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Review article

PHOTOGRAMMETRY AT THE WARSAW UNIVERSITY OF TECHNOLOGY – PAST AND PRESENT

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Abstract

The Department of Photogrammetry, Remote Sensing and Geographic Information Systems at the Warsaw University of Technology is one of six organizational units of the Faculty of Geodesy and Cartography. The photogrammetry has been under interest of scientists in Faculty for over 90 years. The last decades has been characterized by the incredible development of photogrammetric technologies, mainly towards wide automation and popularization of derivative products for processing data acquired at satellite, aerial, and terrestrial levels. The paper presents achievements of scientists employed in Photogrammetric Research Group during last decades related to projects that were carried out in this department.

Keywords: *digital photogrammetry, process imaging, automation, LIDAR*

1. Introduction

The Department of Photogrammetry, Remote Sensing and Geographic Information Systems at the Warsaw University of Technology is one of six organizational units of the Faculty of Geodesy and Cartography. Two teaching groups are active within the structure of the Department: the Photogrammetry Group, and the Remote Sensing and Spatial Information Systems Research Group. This division reflects two basic directions of performed research works: the photogrammetric surveys and the remote sensing implemented spatial information systems. At present, four research and didactic laboratories exist: the Laboratory for Satellite Remote Sensing, the Laboratory of Spatial Information Systems, the Laboratory of Digital Photogrammetry, and the Laboratory for Close-Range Photogrammetry. They all serve didactic purposes as well as the scientific development of the staff and graduate students. This paper will discuss the research works performed in the field of digital photogrammetry by the Photogrammetry Research Group.

The Institute of Photogrammetry and Cartography was established in the academic year 1970/71 at the Faculty of Geodesy and Cartography. The Photogrammetry Group was a part of the Institute until 2007. In 2008, after organizational changes at the Faculty, the present Department of Photogrammetry, Remote Sensing and Geographic Information Systems was established.

2. A brief historical description of research works

Activities at the Department of Photogrammetry began in the 1920s. Professor Bronisław Piątkiewicz was the instigator of those activities: he was responsible for the photogrammetric laboratory in the period 1926–1939, and also taught in the Department. Following his initiative, the Photosurveying Division was established at the Ministry of Public Works in 1924, and in 1928 photogrammetric works were started at the Design Office of Water Melioration in Polesie.

Among other individuals, Professor Edward Warchałowski, the Rector of the Warsaw University of Technology and author of the first photogrammetry manual (*The outline of photogrammetry*, 1911), and Professor Marian Brunon Piasecki, who was involved in teaching activities at the Warsaw University of Technology for his entire adult life (between 1927 and 1975), and authored the university manual *Aerial and terrestrial photogrammetry*, which would become a source of photogrammetric knowledge for many generations of Polish photogrammetrists, should be mentioned in particular. Professor Piasecki connected teaching activities with the practical implementation of photogrammetric methods in the national economy. He was the founder of the first photogrammetric company, Fotolot, established in co-operation with Polish Airlines in 1930. The company developed photogrammetric aeroplanes, which were used, among other things, to create photoplans of more than five million hectares for the Ministry of Treasure. Photoplans were also developed to meet the needs of water melioration and several dozen Polish cities.

Development of photogrammetry after the war was limited, due to the limited access to aerial photographs resulting from regulations concerning the protection of secret information. This resulted in a greater interest of the Department staff in terrestrial photogrammetry, at the expense of aerial photogrammetry.

One of the main areas of interest was creating photogrammetric inventories of architectural and archaeological monuments in Poland and abroad, such as the Old Town in Warsaw, Wiślica, Opatów, Głogów, and the ruins of Saint Brigitte's Church in Gdańsk, as well as restoration of the shape of the upper fragment of the tower of Warsaw Royal Castle based on existing amateur photographs (acquired before the war), and documentation of historical objects in Egypt, among others Deir el-Bahari before it was flooded. Research works performed in the framework of engineering surveys by the Photogrammetry Group were developed. Numerous research topics and implementation works were performed on, among other subjects: dynamic changes of shapes in the process of explosive pressing based on images acquired by a speed film camera; spatial shapes of prefabricated building elements; static and dynamic deformations of lift prototypes; and changes of bearing elements (trusses) of constructions of industrial halls in the area of a copper mine in Lubin.

Despite the limitations connected with the impossibility of using aerial photographs, methods of analytical photogrammetry continued to be developed at the Department, including block aerial triangulation by independent models and independent bundles. These works were supported by the development and growing accessibility of computer calculations. Other research works, concerning, among

other subjects, geometric correction of airborne scanner and radar images, were also developed. The eighties and nineties were characterized by interest in non-photographic techniques and their use, for example in medicine for measuring shapes and changes of body parts (backbones, faces, examinations of eye grounds) with the use of stereo-X-ray photographs and the analogue moiré technology.

In the eighties, the world was shifted from analogue photogrammetric techniques into digital photogrammetry. In photogrammetric works, analogue stereo plotters were substituted by analytical stereo plotters, and digital forms of maps started to dominate in elaboration of maps based on aerial photographs.

This trend was reflected at the Department of Photogrammetry in the form of intensive works aiming at modernization of analogue photogrammetric equipment (stereo plotters, stereo comparators) and its adaptation to analytical works. This concerned analogue and analytical aerial triangulation, digital mapping technology, or digital terrain model (DTM) technology. Many production companies were interested in the results of these works, and they were also implemented in many places.

New research and didactic opportunities were generated by the purchase of P-3, the analytical stereo plotter, at the beginning of the nineties. Works concerning the technology of digital map development based on aerial photographs, generation of DTMs and improvements of methods of inventorying historical objects were also performed.

3. Beginnings of digital photogrammetry

The onset of the eighties and the nineties meant the rapid development of digital photogrammetry, which has been continuing till today. The digital form of data is the main characteristic of digital photogrammetry. Instead of an analogue form (on a film) photographs occur in raster form, and are processed by means of a photogrammetric digital station. Specialized software tools installed on the station determine the photogrammetric functionality. Such stations are therefore called “digital stereo plotters”.

The year 1991 is considered as the beginning of the era of digital photogrammetry, as this is when the first commercial photogrammetric stations were made available on the market. During the second half of the nineties, such stations started to supplant analytical stereo plotters in photogrammetric production works (Kurczyński, 2005, 2007). Digital technologies started to dominate. During the first years of the era of digital photogrammetry, photographs were the only exception in the technological process. In order to input them into the digital technology, it was necessary to transform their analogue form into the digital form through scanning with specialized scanners. The appearance on the market of aerial digital cameras (2000 r.) and the gradual substitution of analogue cameras allowed that exception to be eliminated.

The transformation of photographs into the digital form may seem a technical operation only, especially given that photogrammetric methods applied in further processing of photographs remained unchanged. The issue that has decided the attractiveness of digital photogrammetry and its unquestionable successes is automation.

Processing of photographs in the digital form allows for digitalization. At present, photographs may be observed automatically based on so-called image matching techniques (similar to the computer vision applied in robotics). Automation of observations is one of the keys to automation of the overall aerial triangulation

process. The advanced computer technique allows blocks of thousands of photographs to be connected automatically and adjusted in one process.

Contemporary photogrammetry, including digital photogrammetry, is not limited to processing aerial photographs only. Other important sources of data are airborne laser scanning (LiDAR) and terrestrial laser scanning. The importance of image data acquired from the satellite level is also growing. These sources of data are the subject of interest in digital photogrammetry, where they can be a subject of automated process.

Also in the field of close-range photogrammetry, the nineties were a turning point, marking the beginning of the digital era. The emergence and development of digital cameras, in particular high-resolution cameras, resulted in a revolution in photogrammetric measuring techniques. Digital photogrammetry, including close range photogrammetry, became an interdisciplinary technique, connected with digital processing and recognition of objects in images, computer-assisted visualization and graphics, or real-time automatic control of precise production processes (Bujakiewicz et al., 2014). A popular task was creating 3D models. Three-dimensional modelling of objects is considered a complete process, from acquisition of data to generation of 3D virtual models. Development of terrestrial laser scanning technology considerably widened the scope of 3D modelling. Three-dimensional photogrammetric models, combined with the texture, allow for interactive visualization, connecting with additional information concerning these models and recording them in GIS databases.

In 2000, the modern digital photogrammetry laboratory, equipped with several stations, was established at the Department of Photogrammetry for teaching and research purposes. Following the world trends, teaching of photogrammetry shifted towards an emphasis on digital technologies.

That period coincided with fundamental systematic changes in Poland. In the field of photogrammetry, a market was created in aerial photogrammetric services. A programme aiming to provide colour aerial photographs of the entire country was planned for the years 1995–98 by the Head Office of Geodesy and Cartography (GUGiK) within the EU Phare PL9206 Programme “Land Information System”. Implementation of these photographs represented an “exceeding of the critical mass” in the development of photogrammetry in Poland and in the popularization of the use of aerial photographs and derivative products for many purposes. Service companies using modern equipment were founded, as well as photogrammetric companies able to process photographs using digital techniques.

The new political and economic situation supported the creation of new companies implementing digital techniques. This was also supported by photographs acquired in the framework of the Phare Programme. The end of the 20th century was characterized by the rapid and growing demand for photographs, first in the analogue and soon in the digital form.

The Head Office of Geodesy and Cartography started the pilot implementation of the Topographic Database with an accuracy corresponding to the scale of 1:10 000, aiming at the development of standards of implementation for this huge project. The standards were completed in 2003.

Another serious challenge for the national geodetic service was the necessity to create the LPIS – the Land Parcel Identification System, which was key in deciding subsidies for EU farmers. In Poland, this system was based on a digital orthophotomap in two standards: resolution 0.25 m for south-east Poland, and resolution 0.50 m for other areas. The orthophotomap was developed from

photographs at the scales of 1:13 000 and 1:26 000, respectively. Complete coverage of the orthophotomap from images at that scales was achieved in the period 2002–2004. Photographs and orthophotomaps are permanently updated every four years.

In the period 2007–2011, Polish photogrammetric companies were gradually transferring to the use of digital cameras. Research workers at the Department of Photogrammetry were intensively involved in these changes and the attempts to meet the new challenges. This was reflected in the participation of the entire Department or certain of its members in some of the most innovative projects.

In that period, research works concerning geometric correction and the usefulness of high-resolution satellite images to supply data for topographic databases were initiated in response to the emerging VHRS satellite systems. Several research projects were performed (grants from the Committee of Scientific Research – KBN). These included "Geometric correction of high-resolution satellite images and their use for database creation" (2003–2005) (Kurczyński & Wolniewicz, 2006), and "Processing vector elements of a topographic database and methods of the discrete technology of multispectral analysis of surface changes based on high-resolution satellite images" (dedicated grant, 2003–2005; practical implementation at the Warsaw Surveying Company).

Research works in the field of close-range photogrammetry were also performed during the same period. They concerned, among other things, the development of the projection moiré with automatic analysis of images and specialized medical software for examination of posture faults (Zawieska & Spik, 1990; Zawieska & Podlasiak, 1992; Zawieska, 2003). A KBN grant funded the study "Digital modelling of fragments of sculptures in order to reconstruct the original context of a monument" (2004–2006). The objective was to examine the possibilities of applying digital photogrammetric methods for precise reconstruction of fragments of sculptures to allow their mutual matching (Bujakiewicz et al., 2006a, 2006b, 2008). Experiments were performed using exhibits from the National Museum in Warsaw and the Egyptian Museum in Cairo. An original method for matching fragments of broken sculptures with the use of an amateur digital camera and an appropriate control network was developed (Fig. 1).

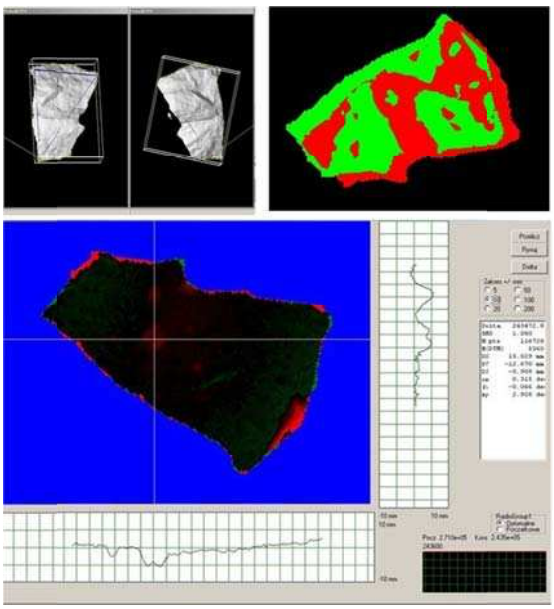

Fig. 1. Example of broken sculptures (Bujakiewicz et al., 2008)

Another important research project funded by a KBN grant was “Testing the true-ortho quality with respect to the applied source data” (2007–2009). All factors influencing the final quality of the true-ortho were examined (Preuss, 2012; Kurczyński & Preuss, 2009; Kowalczyk et al., 2009, 2010). Its methodological element examined conditions of registration of data from different sources: aerial analogue and digital cameras, electro-optical scanners, and high-resolution satellite images (VHRS).

Fig. 2. Examples of: orthophotomap (a), true-orthophotomap (b)

As a result, technological recommendations for the process of true-orthorectification (Fig. 2), the influence of particular technological conditions for final product quality, and production costs were determined.

4. Current research works

The current decade has been characterized by the further development of photogrammetric technologies, mainly towards wide automation and popularization of derivative products for processing data acquired at satellite, aerial, and terrestrial levels.

In the field of aerial photogrammetry, beyond “conventional” photographs acquired by digital cameras, interest in airborne laser scanning (ALS) and data acquired from unmanned aerial vehicles (UAV) has rapidly grown. This has resulted in the emergence of a new photogrammetric term – “low-altitude photogrammetry”. Besides vertical photographs, oblique photographs have become very popular, particularly for the spatial modelling of objects. A strong trend to combine multisource data, in particular photographs and data from scanning, may also be observed. It is very common to transfer from two-dimensional (flat) projects to three-dimensional (spatial) works.

As a result of new financial possibilities, as well as to meet obligations resulting from legal regulations, the following tasks are widely performed in Poland:

- obtaining laser scanning data on the whole country in order to generate an elevation model, to meet the needs, first of all, of the development of flood risk and flood hazard maps (ISOK Project – IT System of the Country Protection against Extreme Hazards) (Kurczyński, 2012; Kurczyński & Bakuła, 2013),
- creation of topographic object databases at an accuracy corresponding to topographic maps at the scale of 1: 10 000 (BDOT10k Project),

- modernization of land and building registration (ZSIN Project – the Integrated Real Estate Information System),
- 3D modelling of landscapes, including 3D city modelling (one task of the Spatial Analysis Centre of the Public Administration Project – CAPAP.

The staff of the Department of Photogrammetry have been actively involved in all of these main areas of activity.

As in the past, the present research works performed by the Photogrammetry Group are highly connected with the world trends on the one hand, and tasks formulated in Poland on the other.

In the field of aerial data processing, these research works are focused on the combination of image data with scanner data in order to enhance accuracy (Bakuła et al., 2015) and create spatial models of objects and entire cities. For that purpose, oblique aerial photographs are additionally applied (Fig. 3) with distinction of the subject related to their effective orientation (Ostrowski & Bakuła, 2016).

Fig. 3. Example of Katowice 3D model based on oblique aerial images

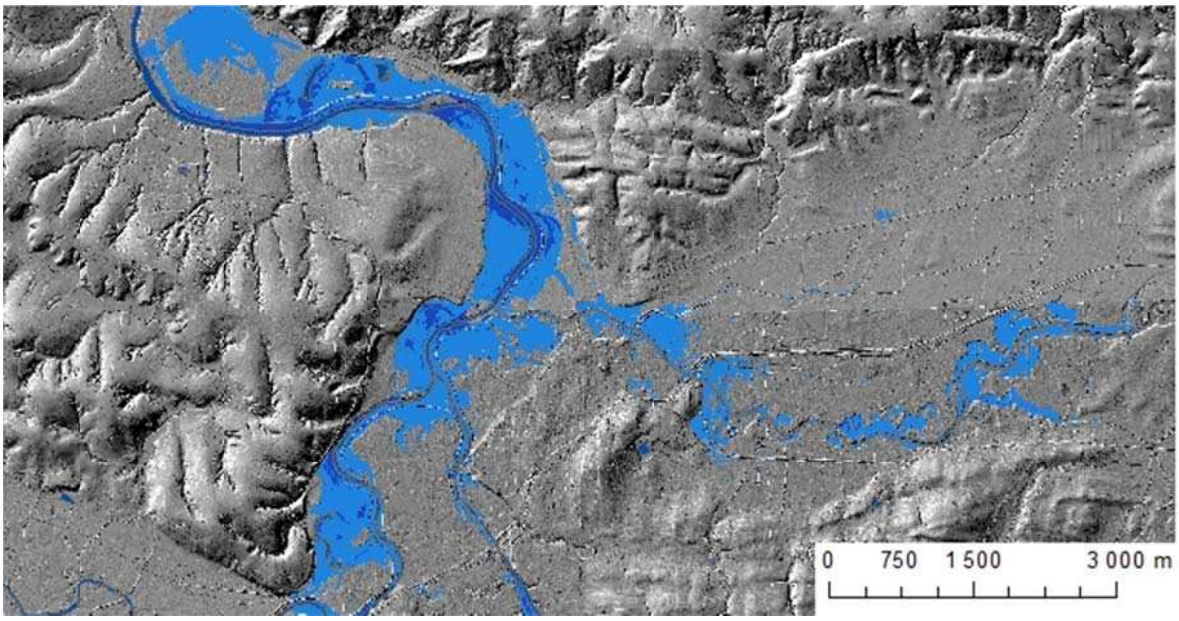

Fig. 4. Example of the results of hydraulic modelling with use of airborne laser scanning data – water depth layer overlying shaded digital terrain model.

Another research avenue is the development of the methodology of using airborne laser scanning data for flood protection. The research project Ventures 9/2012, "The reduction of height data contained in digital terrain models obtained by airborne laser scanning for the purpose of hydraulic modelling" (2012–2014), financed by the Foundation for Polish Science from Innovative Economy Fund, and a doctoral thesis entitled "The role of the reduction of elevation data obtained from airborne laser scanning in the process of flood hazard map creation" were performed in that area with use of data reduction allowing the effective implementation of two-dimensional hydraulic analysis for large-scale studies (Bakuła, 2013; 2014).

Works on the valuation of the possibilities of applying digital photogrammetry for modernization of land and buildings registration (EGIB) were also initiated.

Multi-direction research works concerning the use of photographs acquired from UAV platforms for different applications (Bakuła & Ostrowski, 2012), including modernization of land and buildings registration for small objects, have been continued. It is worth mentioning the project "The evaluation of the possibilities to use low-altitude photogrammetry for selected surveying tasks" (2016) in particular (Fig. 5, 6) (Kurczyński et al., 2016; Zawieska et al., 2016).

Recently, implementation of a big three-year research and development project financed by the National Centre of Research and Development has begun, "Advanced technologies in the prevention of flood hazard (SAFEDAM)"; solutions described in Bakuła et al. (2016) are being implemented to increase Poland's security and defence abilities.

Intensive works in the field of close-range photogrammetry have also been performed (Bujakiewicz & Zawieska, 2011). In particular, they cover digital image processing issues, automation of photogrammetric measurements, 3D modelling and visualization of objects, integration of multi-source photogrammetric data, and utilization of terrestrial laser scanning and digital images in many sectors of the economy, in particular in cultural heritage protection and industrial surveys. Computer Vision (CV) algorithms are analysed with respect to their usefulness for automatic generation of 3D models of objects. The project "Multi-image matching of close-range photographs for photorealistic 3D model reconstruction" (2009/2011) was performed in that area, forming the basis for a postdoctoral thesis (Zawieska, 2013).

Cooperation with other centres has also been developed, in particular with the Museum of King Jan III's Palace at Wilanów, where research works have concerned development of an innovative method of integrating laser scanning data and digital images in order to develop photogrammetric documentation (Markiewicz & Zawieska, 2014).

Fig. 5. Examples of: a) an intersection with the use of the multi-photo measurement method; b) discrepancies between boundaries existing in the cadastre and real land-use conditions detected on the basis of products from the UAS platform (Kurczyński et al., 2016).

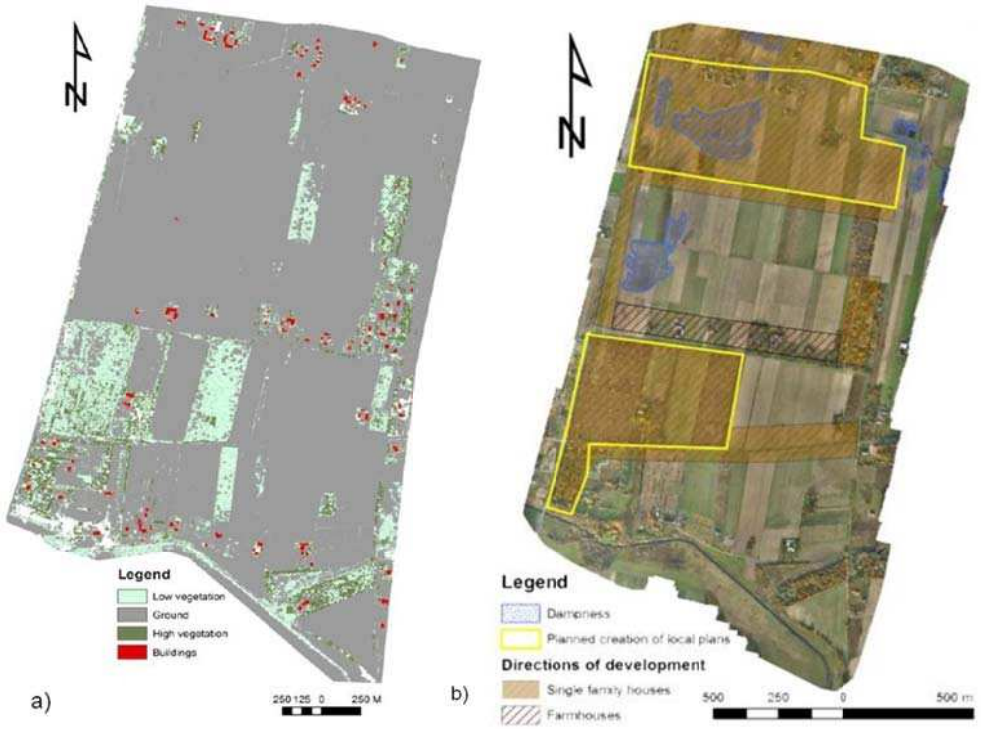

Fig. 6. Examples of: a) land cover map resulting from classification of a point cloud generated from dense image matching; b) identification of areas excluded from development (extensively moist areas), areas to be covered by local management plans, and areas planned for single-family houses (Zawieska et al., 2016)

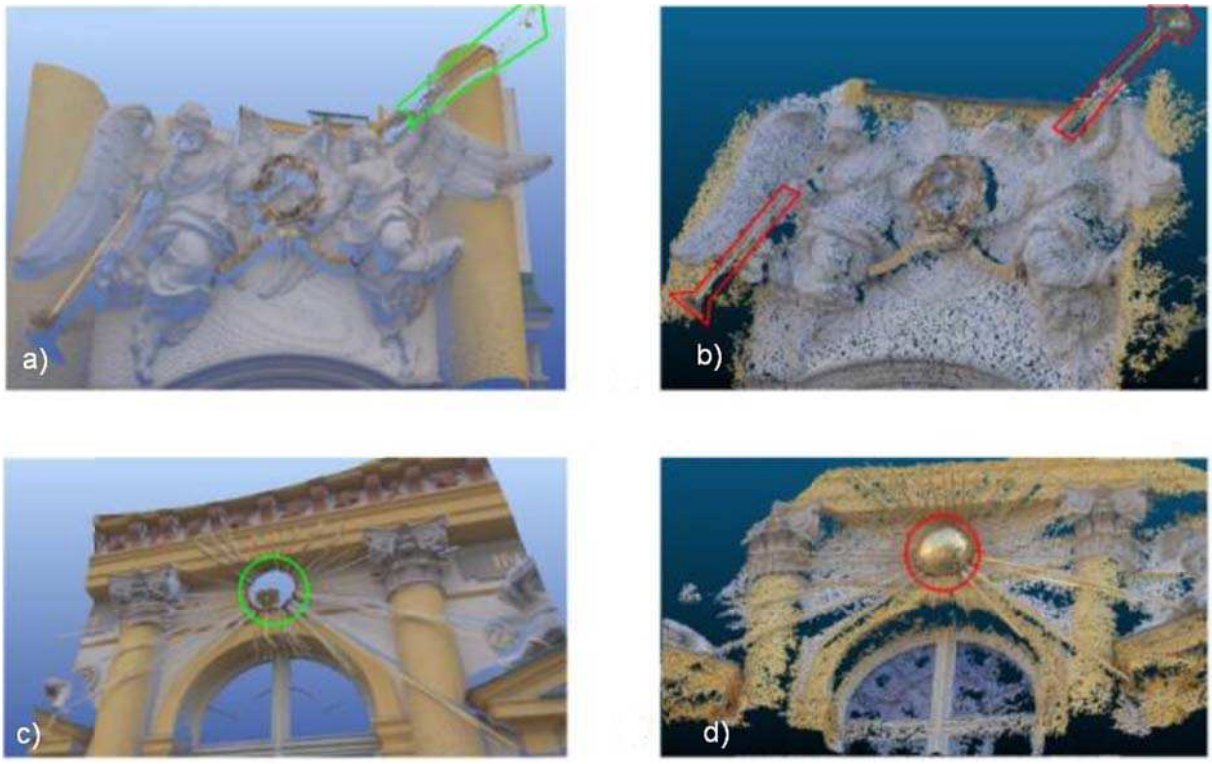

Fig. 7. Examples of: A, C – clouds of points of gilded details, acquired from TLS; B, D – clouds of points acquired from digital image matching (red – blind spots; green – geometric corrections) (Markiewicz & Zawieska, 2014)

Research works are also performed in the Cardinal Stefan Wyszynski University's project "Use of Laser Scanning and Remote Sensing in the Protection, Analysis and Inventory of the Cultural Heritage. Development of Non-invasive, Digital Methods of Documentation and Recognition of Architectural and Archaeological Heritage Resources" within the National Programme for the Advancement of Humanities, established by the Polish Ministry of Science and Higher Education. The ruins of Iłża Castle have also been examined: laser scanning data as well as digital images were used to produce orthoimages, 3D models, cross-sections and vector drawings (Markiewicz et al., 2014). A GIS database was designed which was used to store all multi-source data and products. This will permit performance of specialized spatial analyses. The results of the performed research works have included the development of an original algorithm for automatic orthoimages generation, using CV algorithms (Markiewicz et al., 2015).

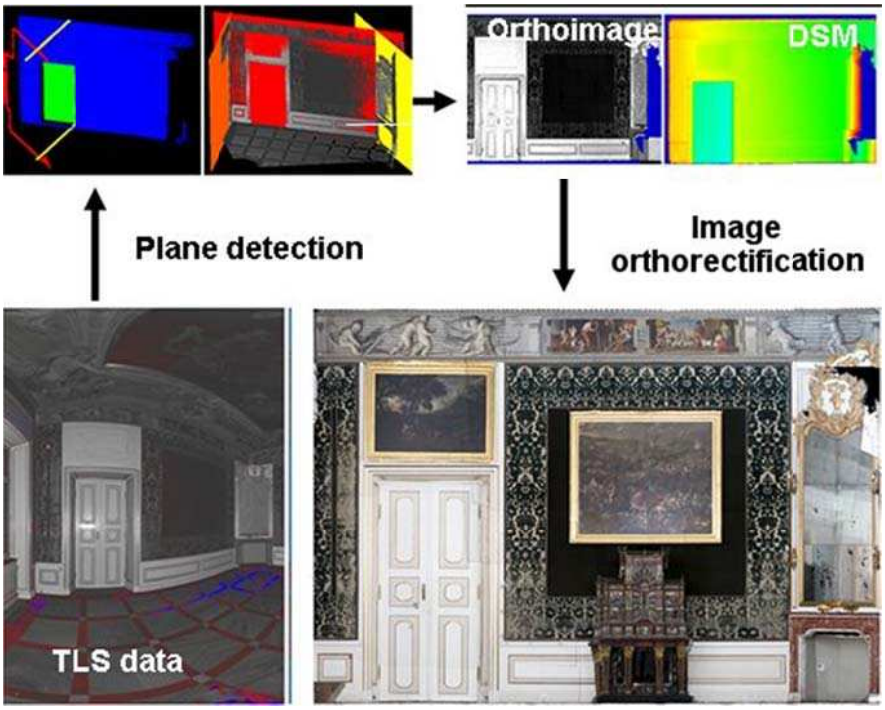

Fig. 8. The schema of automatic orthoimage generation based on CV and photogrammetric algorithms (Markiewicz et al., 2015).

At present, a doctoral thesis entitled "Investigation of possibilities to apply raster intensity images and image matching methods for automated orientation of terrestrial laser scanning data" is being finalized.

Another direction of research is the use of archival data for reconstruction of non-existing historical objects (e.g., the altar at the Saint Cross Church in Warsaw (Zawieska, 2008), the White Palace in Piastów, and the Large Buddha Statue (Zawieska & Markowski, 2010)). At present, the Polish National Heritage Board's project "Investigations of development of the Lusatian settlement at station 4 in Biskupin. Pre-war examinations" is being performed, which was proposed by the Biskupin Museum; staff from the Department of Photogrammetry will develop 3D models of the settlement in Biskupin based on archival photographs. Then, the GIS database will be designed, which will be the basis for analysing and visualizing particular stages of development of the settlement.

Within the framework of implementation and co-operation with the industry, the Smarttech 3D Company is performing the project “Development and practical implementation of a complex, remote system of measurements of industrial facilities adapted to the needs of metrological measurements in conditions of high illumination by the Sun” within the Smart Growth Operational Programme 2014–2020, 1/1.1.1/2015. The aim of the Department of Photogrammetry is to develop the original photogrammetric module, integrated with a 3D scanner created within the framework of the programme. The objective is to develop software tools which will allow partial scanning of large elements in one co-ordinate system, and tracing of markers located on the contact attachment.

Fig. 9. Example of diploma thesis (Piotrowski & Piegat, 2015) which was awarded in "The best diploma thesis competition for geodesy and cartography students" (first place) organized by Association of Polish Surveyors.

The results of the performed research works are being presented during national and international conferences and published in many reputable journals in Poland and abroad. Such research also positively translates into teaching programmes, and both graduates and students are actively involved. Among other things, this results in a high number of engineering Master’s diplomas (Fig. 9). Several students have been successful in nationwide diploma thesis competitions.

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