TOWARDS THE FULL AUTOMATION OF LASER SCANNING AND AERIAL PHOTOGRAPHY DATA PROCESSING

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ABSTRACT:

The theoretical conclusions and practical results described in this article are based on the extensive experience of geodetic, photogrammetry and aerial survey works that are being implemented by Geokosmos in Russia and globally as well. Being a commercial service providing company, Geokosmos is greatly interested in obtaining technologies for aerial survey data processing with extremely short duration of technological cycle while applying such data for generating up to 1:1000 topographical maps. The time factor is rather critical in modern Russia, taking into account the huge Russian territory and the strong demand for various topographical and remote sensing data provoked by intense post-Soviet economic processes. Aerial data acquisition is implemented using Geokosmos' helicopter or fix-wing platforms equipped with Optech airborne laser terrain mappers ALTM 2050, 30/70, digital aerial cameras, infra-red sensors, GPS/GLONASS systems and some auxiliary devices. Joint collecting and ultimate combining of LIDAR and aerial photography data is the crucial point of the company's strategy in both methodological and marketing aspects. Specifically, such an approach makes it possible to reduce the entire processing time and therefore dramatically increase productivity. All these considerations lead to the necessity of automation of all stages of combined LIDAR & aerial photography data processing aimed at topography map making.

The proposed approach to realising the complete automatic technology have been described in this paper based on the experience gained by Geokosmos during the last 5 years. The main achievements and disadvantages have been discussed, especially concerning the maximum achievable accuracy of the method.

1. GENERAL CONSIDERATIONS

The combination of laser scanning and digital aerial photography seems to be very promising for the following reasons:

- these two types of data, namely, laser detection and ranging and aerial photography data, supplement each other to the utmost extent when they are used to produce large-scale maps and plans, 3D semantic models and other geoinformation objects. Indeed, laser scanning data provide detailed information on terrain features and allow the automatic creation of Digital Terrain Models (DTM) as well as models of geographic objects having distinct morphology like power transmission lines, forests, etc. On the other hand, digital aerial photographs give a natural presentation of the scene thus allowing the decoding and identification in the office of meaningful contours of objects that cannot be identified otherwise using laser data only.
- laser scanning and digital aerial photography can be readily combined in practice. Weight, dimensions and power consumption of modern laser scanners and digital cameras allow their easily mounting on light aircraft of almost any type, both on planes and helicopters, so that these two types of survey can be performed concurrently from the same aircraft. It is noteworthy that laser detection and ranging data are by definition supported by a complete set of exterior orientation parameters due to airborne GPS (GLONASS) receiver and inertial navigation system like POS/AV from APPLANIX or IGI. Therefore exterior orientation parameters can be applied, for no extra cost, to all aerial photographs taken with an accuracy within 5-6 cm for spatial coordinates of the point being photographed, and within 0.5-1.0 mrad for camera's optical axis angular orientation. Although this degree of accuracy may be insufficient in some cases, these data can be useful as initial approximations for the final image orientation through phototriangulation, both for the processing of survey path data and sets of aerial photographs.
- The possibility to develop absolutely new algorithms of geomorphological analysis is probably the most interesting aspect of combining laser scanning and digital aerial photography data, such algorithms being capable of using both types of data to reproduce terrain features and ground objects, and perform high-precision spatial geometric measurements. The latter assumption requires some comments. The application of laser scanning and aerial photography (for subsequent stereophotogrammetric processing) makes it possible to achieve similar results in 3D modeling of terrain features and of the entire ground infrastructure of the scene being surveyed in general. In both cases, models of the terrain surface can be generated, outlines of buildings and structures can be determined, and plan and vertical measurements can be taken. The following notes are very important:

1) All above-mentioned methods of 3D modeling of the surveyed scene and its individual components as well as geometric measurements are performed independently meaning that various sources of data

and algorithms are used. This allows us to correctly compare them in order to assess the statistical validity and crosscheck the accuracy of the both types of data.
- Laser scanning data are much more informative due to their ‘natural three-dimensionality’, that is they allow the morphology of the scene to be presented in greater detail, using automatic and semi-automatic methods among others. Yet:
- In most cases, the use of aerial photography data and the methods of digital photogrammetry for their processing allow a better accuracy of geopositioning and geometric measurements as compared to the ‘pure’ laser detection and ranging. Therefore the application of these two types of data in combination will result in improved geodetic accuracy of laser data. As of today, the accuracy of laser data is within 15-20 cm, which is insufficient for a number of important applications.

2. TECHNOLOGICAL BACKGROUND

Data obtaining capabilities of airborne survey equipment, laser scanners and digital cameras in particular, have been enhanced significantly in recent times.

Thus, the last model from OPTECH Inc., ALTM3100 laser scanner, has a pulse frequency of 100 kHz and is capable of recording returns from each pulse emitted. This ensures a scanning density of up to 10 laser points per a square meter of the ground surface. At the same time, digital frame cameras with large arrays have become commercially available. Thus, an ULTRA CAM model from VEXCEL generates images of 11500 by 7500 pixels and offers a frame rate of 1.3 Hz.

Such sophisticated data obtaining capabilities of modern airborne survey equipment create a favorable background for further improvement of algorithms aimed at the integration of laser scanning and aerial photography data because a high degree of detail provided by both types of data (density of laser points and high resolution of aerial photographs) allows the use of analytical methods for the purpose of integration rather than heuristic methods as it used to be.

3. GEOKOSMOS HISTORY

Geokosmos is a privately owned and operated Moscow-based topographical and surveying company established in 1993 in Moscow. The company is reputed as a significant player on the Russian topographic and geodetic survey market, making use of digital land and aerial surveying technologies as well as 3D digital multipurpose modelling.

Geokosmos focuses on three main lines of business: the provision of professional surveying services using laser scanning technologies, development of its own software products for various surveying applications and consulting and development of integrated laser scanning technologies.

In 2001 Geokosmos successfully carried out the first Russian large-scale project involving the use of an aerial laser scanner for large-topographic survey and creation of a 3D digital area model of over 340 sq km for a railway design based on the scanning results. It continued studying ground-based scanning systems, actively co-operating with producers and users, and a successful record of using these technologies resulted in further projects.

The company has at its disposal two aerial laser scanners: Optech ALTM-2050 & ALTM-3100 with 50 and 70 kHz scanning frequencies and a significant number of Trimble GPS receivers, ProXR, tacheometers and ground-based laser scanners.

The company employs a full-time staff of more then ninety specialists: highly skilled, creative, young personnel within a strongly organised structure. In October 2002, an aerial surveying division was established. The new division is fully staffed with highly qualified graduate specialists having extensive experience and an impressive record of the application of airborne laser scanning systems both within Russia an in many other European and Latin American countries. Aerial laser scanning has since become a key line in the company’s activity.

At present Geokosmos clients include major Russian companies, such as OAO Gazprom, RAO UES, MOSAVTODOR and many others. Each of these is ranked high in its respective area. OAO Gazprom holds a huge monopoly in the Russian gas industry, which provides 25 per cent of the national income. All Russian energy resources belong to RAO UES, the biggest Russian power-engineering company, which owns more than 370,000 km of power lines.

4. ADVANTAGES OF LASER SCANNING

Considering the application of the laser scanning method, a number of significant advantages can be mentioned that are provided by this method in contrast to other traditional approaches.
- The efficiency of laser scanning is extremely high. A milestone of 500-600 km has been reached in practice during one day of aerial survey. It should be noted that the post-processing of survey data obtained using the laser scanning method normally takes as much time as the aerial survey itself, which allows survey data to be processed immediately in the field. In its turn it makes it possible to efficiently control the quality of survey data and redo survey work where necessary. It is obvious that laser scanning surpasses other traditional methods of aerial survey in performance, as those methods require intricate and time-consuming data post-processing.
- Laser scanning does not require compilation survey for aerial survey data on the ground. The need to perform such operations may cause a serious problem for traditional survey methods, especially in remote and hard-to-reach areas.
- Traditional stereophotogrammetric methods, whether analytical or digital, ensure that scene components are measured with a high degree of accuracy. However, these methods do not allow the automatic reproduction of the shape of complex engineering facilities. Besides, the spatial location of wires and ropes makes it extremely difficult to apply stereophotogrammetric methods to measure sags, clearances and coordinates of suspension points, thus resulting in an unsatisfactory accuracy of such measurements. Since laser detection and ranging allows all components of the scene to be measured directly, it is absolutely free of the above constraints. Moreover, the computer-aided processing of primary laser data permits a very high accuracy of the above-mentioned parameters, for instance, sags can be measured with an accuracy of 5 to 7 cm. At the same time, the laser scanning method always generates a 3D image of the object, ‘a cloud’ of laser points reflected from the surface of the object. The cloud itself considerably facilitates the visual analysis of the object’s shape and allows all primary geometric measurements to be taken with a standard level of accuracy offered by the method, i.e. 15-20 cm. It is

more important that data so presented can be effectively analyzed by software products and used to generate vector models, which, for the above-mentioned reasons, is extremely significant in implementing present-day design approaches. For instance, laser data processing software systems make it possible to automatically identify types of towers of power transmission lines and their spatial coordinates with an accuracy of 10-15 cm. Besides, such important parameters can be automatically determined as the height of supports, length of insulator strings, structural damages, etc.

- Unlike traditional methods, laser scanning is to a great extent free from seasonal constraints caused by foliage. In most cases laser scanning can be used to survey objects under trees' canopies.
- There are no limitations on the use of laser scanning to survey scenes with no or indistinct surface textures like sandy beaches, snow-covered areas and bodies of water. It is known that stereophotogrammetric measurements of such scenes are impossible as no associated points can be identified in stereopairs.

5. LASER SCANNING IN TOPOGRAPHY

Speaking about the applied aspect of laser scanning techniques, we can conventionally distinguish between the two major groups of applications. The first one includes topographic applications where laser data are used to reproduce landforms and plot important contours to be shown on topographic maps and plans. Another major group of applications includes a wide range of tasks which are not directly associated with topography. To handle such tasks, laser data are used to generate vector models and determine a set of morphological properties of various natural or artificial formations. In most cases, the collection of such data is an essential part of engineering surveys. Anyway, in analyzing the significance of laser scanning, it would be logical to consider it, above all, as an alternative to the stereotopographic method of producing maps and plans or its analogues based on ground photogrammetry. Technological and economic advantages of laser scanning should be therefore considered using the stereotopographic method for comparison. The following arguments can be given in favor of stereotopographic method as a basis to evaluate the efficiency of laser scanning:

- Until now, stereotopographic method has been the main tool used to produce and update topographic data in the most general sense. The application of the method is obligatory which is officially prescribed by applicable regulations. At the same time, in terms of nature, detail and accuracy of laser data obtained, laser scanning techniques help perform largely the same tasks as the traditional stereotopographic method which involves aerial photography, geodetic control and complex procedures of photogrammetric data processing. In this sense, it is quite appropriate to compare laser scanning techniques and stereotopographic method. Another argument in favor of this choice is the tendency of applying laser scanning techniques to the production of topographic materials. There is a clear tendency that stereophotogrammetric methods are being ousted by laser scanning in production of topographic plans, cadastral projects as well as in engineering surveys in such areas as power engineering, oil and gas industry, construction. Generally, it would be more correct to speak about the evolution of the stereotopographic method rather than about its being substituted, as the terrain data and major contours are obtained directly through laser scanning.
- The comparison of laser scanning techniques with other currently known methods of airborne remote sensing providing 3D data directly, in particular, with interferometric side-looking radar systems, cannot be regarded as absolutely correct. Here we must keep in mind the following. Speaking very roughly, a radar image shows the distribution of dielectric and magnetic permeability over the scene so that the intensity of a reflected signal is determined directly as the product of dielectric and magnetic permeability of the medium. The distribution of the radar image intensity is also largely affected by such factors as morphological conditions of the surface (ripples on the water surface), presence of contamination, etc. The main practical consequence here is that, in spite of their capability to ensure that the terrain geometry is measured directly, interferometric radar systems occupy an ecological niche other than laser scanning techniques and therefore may not be regarded as an analogue to be compared with in terms of technical and economic performance. The main characteristics of radar data (resolution at a flight height of 2000 m at the level of first meters, accuracy of geodetic elevations at the level of 3-7 m) allow them to be used in a number of areas such as geology.

Based on the foregoing, it seems to be quite appropriate to speak of a laser scanning method meaning a complex of procedures associated with the application of laser detection and ranging and related techniques in topography and engineering surveys. The laser scanning method is composed of the following thematic issues:

- applicability of laser scanning techniques to a particular group of objects and scenes;
- management of aerial surveying and selection of optimal modes of operation for equipment to meet specified objective;
- assessment of accuracy and validity of obtained data;
- compatibility of laser data and their integration with data obtained using other methods of remote sensing and ground-based measurements as well as the processing of data for further use in various thematic applications.

The laser scanning method is described above in a most general way. Of course, all considerations above need to be detailed when applied to conditions of a certain survey.

6. THE CONCEPT OF REAL-TIME MAPPING

LIDAR technology has today completely proven its effectiveness. Applications like Digital Terrain Model (DTM) generation and power-line corridor mapping are already classical. The technology is still progressing, its main advantage being its combination with other airborne remote sensing data, such as aerial photography. The immanent '3D nature' of laser data allows fully automatic spatial orientation, orthorectification and geopositioning of imagery. It is obvious from practical perspective that the simultaneous recording and combined processing of LIDAR data, aerial imagery and some other kinds of remote sensing data accelerate the processing cycle and increase data accuracy and reliability. Such an approach encapsulates the concept of real-time mapping.

Focus on the development and implementation of systems and software for real-time geodetic mapping remains a high priority for Geokosmos. Its management believes that a fundamental reduction (of up to a few days or even hours) in the duration of the technological cycle of a survey, in particular, aerial survey, has allowed the company to make its image more attractive for potential customers and investors. These have been traditionally used to protracted mapping processes in Russia. An extremely high level of efficiency, along with the highest quality of data provided create, among other factors, a very favourable climate in customer relations. The customer is given the opportunity to monitor quality and completeness of data and even to make adjustments to the operation plan throughout the entire technological process.

7. THEORETICAL ASPECTS

The progress in LIDAR technology and its numerous topographical applications have been rather impressive during the last few years. On the one hand the development of sophisticated algorithms for geomorphological analysis is still ongoing, enabling improved recognition and detailed description of objects. On the other hand, combining with other datasets results in augmented information. In this respect, LIDAR and digital imagery data perfectly supplement each other. LIDAR allows an effective DTM generation while enabling automatic recognition of many classes of objects having a clear geomorphological structure. Digital imagery provides the most natural kind of scene representation, including complete information concerning surface texture. In some cases, this pure visual information may be supplemented with infrared or multi-spectral data. LIDAR data and appropriate processing technology enable the following:

- Avoidance of the stage of on-ground geodetic support for both corridor and area survey;
- Use of laser-derived DTM for ortho-image rectification;
- Creation of new procedures for aerial triangulation in particular, and frames georeferencing in general, by combined geomorphological analysis of laser data and imagery.

Simultaneous recording of LIDAR data and digital imagery requires joint operation of the two sensors on board of an aircraft, which apparently is associated with the solving of a number of technological problems.

Generally speaking, from a practical point of view the concept of real-time mapping proposed by Geokosmos may be regarded as an alternative to a classical stereotopographic method in cartography. Though it would be more accurate to say that this technology is derived from a wide variety of classical geodetic and photogrammetry methods. Numerous particular limitations of the stereotopographic method are well known. These have been studied in detail therefore there is no sense in their thorough description here. Let us just mention the following:

Such problems are quite diverse in their nature, but they all are in general associated with the issue of points correlation on stereopair. In certain cases this leads to complete inapplicability of the method, for instance in snow-covered or sandy landscapes with absolutely no visual texture. In other cases the quality of results largely depends on a number of factors, such as average forest elevation and density when surveying forestry, or buildings shape when mapping city landscapes.

The above-mentioned limitation of the stereophotogrammetry method manifests itself mostly in the most practically important applications connected with surveying complex scenes with numerous objects. Largely for this reason large-scale mapping of city landscapes with a significant share of multilevel buildings cannot be done by exclusively aerial survey methods, thus forcing massive carrying out of on-ground topographic survey, which is extremely expensive in city conditions. Besides, there are seasonal limitations restricting aerial surveys in the presence of heavy snow cover or foliage. For the most part of the territory of the Russian Federation, for example, such limitations leave only 1.5 – 2 months a year for aerial survey.

Practically, such problems often lead to a serious deformation of technology that causes doubts about the accuracy of the results. Thus, generation of a DTM of a big city area considered as compulsory within the stereotopography method, is regarded as such a labor consuming and expensive task affecting the overall cost of the project that a 'compromise' has been offered, namely, to use a relief model taken from an existing topographic map of appropriate scale. Given the extremely low metrologic quality of the existing topography basis in Russia, one may only guess what consequences in future would be caused by such decisions when doing, for example, a cadastre system to regulate real estate relations.

It would be reasonable to note here that the main advantage of the real-time mapping technology is that it is practically free from all the limitations mentioned above. This explains its great attractiveness for potential customers engaged in various kinds of topographic activity.

The proposed digital technology of mapping in real time is free from major disadvantages of the traditional stereotopography method which, as has already been mentioned, include a necessity of on-ground geodetic support, inevitable manual labour at the stages of frames mutual orientation, DTM production and correct combination of orthorectified photos.

8. SOME PRACTICAL RESULTS

The proposed technology of real-time mapping assumes the carrying out of aerial survey missions for an area of interest using Optech ALTM and other aerial survey equipment. The aerial data is to be processed using Geokosmos' specialised software according to the following scheme:

Logically, the first step is true DTM separation from a full cloud of laser points. As it was mentioned above, the implementation of such a procedure is a complicated task. The solution is the application of special topologic analysis algorithms classifying laser points by criteria "belong/not belong" to true ground. Such algorithms are based upon the two obvious postulates:

- A true ground point has a minimal value of geodetic elevation in comparison with other ones in its vicinity.
- The spectrum of spatial frequencies of a true ground surface has no high frequencies.

Practical realisation of such algorithms is normally carried out by modelling mathematical surface, which delineates the laser point cloud from beneath. Spectral selection for the given surface is expressed by limiting the values of the first and second differentials of the surface regarding as a two-dimensional function of planar coordinates. In practice such an approach provides quite satisfactory results.

The next step is the aerial photos automatic mutual orientation:

- The special DTM processing is implemented with a view to detecting the DTM fragments for which the correlation algorithms of point matching can be applied effectively. It means that such fragments must be smooth enough and be free from vegetation, buildings, etc.

- The aim of the next operation is the transfer of the selected “favourable” fragments (their mathematical representation) to the coordinate system of each aerial photo taking into account their visibility (these fragments may be shielded by terrain features or on-ground objects).
- Using only selected “favourable” fragments (more accurate, their projections onto the photo plans) the stereo model is produced, which now is free from miscorrelation. Of course, such a model is not full, because it is made up from fragments. But this is not a problem with this real-time mapping approach, because the created model has only auxiliary meaning unlike the traditional stereotopography method.
- After that the model produced during the previous stages is finally orientated relatively laser-derived DTM, that corresponds to its orientation in geodetic space. Naturally, the orientation of each frame is carried out also.

GPS principal point coordinates for each photo strictly determine the stereo pair position in space with only one degree of freedom - angle of turning around survey basis vector. So, the final true stereo model orientation in relation to DTM may be done by minimising spatial misalignment function for both laser-derived and photogrammetrical terrain surfaces. This can be done using R.M.S. method, for example.

The described method is just a technological basis for Geokosmos’ activity in all parts of the world for miscellaneous application. In addition to topography survey and DTM making which are definitely the main lines of the both companies’ activity, there are some other important applications where this technology is successfully used. These include:

- Power lines inspection;
- GIS and land use systems;
- Forestry;
- Coastal mapping and monitoring;
- Avalanche and flood prediction;

For more relevant information see the articles listed at the end of this paper and also the Internet sites of both companies.

9. CONCLUSIONS

The technology of real-time mapping was originally introduced by Geokosmos and successfully tested in different aerial survey projects all over the world. This technology is commercially available for customers, it is based on Geokosmos proprietary software and hardware products and is permanently updated to enhance its effectiveness. The technology proved its applicability for wide range of topography and non-topography applications where it can be used instead of combining traditional photogrammetrical and geodetic methods.

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