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NEW CLOSE-RANGE PHOTOGRAMMETRIC TECHNOLOGIES

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Abstract

The work suggests the theoretical and practical experience of three international summer schools which propose to promote the new geomatics technologies, very useful for students and specialists, to solve many civil engineering works in many domains. A complete approachment of analytical and digital photogrammetric methods using CAD systems, combined with laser scanning and other non-destructive research techniques of remote sensing has the purpose of finding the best solution for surveying, inventorying, monitoring, restoration and conservation of space-objects. The benefit of combination of close-range photogrammetric methods with others geomatics and geophysics researches is that it provides a solid technical documentation of a space-object as a basis for technical rehabilitation or restoration planning, a total inventory, both quantitative and qualitative. In the framework of the photogrammetric complex process, the work refers to the computer representation techniques of space object obtained by photogrammetric methods for the processing of thematic data interpretation and their mathematical modeling. There are presented new 3D acquisition and processing procedure to map RGB, thermal IR and near infrared images (NIR). The combination and fusion of different data sources allows the generation of 3D thermal data useful for different purposes such as localization, visualization, and analysis of anomalies in contemporary architecture.

Keywords: *Architecture, Geomatics, Laser scanning, Photogrammetry, Surveying.*

INTRODUCTION

The Close-Range Photogrammetry (CRP) relies on the reconstruction of the object simultaneously from several images from different and best possible perspective to ensure a suitable geometry of intersecting rays. (A. Behrens, C. Lasseur, D. Mergelkuhl).
By definition, close-range photogrammetry is meant to be when the distance (range) from the camera to the object of interest can be from 1 m to aprox.300 meters. (J.R. Watson)
The ever-expanding areas of application of close-range photogrammetry can be grouped into three major areas: architectural photogrammetry, biomedical and bioengineering photogrammetry (biostereometrics) and industrial photogrammetry.
CRP is an accurate, cost effective technique of collecting measurements of real world objects and conditions, directly from photographs. Digital Photogrammetry utilizes digital images to obtain accurate measurements and geometric data of the object or area of interest, in order to provide spatial information for engineering design, spatial surveys or 3D modeling.
The benefits of CRP over other field procedures are purported to be: increased accuracy, complete as-built information, reduced costs, reduced on-site time for small and large projects.
Industrial CRP has been described by Meyer (1973) as *"application of photogrammetry in building construction, civil engineering, mining, vehicle and machine construction, metallurgy, ship building and traffic, with their fundamentals and border subjects, including the phases of research, planning, production engineering, manufacture testing, monitoring, repair and reconstruction. Objects measured by photogrammetric techniques may be solid, liquid or gaseous bodies or physical phenomena, whether stationary or moving, that allow of being photographed"*.
Another new technology which is combined very well with CRP techniques is **Terrestrial Laser Scanning (TLS)** which provides highly accurate, three-dimensional images enabling designers to experience and work directly with real-world conditions by viewing and manipulating rich point-clouds in CAD software. By sweeping a laser beam over a scene or object, the laser scanner is able to

record millions of 3D points. These X,Y,Z measurements can be imported into CAD or 3D application software and displayed on a computer monitor as a point cloud of points which has photographic qualities portrayed in one-color, gray-scale, false-color or even true color. Since all laser scan points are 3D, the files can be viewed, navigated, measured and analyzed as 3D models.
Another new technology use **Close-Range Panorama Photogrammetry** which realizes accurate 3D documentation with high resolution 360° panoramic images. [2]

Figure 1 - FODIS panorama camera together with a tablet PC for camera control and image storage.

Panoramic cameras with Linear Array CCD have been originally built for purely imaging purposes, but they also have a high potential for use in high accuracy measurement applications. Panoramic cameras have the advantage of high information content with giga-pixel format size and 360° field of view. *"Viewing 360° images is a natural way for the human being to perceive an space-object environment. The ability to process data directly from 360° high resolution panorama RGB images makes the workflow extremely intuitive, natural and realistic"* (Jafar Amiri Parian, 2012).
Terrestrial applications might also exploit findings and achievements of IR sensors that have been used for many years in satellite and airborne applications. The use of infrared (IR) sensors is today a fundamental tool in many close-range and terrestrial applications.
A new 3D acquisition and processing procedure to map **RGB**, **thermal IR** and **near infrared images (NIR)** on a detailed 3D model of a building was presented in Figure 2, *Remote Sensing Journal,*(Alba M.I,Barazzetti L, 2011).

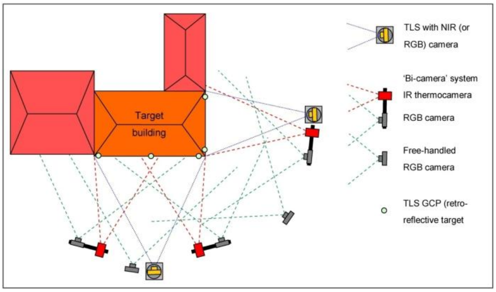

Figure 2. Example of data acquisition process for mapping IR/NIR/RGB images on a 3D model of a building.

The combination and fusion of different data sources allows the generation of 3D thermal data useful for different purposes such as localization, visualization, and analysis of anomalies in contemporary architecture.
Near infrared cameras (NIR) are sensitive to the wavelengths in the range 0.75 μm $< \lambda <$ 1.4 μm and are usually used for the analysis of vegetation.
Infrared thermography (IRT) is mostly used as a preliminary investigation tool, a direct survey of the shape, materials and their damages is necessary to know the real state of the surface to analyze. Now, Infrared Imaging Techniques are used for the analysis of space-object and for buildings especially.
Thermal scanning of a structure allows one to collect information regarding technological elements, shape, physical characteristics of materials, and state of decay. Different kinds of defects affecting building structures can be detected by the analysis of surface temperature, submitted at particular boundary conditions.
Another relative new technology is UAV (Unmanned Aerial Vehicles) photogrammetry which opens various new applications in the close range domain, combining aerial and terrestrial photogrammetry, but also introduces low-cost alternatives to the classical manned aerial photogrammtery.
UAV Photogrammetry is a new terminology, introduced in 2009 by Henri Eisenbeiss from Institute of Geodesy and Photogrammetry ETH Zurich, which describes photogrammetric measurement platforms, which operate as either remotely controlled, semi-autonomously, or autonomously, all without a pilot sitting in the platform, and the photogrammetric processing

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of UAV images. The broad definition covers balloons, kites, gliders, airships, rotary and fixed wing UAVs with the capability for photogrammetric data acquisition in manual, semi-automated and automated flight mode.

The main research in the photogrammetric community should focus more on the integration of the sensors like camera units and LiDAR (Light Detection and Ranging) system as well as the communication with navigation and control unit. It is important also to develop a multi spectral micro sensor concentrated on the use of mini and micro UAVs in agricultural applications.

Figure 3 - Overview of various UAV systems. [10]

These kinds of UAVs (shown in the Figure 3) are more depending on weather and local conditions, since these systems are difficult to control on a predefined path. In addition, most of them are not stabilized, which complicates the hovering on a position.

For the integration of different sensors on the same UAV, the exterior orientation has to be known and therefore the accuracy of the various sensors implemented into the platform has to be investigated.

In the last years, UAV/UAS are used for archaeological applications and cultural heritage documentation, monitoring of hazards, environmental and agricultural applications etc.

MATERIALS AND METHODS

The present paper use the theoretical and practical experience accumulated in three years of international summer schools, held in Italy, organized by Pietro Grimaldi from the *Politecnico di Bari*, based on various simulation models for the period 2010-2012 and which have had the purpose to promote the new geomatics and geophysics technologies, very useful for students and specialists, to solve many civil engineering works in many domains.

I have used also the previous expertise and applications in many projects of analogical, analytical and digital photogrammetry in Romania.

RESULTS AND DISCUSSIONS

A simple question is ―*which camera should be used or purchased when applying CRP to the Earth Sciences"*? (ISPRS 2010)

There is not a simple answer, because project requirements should always dictate the design of any measuring system, which should include camera selection.

In 2010, the photogrammetric data acquisition was made with three digital cameras Nikon D1X calibrated before and mounted on an aluminum steel ruler of 2,000 mm.

Camera positions were chosen according to the best available photogrammetric configuration rules, and system used is shown in the Figure 4 (designed by Italian firm Menci Software).

Figure 4 -Three professional digital cameras Nikon D1X

Sometimes, mathematically a number of factors complicate the terrestrial photogrammetric modeling (camera positions and orientations are irregular; multiple exposures from the same station; uncalibrated cameras; not fixed lens; each photo has a different focus setting; local reference system). Terrestrial photogrammetry often use DLT (Direct Linear Transform) as a way of linearising the collinearity equations, to get a linear transformation between image space and object space coordinates, and get camera parameters from image measurements.

We used a minimum of six non-coplanar control points in XYZ coordinates.

Almost all non-topographical projects use *Bundle adjustment solutions,* with the object coordinates and the camera stations as unknowns. Simple rules which are to be observed for close range photography with non-metric cameras have been written, tested and published on the CIPA-Symposium in Sofia, in 1988. They are called the "3x3x3 Rules", because they are structured in three items, with three sub-items each, for simple photogrammetric documentation of architecture

3 geometric rules:
- Prepare control information,
- Multiple photographic all-round coverage,
- Take stereo-pairs for stereo restitution.

3 photographic rules:
- Keep a constant camera's interior geometry,
- Select homogeneous illumination,
- Select a stable and large format camera.

3 organizational rules:
- Make proper sketches,
- Write proper protocols,
- Don't forget the final check.

In the field of surveying and mapping, accuracy and reliability of measurement tools are the key of success.

If we know the conditions for the photogrammetric project (type of camera, type of instrument, which systematical errors will be modeled, mathematical models used, adjustment method/software used, etc.) then we can make experience-based predictions of the RMS error in the final result.

Laser scanning for inside and outside objects was made with Terrestrial Laser Scanner *Leica Scan Station 2* (shown in the Figure 5) and a number of marks uniform distributed on building corners were used to register scans captured. The check points used are in the same ground coordinate system used for external orientation of photos.

For fusion digital photogrammetric data with laser scanning data, it's very important to have the same coordinate system. So, for each point from the cloud corresponding to image pixel we know the space coordinates (X, Y, Z), the intensity and the three color components (RGB). In that way we can assign the corresponding image pixel for each space point from the cloud.

Figure 5 - Terrestrial Laser Scanner *Leica Scan Station 2*

Finally the main advantage of 3D images obtained after fusion is that moving the mouse on the 3D image, on line 3D coordinates for pixels are displayed on the computer screen. We can extract point coordinates from the image and we can interpolate space coordinates between pixels using interpolation algorithms.

The accuracy of 3D images depends mainly on the accuracy of the points cloud used and the ground pixel size of the images.

The new SLR (Single-Lens Reflex) cameras can be equipped with CCD (Charge-Coupled Device) or CMOS (Complementary Metal Oxide Semiconductor) and these sensors have a pixel size of a few micrometers, and thermal cameras have pixel size between 30 and 50 μm. Digital SLR cameras tend to give better results than compact digital cameras. The number of megapixels is important with high resolutions providing more information, but if the lenses are of low quality, images will lack sharpness and clarity whatever the resolution. Digital SLR cameras are generally equipped with higher quality lenses than compact cameras and therefore give better results. In addition, digital SLR cameras normally provide more controls for image capture, so tend to be more versatile and hence capable of tackling more diverse problems (Chandler et al, 2003). Such cameras also offer the best high ISO performance - this allows working indoors without the need for a tripod or flash or to stop down aperture for increased depth of field.

The main advantages of SLR cameras are:
- the possibility of changing lenses in order to cope with several camera-object distances;
- the availability of large formats for CCD (or

CMOS) sensors that allow one to capture large views of the object and to improve the image block geometry.

A calibrated SLR camera can be used in applications with a precision required of 1:100,000 [4].

Key stages which allow for accurate spatial measurement using digital cameras must be:

- Test-field calibration to derive an approximate lens model;
- Provide sufficient control for restitution and providing independent checks;
- Obtain images for object recording using a convergent image pair configuration with an overlap of 90-95%. If multiple image pairs are combined to mosaics, an appropriate overlap between adjacent convergent pairs can be 5-10%;
- Spatial measurement using digital photogrammetry, including automated DEM acquisition.

For example, the photogrammetric surveys of historic and art monuments can be grouped in three major categories: rapid and relatively simple surveys, accurate and complete surveys, and very accurate surveys.

Rapid and relatively simple surveys are used in preliminary studies for restoration and improvement, in inventory work, and in the study of the history of art. Stereometric cameras and other small format photogrammetric cameras are used extensively, together with normal case stereo plotters. Plotting is generally at a scale of 1:100.

Accurate and complete surveys are used for systematic documentation of architectural heritage. Plotting scale is generally 1:50, while the details are mapped at 1:20 or 1:10. Large-format metric cameras with long focal lengths are preferred in this type of work in view of the accuracy requirements and the sizes of buildings surveyed. The recently developed wide-angle cameras having focal lengths ranging between 100 - 150 mm are particularly suitable for this class of photogrammetric surveys. Such surveys are conducted in conjunction with restoration and consolidation projects. The highest possible accuracy is needed for these purposes and, depending on the needs, the final outputs of the survey can be in the form of plans, cross-sections, elevations and profiles.

Very accurate photogrammetric surveys are needed for highly refined studies. Accuracy requirement is generally in the order of ±1 mm and in some cases ± 0.1 mm. The study of sculptures in monuments and the assessment of the evolution in the surface of defaced stones, in support of chemical and physical investigations into the ―disease of the stone" require this very high accuracy.

For example, two different kinds of sensors are used in IR thermo-cameras. The most largely adopted technology is based on thermal detectors, which feature has a sensitivity in the order of ±0.1 K. Currently, cameras with sensor size inferior to 320 × 240 pixels are used for analyses in building maintenance practice. Larger sensors are also available (up to a size of 1280 × 960 pixels), although at an absolutely different cost.

In the *Remote Sensing Journal 3, 2011*, there are presented three possible combined systems tested before for close range data acquisition:

- ―Bi-camera" system, including a Nikon D80 SLR (3,872×2,592 px, f = 20 mm) and an IR Thermocamera AVIO (320 × 240 px, resolution 0.08 K; FoV 26° × 19,6°, IFOV 1.4 mrad, f = 74 mm);
- ―Bi-camera" system, including a Nikon D80 SLR and an IR Thermocamera NEC H2640 (640×480 px, resolution 0.03 K; FoV 21.7° × 16.4°, IFOV 0.6 mrad, f = 50 mm);
- TLS Riegl LMS-Z420i integrating a SLR camera Nikon D100 (3,008×2,000, f = 20 mm) to gather RGB or NIR images.

IRT is a non-destructive and non-contact technique based on the measurement of the heat energy and its conversion into an electrical signal which is turned into a thermal digital image by a microprocessor. As is well known from [3], the maximum emitted electromagnetic wavelength (λ_{max}) of an object is inversely proportional to its absolute temperature (T):

$$\lambda_{max} = 2897.8 / T$$

This means that in the field of building analysis, the detection of temperatures is required in the range between −20 °C and 100 °C, corresponding to emitted maximum wavelengths ranging from 7.7 μm to 11.4 μm. As a result, the sensors to be adopted must be able to work in the Long Wave IR spectrum. [3]

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CONCLUSIONS

The use of CRP technology is growing in such fields as: architecture, automobile construction, mining engineering, agriculture, machine constructions, objects in motion, shipbuilding, structures and buildings, traffic engineering, aerospace medicine, anthropometry, child growth and development, dentistry, marine biology, neurology, orthodontics, orthopedics, pediatrics, physiology, prosthetics, radiology, criminology, insurance, etc.

The efficiency of IRT as a non-destructive technique is well documented in many fields of engineering to support restoration or conservation projects and treatments. In civil engineering and architecture, IRT can be successfully used as an alternative to conventional inspection technologies, especially for the detection of subsurface defects and hidden structures in wide areas. IRT is often complemented by other non-destructive techniques such as GPR or sonic measurements.

The integration between photogrammetry, terrestrial laser scanning, and IR thermography allows to optimize mapping of thermal anomalies, to ascertain their location, and to improve the geometric resolution of the final textured 3D model. For the better evaluation of the defect extension allows to prioritize the conservation plan and the modality of the maintenance activity. Furthermore, the released graphic documentation consists of orthoimages that can support the preliminary projects for the conservation plan.

The application of NIR images in building analysis is innovative. NIR images can be easily used to texture 3D models if a low-cost camera is integrated to a terrestrial laser scanner, but we need in the future to understand better the response of construction materials in the NIR spectrum.

Comparative with the traditional aerial photogrammetry, UAV systems can operate autonomously. The coordinates in the flight planning are frequently defined relative to the start point, which allows flight planning independently from existing maps and coordinate systems. Using UAVs it is possible to fly closer to objects than with manned systems and the capability of using UAVs in unaccessible and dangerous areas, and the improvements in the data processing, open up new applications in photogrammetry.

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