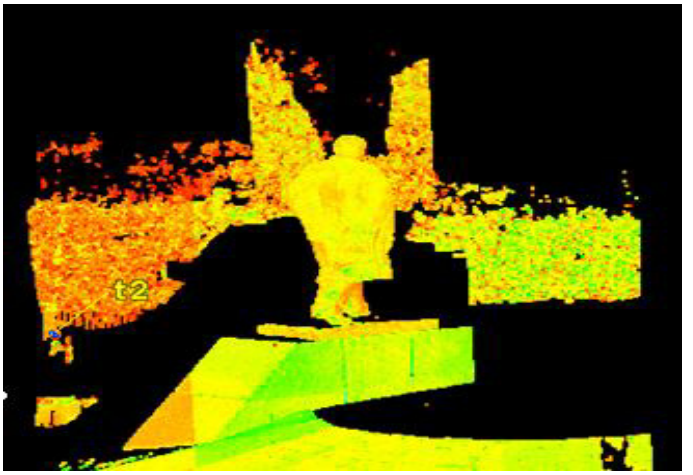

Fig. 5. “Point cloud” obtained during the scanning process from the second scanner station point.

Immediately after scanning of one object from different locations, it becomes possible to make all the points combined into a single space. We get the spatial cloud consisting of a number of points painted in a specific colour. The obtained point cloud can be divided into as many parts as you need, in order to build the sections, to save the position, from which this or that object is better seen.

Time spent on the field survey depends on the object location, the distance to it, the requirements for the measurement density and details. The office analysis of field survey has been also carried out with the help of Cyclone and has consisted of two main stages. The first one is the union of the separate scans into a single point cloud; the second one is to build a digital model of the monument.

In order to create a single cloud, it is necessary to combine both results of the scanning process, in order to do this, in the tab of registration, check both scans using the mouse - ScanWorld1 and ScanWorld2. First of all, there has been performed the trial registration (alignment) of the data by four points via the menu Registration- Registr.

As according to the technical characteristics, the accuracy of the position determination of each mark should not exceed 2 mm, but during the registration, the accuracy has been greater due to the fact that one of the marks has been shifted during the scanning process. Therefore, it is necessary to leave out one of the marks (R1) because of the large value of the error. It has been 28 mm. Then, there has been held the registration again. After the changes, the accuracy of the position determination of each mark does not exceed 2 mm. Figure 6 shows the image of two united scans.

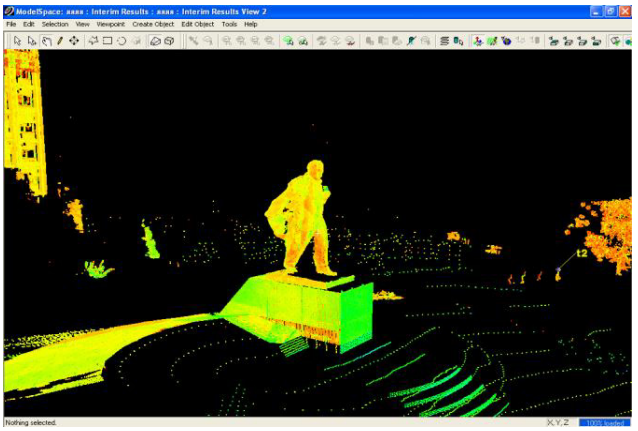

Fig. 6. Image of two united scans.

The visual observation of all the sites of conjugation of two scans has showed that the combination of scans has passed correctly, i.e. the image is clear; there are no “silent zones”. Consequently, the scheme of the scanner and the target location has been chosen correctly. If the combination has passed incorrectly (the scans have superimposed upon each other), the registration process should have to be repeated. In order to bind the scans to each other and to the coordinate system, there has been performed the identification of marks, the viewing of the checkpoint, given the mark names. Figure 7 shows how the identified mark looks like, in the center of which there are the coordinate axes. This operation should be done for all the points for the first scan as well as for the second scan.

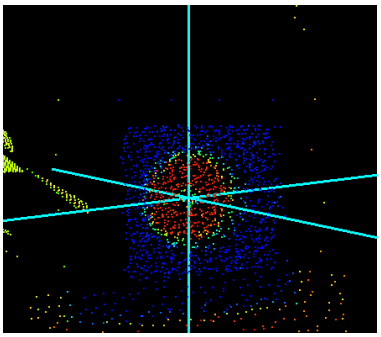

Fig. 7. Image of the identified mark.

As the coordinates of the points of the scanned object are defined in the conventional coordinate system of the scanner itself, it is necessary to bind them to the local coordinate system. In order to do this, there has been created the text file with the coordinates of the points, which have been defined in the local coordinate system, using GPS.

After project registration and binding to the local coordinate system, we proceed to the creation of a three-dimensional model of the object. Once the coordinates of the points have been imported into Cyclone, we perform the key stage of the work - we create a model of the monument. According to the stated tasks, the end result of work on scanning can be a point cloud (the spatial raster) or a full 3-D model of the object on the basis of which there are solved various engineering problems.

In order to create the three-dimensional model of the object, there should be opened the object model, consisting of the combined scans, then there should be cut out unnecessary parts of the “point cloud” and there should be left only the necessary object part, the 3D-model of which should be created, i.e. there should be purified the “point cloud” of extra circuits [27]. As a result of the implemented work, there has been got a ready three-dimensional model of the monument, as shown in Figure 8.

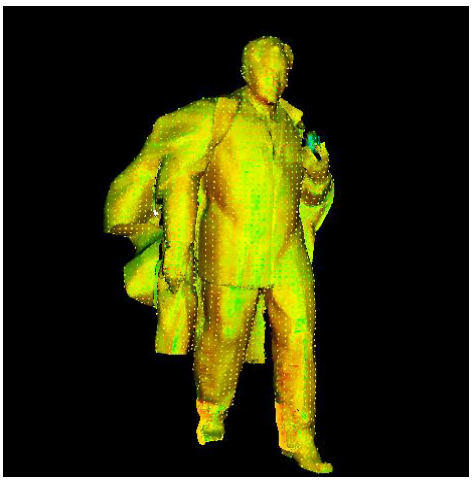

Fig. 8. Three-dimensional model of the monument.

The three-dimensional model can be considered as a kind of virtual world, in which you can make the movement along the model, view the model from any point, create the sections, and take the measurements and so on. Figure. 9 (a, b) shows the view of the monument from the side and bottom.

a b

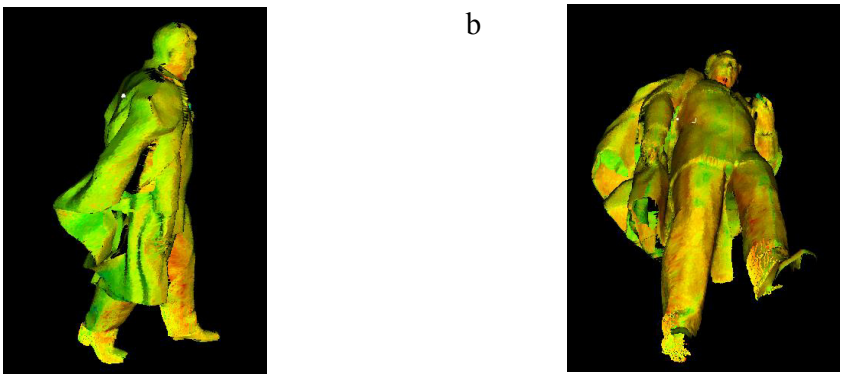

Fig. 9. View of the monument: a) from the side, b) from the bottom.

In the future, the three-dimensional model can be used in order to observe the deformations of the object, the implementation of the restoration work, to get frontal and measuring drawings, the fault detection by comparing with the design model, and the creation of the drawing sections in any section during the restoration and so on [28].

Figure 10 shows the three-dimensional model of the object with the horizontal sections. The step of the section may be different. It is determined depending on the stated task.

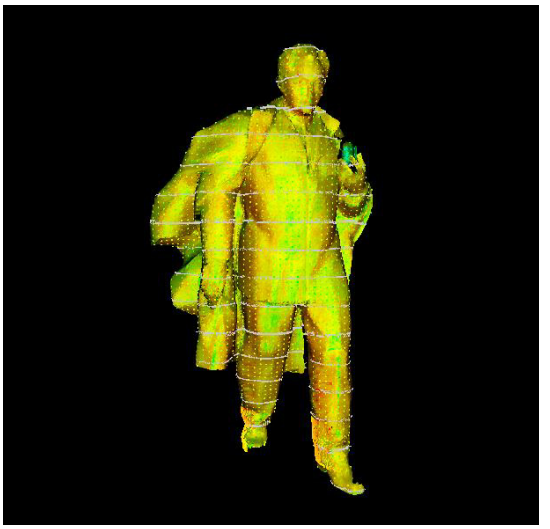

Fig. 10. Three-dimensional model with sections.

Thus, the process of creation of the three-dimensional digital model of any object comprising:

- the field survey concerning the marking of the checkpoint and object scanning
- “combination” of the separate “scans” in one “point cloud”
- the changing of the “point cloud” into the digital model in the given software environment for its further processing [18]

Conclusion

The method of laser scanning has the undeniable advantages in comparison with other methods. This method allows reducing the time of field and office survey, several times increasing the information content of the data, provides the visual and convenient visualization of the three-dimensional form. It is achieved due to the fact that the laser scanning technology is fully implemented the principle of remote sensing, allowing to collect the complete and detailed information about the analyzed object in the form of surface point coordinates at a distance. This feature can significantly reduce labour costs, increase efficiency and make the work safer.

The information concerning the object in the form of a point cloud can be got in minutes. Thus, we have a unique opportunity for real-time monitoring of the processes, both natural and manmade character.

The laser scanning technologies are accepted and highly useful in solving different practical problems concerning the urban planning, land registry, architecture, building construction and operation of engineering structures, as well as can also be used in such areas as: oil and gas production, power generation, mining industry, archeology.

References

[1] N.V. Usov, Surveying (for restorers). - M .: Architecture, 2006, pp. 140-185.
[2] E.S. Bogdanets, A.A. Kryvenko, V. Musikhin, Creating a three-dimensional model of an architectural object, according to terrestrial laser scanning, Geoprofi, http: // www.geoprofi.ru, № 4, 2007, pp. 50-52.
[3] J.Tomasiak, Rapidtechnology in Industrial Fitting, Annals of DAAAM for 2012 & Proceedings of the 23rd International DAAAM Symposium, pp.433 - 436, Editor Branko Katalinic, Published by DAAAM International, Vienna, Austria, 2012.
[4] R. Konieczny, Robot Programming for Surface Scanning Based on Data from Photogrammetry, Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium,Vol. 22, pp. 351-352, Editor Branko Katalinic, Published by DAAAM International, Vienna, Vienna, Austria, (2011).
[5] Ma, J.-W.,Tang, H.-M.,Hu, X.L., Yong, R., Xia, H., Song, Y.-J.,Application of 3D laser scanning technology to landslide physical model test, Yantu Lixue, Rock and Soil Mechanics, Vol. 35, pp. 1495-1505, (2014).
[6] Yue, D.a, Wang, J.b, Zhou, J.c, Chen, X.d, Ren, H.a,. Monitoring slope deformation using a 3-D laser image scanning system: A case study, Mining Science and Technology, Vol. 20, pp. 898-903, (2010).
[7] M.Marsico, A. L Pennetta, Some results of coastal defences monitoring by ground laser scanning technology, Environmental Earth Sciences, Vol. 67, pp. 2449-2458, (2012).
[8] J. Kofman, K. Borribanbunpotkat, Hand-held 3D scanner for surface-shape measurement without sensor pose tracking or surface markers: A compact hand-held 3D scanner simultaneously projecting multiple light lines is presented, enabling 3D surface-shape measurement without requiring sensor tracking or surface markers, Virtual and Physical Prototyping, Vol.9, pp. 81-95, (2014).
[9] R Marani, G.Roselli, M.Nitti, G.Cicirelli, T.D'Orazio, E. A. Stella, 3D vision system for high resolution surface reconstruction, Proceedings of the 7th International Conference on Sensing Technology, pp. 157-162 Wellington; New Zealand; (2013).
[10] Z. Qun, H. Wenbo, J. Chenghao, J. Yutong, and Y. Jinhua, Studies on portable 3D laser scanner for surface flaws, Proceedings of the 2nd International Conference on Instrumentation & Measurement, Computer, Communication and Control, pp. 1297–1299, Harbin, China, (2012).
[11] M.Piszczek, K.Rutyna, M.Kowalski, M. Szustakowski, & K.Ludwikowski, Hardware Implementation of Time-Spatial Framing Method, Annals of DAAAM, Proceedings of the 23rd International DAAAM Symposium, pp. 0305 - 0308, Editor Branko Katalinic, Published by DAAAM International, Vienna, Austria, (2012).
[12] J.Forest, J.Salvi, A review of laser scanning three-dimensional digitisers, IEEE/RSJ International Conference on Intelligent Robots and Systems, Vol. 1, pp. 73-78, Lausanne, Switzerland, (2002).
[13] S. Pescari, D.Dan, V.Stoian, Using the laser scanning technology in the rehabilitation of existing buildings, Structures and Architecture: Concepts, Applications and Challenges, Proceedings of the 2nd International Conference on Structures and Architecture, pp. 1135-1142. Guimaraes, Portugal, (2013).
[14] L.Shen, H.X.Tai, T.Y.Ni, Application of 3D laser scanner in surveying of traditional architecture: Case study on surveying practice of Hangzhou Haichao Temple, Applied Mechanics and Materials, 3rd International Conference on Civil Engineering, Architecture and Building Materials, Vol. 353-354, pp. 3405-3409. Jinan, China, (2013).
[15] S. E. a. Chen, W. b. Liu, H. a. Bian, B. a. Smith, 3D LiDAR scans for bridge damage evaluation. Proceedings of the 6th Congress on Forensic Engineering, Gateway to a Better Tomorrow, pp. 487-495, San Francisco, United States, (2012).
[16] Fedotov GA Engineering surveying, High School, pp. 201-205, (2007).
[17] B. Buechler, M. Bordas Vincent A. Marbs. Analysis of the accuracy of laser scanning systems, Newsletter GIS Association, on the website http: // www.gisa.ru, № 1 (43), 2 (44), (2004).
[18] M.J. Bryn, G.S. Bronstein, V.D. Vlasov, V.A. Kougiya, B.A. Levin, S. Matveev, U.D. Niyazgulov, Engineering Geodesy and Geoinformatics, Academic Project, Fund "Mir", pp. 220-225, (2012).
[19] M.N. Anikushin, Terrestrial laser scanning systems, Work experience, Geoprofi http: // www.geoprofi.ru, № 1,pp. 49-50, (2005).
[20] Z.A. Gaevskaya, X.M. Rakova, Modern building materials and the concept of "sustainability project", Advanced Materials Research, Vol. 941-944. pp 825-830 (2014).
[21] N.S. Bolshakov, S.A. Krivoy, X.M. Rakova, The "comfort in all respects" principle implementation by the example of an elementary school, Advanced Materials Research, Vol. 941-944, pp 895-900 (2014).
[22] X.M. Rakova, Wind Power Market Development Initiative, Advanced Materials Research, Vol. 617, pp. 307-312, (2014).