УДК 528.073

COMBINATION OF PHOTOGRAMMETRY AND TERRESTRIAL LASERSCANNING – POTENTIALS AND LIMITATIONS. PART 2: SYSTEMS, ALGORITHMS AND APPLICATIONS

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Combination of photogrammetry and laserscanning
System concepts

The basic concepts for the combination of photogrammetry and laserscanning can be distinguished between instrumental solutions and processing aspects. Instrumental solutions are mainly addressed to:

TLS with integrated camera

Meanwhile terrestrial laserscanners with integrated digital camera are offered by most system suppliers. If the TLS is equipped with a typical video camera (up to ca. 1300 x 1000 pixels at 25 fps, example in Fig. 1), the recorded images are usually used for control of the measured object area and colouring the 3D point cloud by the RGB values of the image. The camera has to be calibrated and oriented with respect to the internal TLS coordinate system so that each 3D point can be back-projected into the image. If a high-resolution digital cameras used (example in Fig. 2) real-time processing in video frame rate is not desired but the simultaneous acquisition of high-resolution colour images for subsequent generation of orthophotos or for other photogrammetric applications.

Video tacheometer

Motorized tacheometers with integrated video camera are usually applied for automatic point detection and measurement. Targets with known pattern can be detected, tracked and measured fully automatically. In principle the acquired images can also be used for contour and surface measurements since the exterior orientation of the camera is given by the tacheometer. Some approaches for photogrammetric processing of image data of video tacheometers are reported by Reiterer et al. (2010), as example.

Mobile mapping systems

Systems classified as mobile mapping systems are used for the measurement of lines and driving surfaces, well-defined object (e.g. traffic signs) and urban roads with adjacent facades (see for example: Schwarz & El-Sheimy 2004, Kersten et al. 2009). Image acquisition is done by multicamera systems or panorama cameras. Again, as a pre-condition, all measuring devices and sensors have to be calibrated and oriented with respect to a common platform coordinate system. A special case of mobile platforms is given by remotely controlled aerial vehicles (drones, UAV) which can be equipped with laserscanner and camera if sufficient payload is provided (Fig. 5). Besides recording of aerial images the camera can be used for navigation and stabilization purposes too.

TLS with independent camera

In principle each object measured by TLS can be observed with an arbitrary number of additional images. The joint processing of camera and laser scan data can be utilized in different ways if both systems oriented with respect to the same coordinate system.

Autonomous automotive systems

Autonomous vehicles (robots) are increasingly used for applications in storage houses, logistics or inspection tasks in critical environments etc. Again laserscanners with simultaneous image acquisition are used in order to measure unknown surroundings in 3D from that routes and decisions can be derived. Fully automatically driven cars are recently developed but still in research process, e.g. Leonie (TU Braunschweig, Fig. 6).

Laser projection with cameras

In industrial metrology laser projectors and cameras are applied for numerous tasks. Projection of discrete laser spots is mainly used for applying patterns on untextured surfaces, or for providing unique target points. There is a large variety of system solutions ranging from stationary measuring cabins to hand-held mobile systems. Fig. 7 shows a 3D body scanning system that scans a human body by a mechanically driven laser profile sensor. Fig. 8 illustrates a multi-camera system (Mapvision) which creates points on glass surfaces by laser projection whereby a suitable wave length is stimulating fluorescence. The visible points are measured by a multi-camera set-up. Fig. 9 shows the HandyScan system (Creaform) that projects a laser pattern on the object surface which is then recorded by two cameras. The exterior orientation of the sensor is provided by control points that are typically measured prior to the surface measurement process.

Processing methods
Orthophotos

Geometric image rectifications, orthophotos and image mosaics require a given transformation between image and object surface. It can be formulated as 2D or 3D approaches depending on objet shape and desired map projection. Non-planar objects have to be described either by a geometric model of the surface (e.g. CAD model) or by a sufficiently dense point cloud, e.g. measured by laser scanning. The principle of orthophoto generation is described by Kraus (2004) or Luhmann (2010).

Fig. 1. Laserscanner with integrated camera (Trimble)

Fig. 2. Laserscanner with attached SLR camera (Riegl)

Fig. 3. Video tacheometer (Topcon)

Fig. 4. Mobile mapping system with laserscanner and cameras (Riegl)

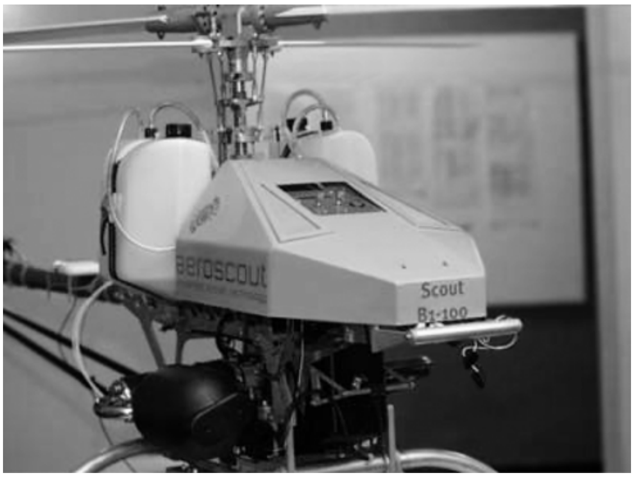


Fig. 5. UAV with laserscanner and camera (Aeroscout, Riegl)

Fig. 6. Autonomous car (TU Braunschweig))

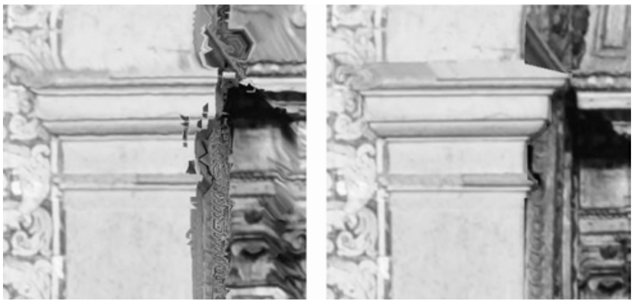
Fig. 7. Body scanner with laser profile sensor (Logisch Consulting)

Fig. 8. System for measurement of glass wind shields (Mapvision)

HandyScan 3D: MaxScan
Object measurement with photogrammetric tie points

Fig. 9. Orientation of a surface sensor by passive tie points (Creaform)

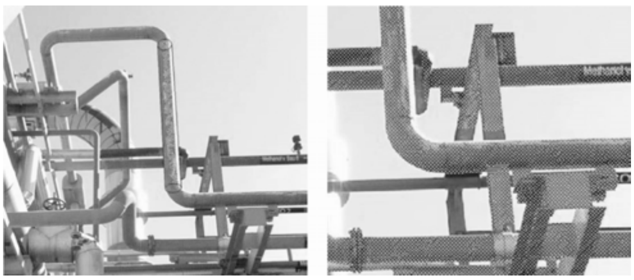
a *b*



c *d*

Fig. 10: Orthophoto of a complex building facade (PHOCAD): a – Original image; b – Orthophoto; c – Object modeling using 3D elements; d – Remaining errors of object modeling using a 3D point cloud

Fig. 11. Matching of interest points in intensity image (laser scan) and RGB image (Shahzad & Wiggenhagen 2010)

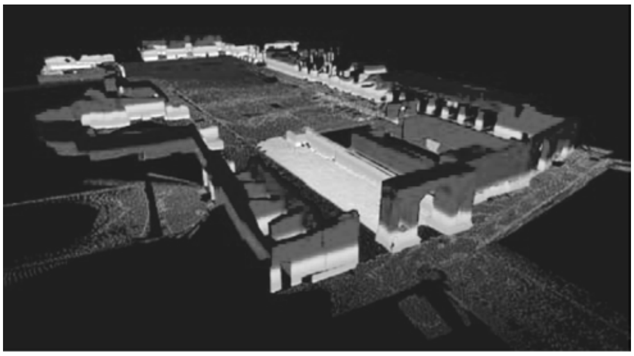


a *b*

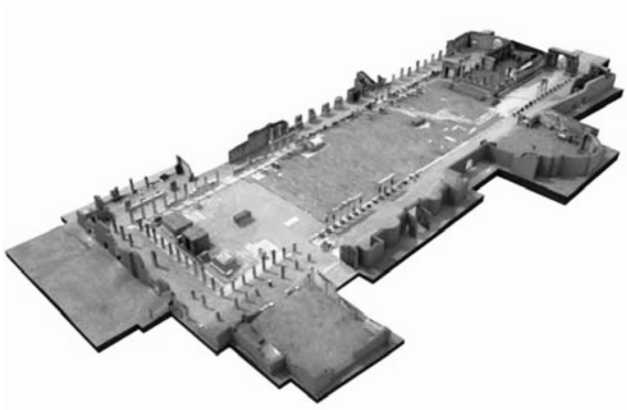
Fig. 12. Monoplotting for pipe measurement by intersecting image rays with 3D point cloud of TLS (Riegl, PHOCAD): a – Image superimposed by a cylinder; b – Image section with superimposed point cloud

High quality orthophotos (true orthophotos) should be free of geometric errors, object occlusions and colour edges between adjacent images of a mosaic. Fig. 10 shows an example processed by PHIDIAS. If a well-structured CAD model is given (e.g. from a photogrammetric measurement) objet edges are clearly defined (Fig. 10c). In contrast, with grid-type surface models or triangulated meshes several artifacts can be observed at the edges of surface patches

Fig. 13. Image-based extraction of road contours (PHOCAD



a



b

Fig. 14: 3D modeling of the Forum in Pompeji (FBK Trento, Polytecnico di Milano): a – Point cloud from terrestrial laserscanning; b – Textured 3D model

if the point density of the mesh is not equivalent to the resolution of the orthophoto (Fig. 10d). For complex objects with occluded areas it is recommended to use a laser scanner and camera with small viewing angle (larger focal length). If all required orientation data and surface models are given the orthophoto process can be fully automated. However, in practice it is often an interactive process if high quality orthophotos results are desired.

Orientation and registration

Due to the higher semantic information content of a digital image several options for the calculation of orientation and registration parameters of a 3D point cloud are provided.

Automatic relative orientation of image pairs and image sequences is practically solved. If coded targets are provided this task is also fully automatic for arbitrary convergent imagery. Nontargeted scenes with small to medium base lines can be oriented by applying interest operators and intelligent matching strategies (overview in Mayer 2007).

Al-Manasir & Fraser (2006) use automatic relative orientation of two images for the registration of 3D point clouds from adjacent stations. Since camera and TLS form a stable and calibrated system the parameters of relative orientation provide directly the 3D transformation of both point clouds. Local control points are not required.

Shahzad und Wiggenhagen (2010) present a registration solution based on the analysis of the intensity image of the TLS and the RGB image of a digital camera. In both images corresponding point candidates are located by an interest operator and matched by a RANSAC approach (Fig. 11).

Schneider (2008) has investigated the integrated processing of TLS and photogrammetry data including panorama cameras with special interest to a joint calibration and orientation within a combined bundle adjustment.

Monoplotting

The idea of monoplotting has been developed in aerial photogrammetry for the measurement of topographic structures by a single aerial image and a given terrain model. The method is well suited in close range for the reconstruction of complex objects (e.g. industrial plants, structured facades) which are recorded by oriented images and 3D point clouds. Identification and segmentation of object features is done by means of the image while the related 3D coordinates are interpolated from the point cloud (Schwermann & Effkemann 2002). Fig. 12 shows an example processed by the software package PHIDIAS (PHOCAD).

Feature extraction

Image analysis methods can be used to extract those features that cannot be detected in simple point clouds due to their related object structure or reflectance properties. As examples, object edge on walls (e.g. jointings) or road marks which can be located by image processing supported by point clouds. Higher geometric elements can be extracted by analysis of adjacent points of the point cloud, optionally under consideration of extracted image edges (Becker & Schwermann 2005). Fig. 13 shows the example of an image-based but interactive extraction of object contours for a mobile mapping application. Under suitable condition edge operators can be used for contour measurement if sufficient image contrast and a more or less simple edge contour are given.

Applications and outlook

Combination, integration and fusion of photogrammetric image data with terrestrial laserscanning offer numerous practical applications. They can be classified as follows:

Static laserscanning with additionally recorded images Mainly building reconstruction, measurement of historical sites, archeological sites, industrial plants etc. where a complex object geometry is existing, results in different resolutions are required, resulting object models and visualizations based on high resolution RGB information are required, high interactive effort is accepted.

Numerous examples have been published in this area, especially in the field of archeology and cultural heritage. Prominent examples are the Akropolis temples in Athens (El-Hakim et al. 2008) or excavation sites in Pompeji (Remondino 2007, Guidi et al. 2009, Fig. 19). The degree of automation is low. However, a number of developments are under progress including registration and object extraction.

Kinematic laserscanning with synchronized digital images

In this case TLS, cameras and additional sensors are mounted on a moving platform where they are calibrated, oriented and synchronized with respect to each other. The objective is the fast recording of unknown environments, e.g. road lines and 3D city models. Huge amount of data is acquired in short amount of time that and processed off-line. Partial automation is possible if sufficient object and image structures are provided, e.g. for the extraction of road boundaries.

In principle this configuration is also able to measure a fast moving object if the single laser points can be assigned to the object. This can be enabled by synchronous image acquisition used for computing the exterior orientation of the object for each scanning point.

Real-time navigation with laserscanning and digital images

The objective is the real-time navigation of moving platform (cars, UAV) in hybrid systems that also process image data in real-time (video rate). While autonomous guidance of cars in real traffic is still in research stage, a number of operational systems exist for the reconnaissance of unknown terrain, for surveying of caves and tunnels systems, for control of UAV, drones etc. where errors in navigation do not result in dangerous situations.

Automatic generation of image mosaics from images with low textures

If a laser scanner with integrated camera is used for recording of large object scenes, each camera image has a given exterior orientation by the orientation unit of the TLS. Using the simultaneously recorded 3D point cloud orthophotos or other projections can easily be derived even for images that provide no texture for the extraction of tie points.

In industrial optical metrology the combination of photogrammetry and area-based measuring methods (e.g. laser, fringe projection) is a standard procedure for a couple of years. Particular interest is given to the ability of photogrammetry to measure single points for the orientation of surface sensors with an accuracy which is higher than the surface sensor's performance.

The combination of laserscanning (3D point clouds) and photogrammetry (image data) provides an innovative concept which will be increasingly used in practical systems and applications. Increasing pixel resolution of digital cameras at reduced costs will allow for extended use of the photogrammetric advantages (high object resolution, simultaneous data acquisition) for even larger objects and measuring volumes. The overall objective is still to provide high quality products with high degree of automation of data processing at reasonable price-performance ratios.

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Комбінація фотограмметрії та наземного лазерного сканування – можливості та обмеження. Частина 2. Системи, алгоритми і додатки

Т. Люмен

Описано сучасні розробки та застосування для комбінації цифрової фотограмметрії та наземного лазерного сканування. Обидва методи мають певні переваги, які можуть доповнити одна одну. Основним силою лазерного сканування є можливість виміру 3D хмар точок об'єктів, тоді як фотограмметричні методи є дешевими у використанні. У статті розглядаються аспекти точності, вартість системи, комбіновані конфігурації системи з кількістю практичних прикладів.

Комбинация фотограмметрии и наземного лазерного сканирования – возможности и ограничения. Часть 2. Системы, алгоритмы и приложения

Т. Люмен

Описано современные разработки и применения для комбинации цифровой фотограмметрии и наземного лазерного сканирования. Оба метода имеют определенные преимущества, которые могут дополнить друг друга. Основным силой лазерного сканирования является возможность измерения 3D облаков точек объектов, тогда как фотограмметрические методы являются дешевыми в использовании. В статье рассматриваются аспекты точности, стоимость системы, комбинированные конфигурации системы с количеством практических примеров.

Combination of Photogrammetry and Terrestrial Laserscanning – Potentials and Limitations Part 2: Systems, Algorithms And Applications

T. Luhmann

This article discusses recent developments and applications for the combination of digital photogrammetry and terrestrial laser scanning. Both methods provide a number of advantages that can be added to benefit from both. The major strength of laserscanning is the measurement of 3D point clouds of arbitrary objects while photogrammetry offers fast object recording, images as documents and data storage and low costs for equipment. The paper addresses aspects of accuracy, system costs, combined system configurations and applications with a number of practical examples.