# Application of Laser Scanning Technology for Civil Engineering Projects in Serbia

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**Key words**: LIDAR, DTM, DSM, Corridor mapping, Accuracy analyses

**SUMMARY**

The review of the results of the application of laser scanning technology in the processes of generating 3D terrain models and Civil engineering structures has been given in this paper. Generated 3d models of corridor terrains and existing Civil engineering structures are used as bases of computer design of line structured objects (roads, railways, power lines, river embankments…) and projects of reconstruction and rehabilitation of existing civil engineering structures. Technologies of laser scanning on airplane have been used for generating 3D models of long corridor, and for tight corridors laser scanning from helicopters has been used. The results of measuring, data processing and accuracy analysis of 3D models of corridor of powerline from the Town of Leskoavac up to the border of the FRY Macedonia in the length of 100 km and 400 m wide corridor has been used as the example of the mentioned technology. Stationary scanners of the companies Leica and Trimble have been used for the scanning of the existing buildings, mostly historical monuments. Generated 3D models of the Fortress in Bac and Castle in Vrsac have been used as an example of the application.

**SUMMARY**

U radu su prezentirani rezultati tehnologije laserskog skeniranja i generisanja 3D modela terena i objekata. Generisani 3D modeli su korišćeni kao osnova za projektovanje linijskih struktura (puteva, železnica, dalekovoda, nasipa…) i projekata rekonstrukcije i sanacije postojećih građevinskih objekata. Tehnologija laserskog skeniranja iz aviona je korišćena za generisanje 3D modela širokih koridora, dok se za uzane koridore lasersko skeniranje može realizovati iz helihoptera. U radu su prezentirani rezultati merenja, obrada podataka i analiza tačnosti premera dalekovoda od grada Leskovac do granice države Makedonije, u dužini od 100 km i širini od 400 m. Laserski skeneri u stacionarnom režimu rada, od proizvođača *Leica* i *Trimble*, korišćeni su za skeniranje fasada zgrada i istorijskih objekata od kulturnog značaja. Kao primeri su prezentirani 3D modeli tvrđava u gradu Bač i kula u gradu Vršac.

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## 1. INTRODUCTION

Updated and high quality geodetic layouts, which comply with needs of modern design, are requested for the projects with high level of detail. In the process of preparation of zoning and other spatial plans, as well as in all other phases of works in civil engineering, architecture and town planning, surveying and cartographic activity have application, starting from the Project concept, surveying and Project execution in the field as well as control of it in the exploitation. Conventional method of preparation of geodetic and topographic layouts referred mostly to cadastral and cadastral-topographic layouts, which in its updated version do not fully suit the specific needs of users. With highly intensive development of geo – information technologies, the conditions for the preparation of geodetic layouts are fulfilled which would suit more and more complex design requests. The technology of preparation of digital topographic layouts in vector and raster format is in expansion, great number of satellites with sensors for remote sensing provides the resolution better than 1 meter, which means that one pixel of digital image represents the square of earth area of 1 x 1 meter size.
Obviously, there are significant events in the area of spatial information technologies. Systems are more powerful than ever, but still easier and cheaper for use. Now it is possible to use different sources of information and extract from them wide range of information. All this, of course, is done with significant increase of the system performances. All in all, it is reasonable to expect that future development in the field of geo – information technologies is going to be as much as exciting as it has been in the last couple of years. And this is the reason which point out to the breaking point from transfer from conventional method to introduction of new technologies of preparation of digital topographic layouts. In short, goals for transfer to modern work regime in the area of spatial information technologies are as follows:

- Obtaining quality digital layouts for the preparation of all types of zone planning and other projects;
- Significant saving in money, time and resources, but with compulsory initial investment;
- Introduction of modern technologies in the processes of spatial planning, in order to keep up with modern global trends.

According to a better presentation of spatial data, GPS has a special application in efficient gathering of data (positioning with the use of satellite), especially in the sense of generating spatial data by methods of continual kinematics, as well as robotized total station, i.e. integral system of surveying which provide spatial data of very high density.
Relatively new technology which is more and more in use is terrestrial and kinematics laser scanning of the terrain, whose result represents very dense display of measured points,

whereas the result processing takes more time than measuring itself. At terrestrial (stationary) terrain and building scanning, density of measured points amounts to 1 dot/0,5 $cm^2$, while at scanning from air (kinematics) density amounts up to 150 dots / $m^2$. The accuracy of determining the spatial coordinates of points ranges from 2 to 3 mm at stationary measuring, while at kinematics measuring from the air, the accuracy can be achieved up to 5 cm. Density and achieved accuracy of determining the spatial coordinates of points of the terrain and buildings provide complete justification of the use of the mentioned technology in all designs of procuring layouts for zone planning and all other designs and plans. Having in mind that density of the survey provides identification of even the smallest structural lines of the terrain and buildings, the conditions for generating 3D models of building and terrain have been secured by the combination of these geometrical data with raster (photographs) which were obtained from professional terrestrial digital cameras of high resolution. In such way obtained 3D models, which in a picturesque way enable the real display of the terrain and building represent ideal bases for digital archiving of spatial information for all types of design, as well as all possible repairs and rebuilding. In this way the conditions for leaving the conventional method of data archiving have been met, and the assumptions for the application of contemporary geo-information technologies where manipulating with, in this way, generated spatial data becomes significantly easier with obtaining much more information than with what recent techniques have been providing.

## 2. TECHNOLOGY OF LASER SCANNING OF TERRAIN AND BUILDINGS

For the purpose of solving practical problems in many branches of engineering industry, there is a need for measuring and modeling of measured data as much as possible real display of spatial surroundings. By development of laser scanning technology the conditions for application of 3D measuring of points of very high density have been met in a way that modeling of subject survey can be carried out by using this data. The necessity for highly detailed 3D terrain and building coordinates occurs in different engineering disciplines, such as:

- Quality control, supervision and comparison of construction with plans, especially on complex construction sites
- Virtual planning, analysis of spatial relations between buildings themselves, but also between a building and surroundings (complex buildings)
- Digital archiving of infrastructure (tunnels, bridges and road network) in order to provide the basis for efficient management
- Control of different deformations on construction sites (landslides, strains, faults on facilities), surveying of entire construction sites, not only the previously determined selected points.

Detailed survey of culturally significant buildings, monuments, churches, towers with very accurate documentation of their condition (interior and exterior) in order to repair them in case of collapse or destruction of any kind.

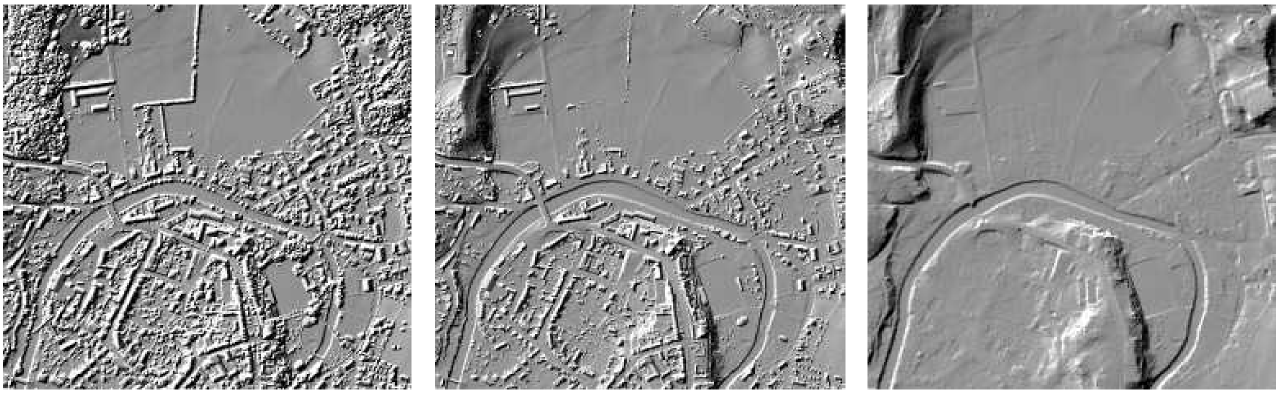
### 2.1. Kinematics laser scanning

Laser scanning of the terrain from the air (LIDAR) today represents one of the most contemporary technologies which is used in surveying and preparation of topographic plans and maps for different purposes. The technology is based on gathering three different sets of data. The position of a sensor is determined by the use of Global Positioning System (GPS) using a phase measuring in the regime of relative kinematics, and the orientation is determined by use of Inertial Measurement Unit (IMU). A laser scanner is the last component. The laser sends an infra red beam to the earth and it reflects to the sensor. Time lapsed from emission to reception of signal with knowledge of sensor and orientation position, enables for the three dimensional coordinates on the Earth to be calculated.
During flight speed of approximately 250 km/h and altitude of approximately 1000 meters with standard characteristics of a sensor (130000 emissions / second), the data on position of points on the ground with density of up to 100 dots/m$^2$ have been gathered. Usual relative accuracy of a model with calculated omission of GPS and inertial system amounts to 5-7 cm. Absolute error is always better than 15 cm and it can be significantly reduced by use of control points on the ground.
Almost all modern LIDAR systems, next to GPS, IMU and laser scanner also integrate RGB/NIR (Red – Green-Blue, Near Infra Red) cameras of high resolution which enable the making of quality ortho-photo plans of resolution of up to 2 cm (depending on the height of over flight).


*Picture 1. Laser scanning of the corridor from the Town of Leskovac to FYRM border, 2007 (Aircraft with integrated GPS, INS and laser scanner and GPS transmitter on the terrain)*

Survey with LIDAR is carried out while moving and the system can be mounted to a vehicle in the aim of scanning corridor such as roads or similar line facilities or to an aircraft for scanning the corridor from the air (Picture 1). LIDAR has a very simple principle of measuring. The scanner emits the high frequency impulses and it reflects from the surface to the instrument. The mirror inside laser transmitter moves by rotating perpendicular to the flight direction which enables the measuring in wide belt. Time elapsed from the emission to the return of each impulse and angle of divergence from the vertical axes of the instrument are used for determining relative position of each measured point. Data from laser scanning are combined with scanner position and orientation in order to obtain three dimensional coordinate of laser print on the surface of the terrain. Emitted beam can have multiple reflections which cause certain point to have the same coordinates, but different altitude. The first reflection can come from vegetation or edge of the facility, power line or similar, while last reflection most likely comes from the surface of the Earth or the artificial building.
After the processing of GPS vector from base stations to each measured sensor position, orientation and determining relative position on the ground in regard to the sensor, the following data are obtained:

- The cloud of points of first and last echo
- DSM first and last echo
- RGB and NIR recording



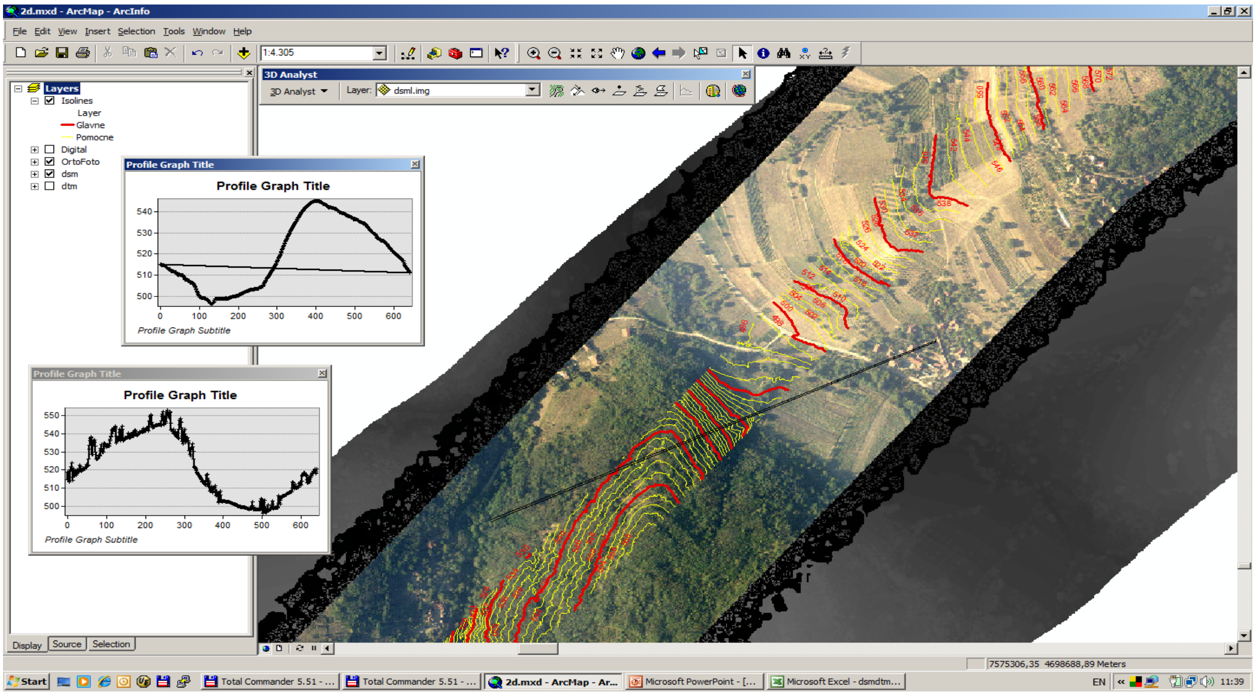
*Picture 2. DSM from the first and last echo and DTM*

Based on RGB and NIR recordings and DSM of the first echo, orthorectification and georeferencing is carried out and as a final result orthophoto plans in color and in specter close to IR are obtained. DTM is obtained by classification of points of LIDAR data and by creating models from points which belong to the terrain. [1]

The surveying of the corridor 110 km long and 400 m wide from the Town of Leskovac to FYRM border was carried out in the middle of 2007 for the needs of Serbian Transmission System and Market Operator (Picture 1). The survey with LIDAR technology from the aircraft has been carried out in 6 hours, with average flight altitude of 1200 meters above the ground. The measuring of the trigonometry points with GPS in the aim of marking unique parameters of transformation from the system WGS84 into the state trigonometry network system has been carried out within the preparation works. The state network of permanent stations has been used for base GPS stations, where all data have been obtained in unique coordinate system which have optimum integration with the state system for the given territory.

DSM from the first and last echo in the shape of raster of 1m resolution with altitude resolution of 2 cm has been obtained from the survey and processing. Final DTM has been obtained by further processing, and orthophoto recording for the entire area of the surveying has been obtained with the help of RGB/NIR recordings and DSM of the first echo. The resolution of the orthophoto recordings amounts to 20 cm by which the preparation of orthophoto plans of up to 1:1000 scale has been enabled. Isolines for the entire area with equidistance of 2 meters have been generated based on DTM. Transversal and longitudinal sections have been generated at the request of the Designer. DTM and DSM of the first echo have been used for generating the sections, in such way that height of the buildings, forest and similar through which the section passes can be seen on the sections besides the terrain.

Three basic classes have been obtained based on the classification of points obtained with LIDAR: terrain points, building points and points representing the higher part of the vegetation. Polygons of cultures and classes, lines of smaller roads and springs and points of lonely trees have been obtained by digitalization of orthophoto plans and GIS results processing. Quality control of the spatial data has been carried out in 10 locations, directly by terrestrial survey on the terrain by use of GPS receivers and comparison of recording data with LIDAR.




**Picture 3. Ortho-photo plan of the part of the corridor and cross section of the terrain with and without vegetation**

The control results are the following:

- Position accuracy is better than 10 cm
- Altitude accuracy is better than 15 cm
- Altitude accuracy is better than 5 cm for 80% of the results
- GIS of the corridor Town of Leskovac – State border with the following contents has been implemented after the all data processing from LIDAR surveys and cadastral plan in 1:2500 scale:
- Geo referenced cadastral plans
- Orthophoto plans
- DTM
- Isohypse with equidistance of two meters
- Digital topographic plan
- All recording points with accompanying attributes (point and the class affiliation)

## 2.2. Terrestrial laser scanning

Terrestrial laser scanning i.e. scanning in stationary mode has provided the measuring of high number of points in short period of time, whose result represents highly dense spotty display of a measured facility. Usual geodetic methods of survey, total stations or GPS measuring are not the most suitable for measuring all structural lines because they are based on survey of discreet points of a building. Terrestrial photogrammetry represents an efficient method of survey, especially at surveying of the facilities (buildings, construction sites), façade restorations of the buildings with cultural significance, but there are some shortcomings. The main disadvantage of photogrammetry technique of survey comes from the work methodology itself. The way from measuring to obtaining coordinates is relatively long whereas the coordinates cannot be obtained in a real time. The second disadvantage of photogrammetry method is such that it is not suitable for measuring the environment during unfavorable physical conditions (not enough light, dust). Terrestrial laser scanning, which is carried out in stationary mode, enables direct 3D measuring of dense grid of points on the building with high accuracy. Terrestrial laser scanners are quite similar to cameras, have their own window of shooting and they can record only the buildings which are not secluded. While cameras shoot the image of the building, laser scanners measure the spatial coordinates of the points in their window of recording.[2]

Data measured with laser scanner are directly stored in the memory of a laptop, therefore they could be processed on - line, that is, integration and geo referencing scans from different stations of survey is carried out together with data collection. Having in mind that there are millions of points, during work process of the scanner noises of measuring appear which influence the final accuracy of a model, therefore the data must be filtrated in suitable software for data processing in which specified implemented algorithms negate noises occurred during measuring. Laser scanners of the latest generation have an installed horizontal and vertical compensators, as well as total stations, which enable the positioning of the scanner in a requested coordinate system and use of scanners in the same way as with classic geodetic instruments. The use of CAD or MicroStation application in the aim of manipulating the cloud of points is justified only in case of tens of thousands of points; therefore there are additional program supplements for this purpose. [3]

Terrestrial laser scanner is highly efficient measuring instrument, but it shows its full potential by integration with some of the traditional geodetic techniques. Laser scanner integrated with digital camera represents the most efficient system of measuring. Digital camera provides the photo-images of high resolution which can be joined with geometrical 3D model generated from the cloud of points and as a final product we get a photo real 3D model of the building.

**Picture 4. 3D model of the church at Medun (near Podgorica) generated from the data from laser scanning and digital photogrammetry**

The highest resolution measured by the laser scanner between two neighboring measuring points, vertically and horizontally, is 1,2 mm. Minimal distance is not the only decisive factor of maximum density of survey which depends on the size of the laser beam scanning the building which is the subject of survey. The smallest absolute possible distance between points on the building is 10 mm due to the size of the laser beam, because if the distance is smaller, two measured points would have the same value. Terrestrial laser scanners provide possibility to choose the survey resolution (high, medium and low resolution of survey).

**Picture 5. Laser scanning of the building façade in Vrsac, ortho-photo plan of the part of the façade**

Therefore, in regard to conventional geodetic techniques of surveying (total stations), where geodetic expert chooses a priori characteristic points on the building, the advantage of the laser scanning lies in fact that points are surveyed with previously given resolution (density), whereas the quality of measuring is represented by geometrical elements recorded with much more points than by classical methods. The mesh, which is a regular and irregular network of points, depending on the vertical and horizontal resolution of terrestrial laser scanner, is formed by generating a cloud of points. The size of the network is chosen directly by the expert who does the final processing of the measuring and the result is the resolution of measuring and density of the points which is desired to be achieved after the filtration.[4]

***Picture 6. 3D model of the culturally significant buildings based on data from laser scanning and digital photographs of high resolution (The Tower in Bac and the Tower in Vrsac, GeoGIS Consultants 2008)***

## CONCLUSION

Modern technological procedures of gathering and processing of spatial data enable 3D display of spatial forms (terrains and buildings) in full-color regime. Practically all most recent geo-information systems have an integrated module for 3D visualization which enables a 3D positioning of the buildings in relative and absolute model, i.e. coordinate system. Many of them have some additional possibilities such as the extraction of the building height, flight simulation over the digital terrain model etc.

Observing the surface of the Earth in spatial mode, users can visualize, interpret, measure and extract the buildings in 3D surrounding. As we have seen in this paper, an excellent effect of a display and simulation of spatial surrounding can be achieved by integration of geometrical data of centimeter density and digital photographs of high resolution, based on which spatial data of any kind can be generated. Civil engineers, spatial planners, town planners, communal services, they will all be able to watch cities in 3D forms, and to present to the public the form of the building, the structure of the settlement, bridges, roads and other buildings of infrastructure in the effective way. Engineers of different professions connected with spatial planning shall consider this 3D analysis as extremely useful for planning the transport and telecommunications, environment protection etc.

The conventional manner of the presentation of spatial data in 2D form enriched with information on the sea level of certain points (isohypses) is slowly abandoned and it is replaced by modern concept of 3D presentation of altitude display of the terrain and buildings, where in regard to recent experiences more geometrical and visual information on terrain configuration and artificial buildings on it is obtained by manipulating 3D model in suitable software surroundings. For that purpose, the technology of laser scanning of the terrain and buildings is becoming more and more dominant technique of mass gathering of spatial information in regard to recent techniques, with great saving in time and money.

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