TERRESTRIAL LASERSCANNING AND PHOTOGRAMMETRY – ACQUISITION TECHNIQUES COMPLEMENTING ONE ANOTHER

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ABSTRACT

The high spatial resolution of photogrammetric imaging and the excellent capability of measuring the 3D space by laser scanning bear a great potential if combined for both data acquisition and data compilation. One field of the Christian Doppler Research Laboratory at I.P.F. for "Spatial Data from Laser Scanning and Remote Sensing" focuses on exploiting this potential, in particular in terrestrial applications. The Austrian company NoLimits as one of the lab's partners uses this sort of fusion for city modelling. NoLimits operates a City Scanner, a mobile mapping device with Riegl scanner and digital camera. Accuracy after a block adjustment can be improved by up to a factor of three if both technology were utilised simultaneously, as first investigations demonstrate. Besides, combining both data sets presents an opportunity of quick and illustrative visualisation of the objects under investigation.

ZUSAMMENFASSUNG

In der hohen räumlichen Auflösung der photogrammetrischen Aufnahmetechniken und der hervorragenden Möglichkeit, den 3D Raum mit Laser Scanning zu vermessen, hat man ein Potential zur Verfügung, welches durch Kombination beider Aufnahmeverfahren genutzt werden kann. Ein Bereich des "Christian Doppler Forschungslabors" für "Räumliche Daten aus Laserscanning und Fernerkundung" konzentriert sich auf die Nutzung dieses Potential, im Besonderen für terrestrischen Anwendungen. Die österreichische Firma NoLimits, ein Partner des Forschungslaboratoriums, verwendet diese Datenfusion in einen City Scanner, einer mobilen Aufnahmeeinheit mit einen Riegl Laser Scanner und einer digitalen Kamera. Die Genauigkeit nach einem Blockausgleich kann bis zu einem Faktor 3 verbessert werden, wenn man beide Technologien gleichzeitig nutzt, wie erste Untersuchungen zeigen. So nebenbei hat man eine schnelle und eindrucksvolle Visualisierungsmöglichkeit von den untersuchten Objekten.

1. INTRODUCTORY NOTES

Terrestrial laser scanning has become one of the standard technologies for object acquisition in surveying engineering. The possibility to obtain a dense three-dimensional point cloud of the surface of the object under investigation almost immediately excels other common surveying techniques. Basically two measurement principles are common: light sectioning and triangulation; and time-of-flight measurement. One representative of the first group is, for instance, the Minolta VI-900, (Minolta, 2004). While this laser scanner works well for very close-range application of no more than several meters, terrestrial surveying in the range of above 1 m up to 100s of meters is usually carried out with the help of the second sort of instruments. Examples are Riegl's LMS-Z420i (Riegl, 2004) or Cyrax HDS3000 (Cyrax, 2004).

In addition, the reflectance of the surface may be measured by recording the intensity of the reflected laser beam, although this way of generating a grey-level image is limited to the wavelength of the laser beam (e.g. near infrared at Riegl or green at Cyrax). A more sophisticated technique is able to measure true colour intensities at each laser dot location in a separate measurement step practically simultaneously to the distance registration. There is a certain drawback that has to be taken into consideration: the spatial resolution of the laser measurements is limiting the practically possible resolution of conventional imaging. Digital cameras could provide a higher spatial resolution than laser scanners (if economic aspects are taken into account) and most importantly, the relative geometrical stability (from one point to the other) is guaranteed by the CCD sensor matrix, while the laser beam is individually positioned between each measurement, representing a dynamic principle. Therefore, current laser scanners use a combination of the two sensors – the distance measurement unit and a separate digital camera unit. Still, a certain shortcoming remains: While many laser scanners can acquire data over a (part of a) sphere, e.g. an angular range of 360° degrees horizontally and at least 90° vertically, the cameras' field of view is by far smaller and the cameras have to be positioned in several directions in order to cover the same region as the laser. Cyrax HDS300, for instance, needs 111 individual images of 1024 x 1024 pixels for one 360° x 270° scan.

Pure photogrammetric compilations based on images usually don't cause many interpretation problems and also the achievable accuracy may be rather high. Due to efficiency considerations the 3D point density of the measurements is commonly low (even if automatic matching procedures are employed) or, in case of poor or missing texture, measurements may even fail. Both shortcomings can be overcome by laser measurements where in turn the image contents may support the interpretation of the range data and additionally allow the surveying of grey or colour details of the object texture which, of course, is not included in the range measurements. Hence, by fusing range and image data more complete, more reliable and more accurate results can be expected. One might call this sort of combined data acquisition and compilation "Tactile Vision".

Table 1 shows a comparison of several sensor characteristics. It clearly demonstrates the partly low correlation between both instrument properties what leads to the conclusion that both techniques may complement each other in an ideal way.

	Laser Scanner	Photo Cameras
Spatial Resolution	High	Very High
Spatial Coverage	Very Good	Good
Intensity/Colour	Limited	Very Good
Illumination	Active	Passive (& Active)
3D Pt Density	High	Depend. on Texture
Depth Accuracy	High	High
Acq. Procedure	Dynamical	Moment Shot
3D Reconstr. Effort	Medium	High
Texture Reconstr.	No or Very Limited	Very Good
Instrument Costs	High	Low

Table 1: Comparison of Sensors

While accurate and efficient photogrammetric reconstruction procedures are state-of-the-art (many commercially available software packages exist) and may be automated to a high extent, processing and compilation of laser scans still need further development. The hardware is still under development too and significant improvements may be expected for the future, although a high degree of precision, reliability, and practi-cability has been reached. A wide range of laser scanner models are available and several companies turned out to have gained a significant position on the world market. One of those companies is Riegl Laser Measurment Systems GmbH, Austria (see www.riegl.com). Close co-operation exists with I.P.F. and in near future also with the Christian Doppler Research Laboratory for “Spatial Data from Laser Scanning and Remote Sensing” (LS&RS) which was founded in 2003 and is integ-rated in I.P.F.’s activities. The Austrian company No Limits IT GmbH, a subsidiary company of Geodata Austria, (see www.citygrid.at) is also partner of the LS&RS. This company has developed a “CityGRID Scanner” (Forkert, 2004) consisting of a Riegl Laser Scanner and a digital camera. The device is mounted on a motorised vehicle which moves through the road of a city and acquires building facades in three dimensions together with the building texture. A highly auto-mated reconstruction procedure for efficient scanning is currently under development which should allow the generation of a detailed virtual urban environment in a fast and affordable way.

2. ORIENTATION AND RECONSTRUCTION

In order to achieve the optimum results in terrestrial laser scanning, the utilisation of both range imaging and photo-grammetric imaging is the preferred approach. Consequently, also the reconstruction process has to concentrate on the concurrent usage of both imaging products, by fusing the data. The fusion can be applied during two fields of compilation:

- Orientation of sensors
- Object reconstruction

The first work is responsible for establishing a uniform and geometrically consistent block of measurements from both laser scanner and the photographic images. Basically two set-ups are possible. One set-up uses totally independent positioning of the laser scanning device and the photogrammetric camera, the other uses a combined, stable and calibrated arrangement of laser scanner and camera. The geometric relation between camera and laser scanning device is given by the so-called mounting calibration, which has optimally to be determined in advance and serves as a sort of interior orientation of the acquisition system.

While the combination of both acquisition techniques offers a series of advantages for the orientation of the sensing system, as we shall see later, data fusion may also be used for the object reconstruction procedure where range and intensity data complement each other. Matching of individual scans and/or of individual photographic images can be supported by 3D object data as well as by 2D radiometric data. Thus, the geometric accuracy, the reliability and the completeness of the recon-structed object can be improved. In particular objects with complex shape and/or texture benefit from the combination of both acquisition techniques.

2.1 Orientation of the sensor set-up

2.1.1 General Remarks

In order to describe the geometric properties of the sensors and in order to define a homogeneous coordinate system for the object reconstruction, the different sensor observations must be transformed into one global object co-ordinate system. A hybrid adjustment approach provides the ideal means for determining both the internal and the external sensor geometry. The Institute of Photogrammetry and Remote Sensing of the Vienna University of Technology has been working on problems of bundle block adjustment techniques for years. The software packages ORIENT and ORPHEUS are the result of this research activities (Orpheus/Orient, 2004). This universal approach realized in ORIENT can easily be adapted to various acquisition techniques, even to the simultaneous orientation of different techniques as in the case of laser scanning and photographic imaging (Ullrich, et al., 2003).

For block adjustment tie points have to be measured which not only tie the individual images and laser scans to each other but also link the range measurements to the photographs. Control points or control information, i.e. points with known position or other known geometric properties with respect to a higher level co-ordinate reference system, are necessary only to define the orientation of the reference system. The scale can exactly be determined by the range measurements. The translation and rotation parameters may, for example, be defined by one control point and additional so-called fictitious observations, such as horizontal plane, vertical plane, lines with known spatial orientation, etc.

2.1.2 Solution in Riegl Systems

Riegl Laser Measurement Systems GmbH has recently started to offer, as an option, their 3D laser sensors together with a firmly mounted high-resolution digital camera. Due to the well-known camera calibration and camera orientation with respect to the scanning device the entire equipment can be treated as a single hybrid acquisition system. The measurements are stored on-line on a mobile computer (connected to the scanner through a high speed data link) in an indigenous structured format which contains all relevant exterior and interior sensor parameters thus making separate alignment procedure unnecessary. The data format is defined in XML and is open to everyone thus enabling data export and import between various utilities and any post-processing software.

The software package RiScan Pro organises data acquisition, calibration, visualisation and archiving, and prepares data for further processing. The hierarchical data structure is used for both the range measurement and camera data. A series of co-ordinate systems which define the geometric dependence between the sensor's raw data to a higher order reference system (for details see Ullrich et al., 2003) is the basis of all co-ordinate transformations. The following list provides an overview of the various local co-ordinate systems:

- SOCS (Scanner's own co-ordinate system) is the coordinate system of the raw data where the polar measurements are based on. It is defined by the rotation axis of the scanner unit (=the origin for the angular measurements) and the reference direction (i.e. internal 0-azimuth)
- PRCS (Project co-ordinate system) is the central reference system for a Riegl laser scanning project. It is as local system as far as the project area is concerned whose co-ordinate range should not exceed 10 km.
- GLCS (Global co-ordinate system) is hierarchically above the PRCS. It is usually the co-ordinate system of a national reference system.
- CMCS (Camera co-ordinate system) is the reference of the camera mounted on top of the laser device.

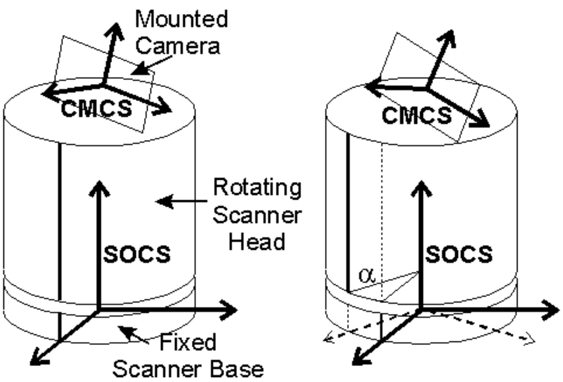

Fig.1: Scanner and Camera Coordinate System

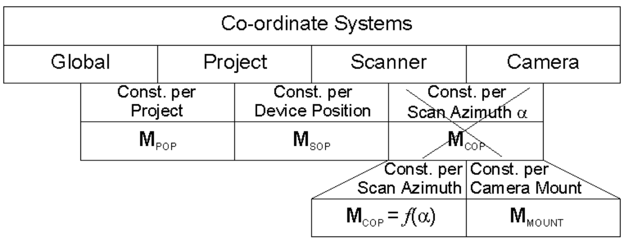

Fig.2: Co-ordinate Systems and Transformation Matrices

The two transformations with their respective matrices $\mathbf{M}_{SOP}$ and $\mathbf{M}_{POP}$ describe the transition from raw laser data to the global co-ordinate system via the project co-ordinate system. In the case of camera data, an additional transformation has to be applied, i.e. the transformation of the camera system into the scanner system. One should keep in mind that the scanner body, and therefore also the camera mount, is rotating during the range measurement process and thus the camera system also rotates with respect to the SOCS (Fig.1). This transformation has been realised by splitting up this time-variant step into (Fig.2):

- The time-variant rotation of the range measurement unit (i.e. the body) with respect to the 0-azimuth reference direction, expressed by the matrix $\mathbf{M}_{COP}$, and
- By the time-invariant rotation and translation of the camera system with respect to the SOCS, expressed by the so-called mounting calibration $\mathbf{M}_{mount}$

The following two equations are used for the transformation of the measured co-ordinates from the scanning system to the global system and from the camera system to the global system, respectively:

$$\mathbf{x}_{GLCS} = \mathbf{M}_{POP}\, \mathbf{M}_{SOP,n}\, \mathbf{x}_{SOCS,n}$$
$$\mathbf{x}_{GLCS} = \mathbf{M}_{POP}\, \mathbf{M}_{SOP,n}\, \mathbf{M}_{COP,n,m}\, \mathbf{M}^{-1}_{mount}\, \mathbf{x}_{CMCS,n,m}$$

where n denotes a certain position of the scanning device in the project area and m denotes (at the device position n) a certain camera position (determined by the azimuth angle α), when the photo has been taken. Note that $\mathbf{M}_{mount}$ is constant as long as the camera has not been moved with respect to the scanner body, i.e. not been detached from the scanner body and mounted again. The great advantage of the stable mounting calibration is the possibility to reference camera images to the laser scanner data at any stage of the data acquisition as the geometric relation between each laser point and the camera direction is known at any time. (Note that the azimuth angle α is delivered by the laser unit for each measured laser point.)

2.2 Orientation using Laser Scans and Images

The determination of the $\mathbf{M}_{SOP}$ matrices is the central task of a laser scanner project where usually an arrangement of many scanning positions is necessary to cover the whole area of interest. The individual scanning positions are tied to each other with the help of tie points through a block adjustment. RiScan Pro provides appropriate means to built a homogeneous block and determine the transformation matrices. Tie points can be identified in the intensity image of the range measurements (i.e. the intensity of the received echo pulse), they may be measured in the camera images, or in both. A combination of both techniques is to be preferred, as it bears the potential to reduce the time for measurement and to improve the accuracy. On the one hand, laser measurement can support measurement of targeted tie points in the images, on the other hand both sets of measurement may be input to the block adjustment procedure in order to determine all unknown orientation parameters of the set-up and, if necessary, even the instrument calibration in one step of a hybrid bundle adjustment.

2.3 Reconstruction of the Object

As for the object reconstruction the great advantage of camera images is their relatively high spatial and spectral resolution. In particular coloured object features, small details and prominent object discontinuities, such as edges and corners, can be identified more accurately in photographs than in range images. The disadvantage of reconstruction from photographs is the high effort and quite often low reliability if automatic procedures are employed, especially in close-range applications. Image matching algorithms usually need good approximations before accurate fine measurement can commence. The range measurements of the laser scanner deliver 3D object points and thus very good first approximate positions in the images. The automated reconstruction process works much faster and is able to provide more reliable, more complete and possibly even more accurate results.

One metric product which can be created very quickly and without great effort is a Z-coded True Orthophoto (*ZOP*) of an object area. This sort of orthophoto is especially useful if building facades have to be plotted, where the projection plane for the orthophoto can be positioned approximately parallel to the main plane of the facade. An additional layer of the orthophoto contains the z-distance of the facade points above the reference plane, i.e. the distance of each surface point from the projection plane of the orthophoto. The *ZOP* is a 2½D data set and can, in general, provide only a simplified representation of a facade, as overhangs with respect to the *ZOP* projection plane cannot be modelled. It has to be explicitly mentioned that a *ZOP* is a digital product rather than a graphical representation like a conventional orthophoto. It is actually a digital surface model of the facade draped with the image of the facade. Therefore, the *ZOP* can be used, in a similar way with similar tools as for DTMs, for creating virtual perspective views, calculating profiles across the facade in any direction, showing visualisation via a 3D viewer, and last but not least, generating true orthophotos. The latter term is justified as very small details can be modelled due to the high resolution of the laser scanner. If the pictures are taken from the scanning direction the problem of multiple mapping, which could only be avoided by strict visibility analysis, does not appear, although occluded areas are likely to exist. Fig.3 shows a part of a true orthophoto mosaic derived from a *ZOP* and a series of original oblique images taken from a mobile city scanner. The *ZOP* may serve as a valuable product for archaeologist, architects, etc., who do not have photogrammetric expertise nor an appropriate workstation. They can use a standard CAD program like AUTOCAD for visualisation, measurement and even simple reconstruction.

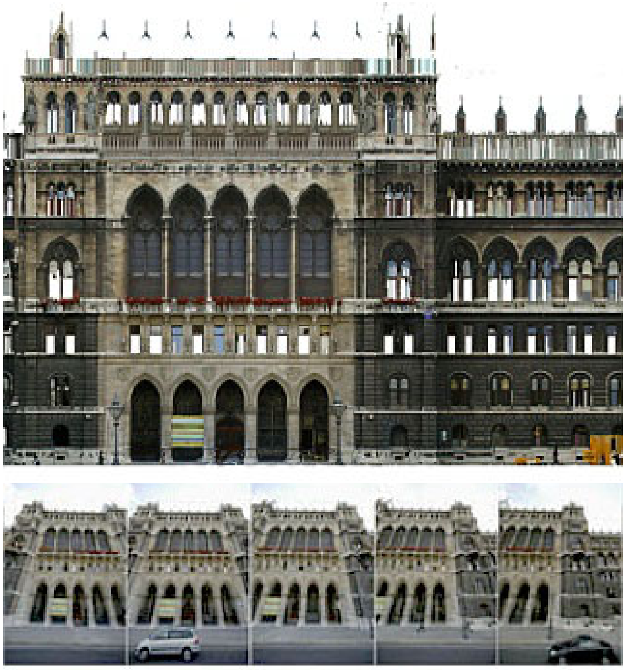

Fig.3: True orthophoto and examples of original images

For more sophisticated object reconstruction the laser point clouds together with the images have to be analysed. Due to the huge amount of data to be processed within one project automated methods are required. Many research activities have been started worldwide. The above mention LS&RS conducts several projects which make use of the combination of laser scanning and photography for detailled object reconstruction. The focus is on the development of interactive semi-automatic methods rather than fully automated procedures.

3. EXAMPLES

3.1 The CityGrid Scanner

The CityGrid Scanner (*CGS*) by NoLimits is a mobile universal multisensor platform consisting of a 3D Scanner, several high resolution digital cameras and a GPS receiver. Its main area of application is the fast and efficient acquisition of building facades along roads and the 3D city environment of local areas of special interest. The *GCS* may be operated in basically four modes:

- Dynamic Mode (*DYMode*)
- Dynamic Stop Mode (*DSMode*)
- Stop & Go Mode (*SGMode*)
- Street Scene Mode (*SSMode*)

While the main acquisition device in *DYMode* and *DSMode* are the digital cameras, in *SGMode* and *SSMode* the laser scanner comes into action. Fig.4 demonstrates the principle of the different modes as ground sections of coverage plots.

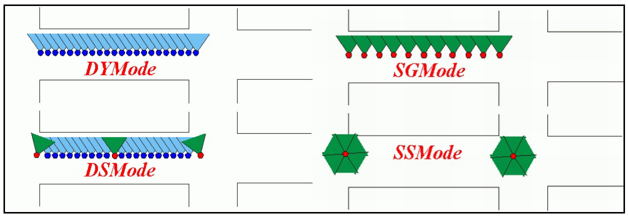

Fig.4: CityGrid Acquisition Modes (Left: Camera/Scanner Modes; Right: Pure Scanner Modes)

The dynamic modes are used for quick building acquisition with the main intention to generate facade image mosaics. The vehicle may constantly move along the street and photo shots of the facade are triggered at certain distance intervals so that a sufficient overlap of information is guaranteed. The orientation of the pictures is based on a line matching process between images, which can run semi-automatically. In order to keep acquisition time as short as possible, laser scanning may be reduced to horizontal profile scanning only, thus delivering a longitudinal profile of the building block. The profiles serve as aid for orientation as they may be treated as approximate ground section of the building blocks. Satellite based navigation systems are not suited for reliable use as especially in old towns with their narrow streets the GPS signal cannot be received most of the time.

The orientation approach of the images has been developed by NoLimits in co-operation with the K-plus Research Centre VRVIS (Vienna, Graz) and uses horizontal and vertical edges and vanishing points. Great overlap of the individual images is a prerequisite (see lower image of Fig.3) (Karner et al., 2003). In order to stabilise the geometry of a pure photo block (in particular when surveying long facades in *DYMode*) and to provide reliable control information at corners of building blocks, where one photo series ends and another commences possibly in another direction, 3D laser scans are taken. The *DSMode* needs stops of the vehicle now and then. If the 3D structure of the entire facade mosaic is requested, the stops must be positioned so that the laser clouds overlap, too. This mode is *SGMode* and may be combined with the *DSMode*-specific acquisition so that both a complete overlap photo block and an overlaping laser cloud can obtained. This later mode has to be used, for instance, if *ZOPs* are to be created (see Fig.3). Eventually the *SSMode* is intended for the acquisition of a complete street scene, where hemispherical laser scans are carried out. This mode is the most time consuming one and will be used in order to fulfil special requirements of a project, e.g. thorough mapping of urban street environments. In general it will be placed at street crossings where it can also serve as valuable tie information for individual facade acquisitions.

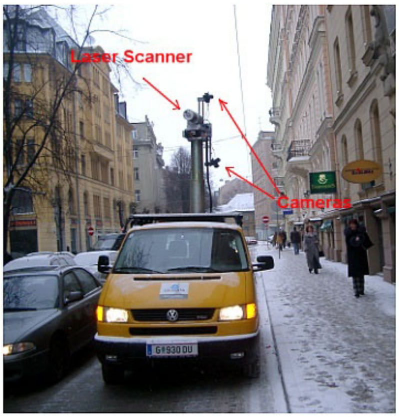

Fig.5: CityGrid Scanner at work

Fig.5 shows the CityGrid Scanner in action driving through a narrow street. The scanner is put in horizontal position and works in a profile scanning mode (body rotation inactive, mirror rotation active). The cameras (their number is theoretically not limited) are mounted separately on the vertical device bar, which can be moved up to some 4 m in order to look over possible obstacles, like parking cars. Though not firmly mounted on the scanner body, cameras and laser scanner can be kept in a stable relative position to each other at least during one acquisition campaign. The arrangement may be calibrated in advance or calibration could also be calculated simultaneously later on within the orientation of the entire block arrangement. The distance between *SGMode* stops depends on the prevailing situation, but is typically between 20 m to 50 m.

3.2 Monument Reconstruction

Laser scanning has already been approved as appropriate method for documentation of monuments. In the following, a project should be presented, where a complex sculpture has been surveyed with a great number of laser scans and in addition with a block arrangement of conventional photographs. Scanning and photo shooting has been carried out completely independently. The scanning device was a Riegl LMS-Z360 instrument with a single shot accuracy of some ±12 mm, the colour camera a Kodak DCS-460c with a 6 MB sensor frame and a 28 mm lens. The reconstruction of the object was based on a hybrid bundle adjustment, where the intensity images of the laser scanner data and photographs have been processed simultaneously. In the course of the project the benefit of using images together with laser data has been investigated (Haring, 2003).

The monument (see Fig.6) has been captured by 22 digital photographs and by 20 laser scans altogether (from each of the 10 positions a coarse scan with 0.2° and a fine scan with 0.05° step width was taken). The entire field of interest was targeted with 29 signals, one part as retroflecting square foils of 4 cm² glued onto the monument, another part as retroreflecting cylinders with 5 cm diameter and 7 cm height around the monument. They intention was to see from each sensor position at least 4 targets, in order to be able to links all captured data to each other.

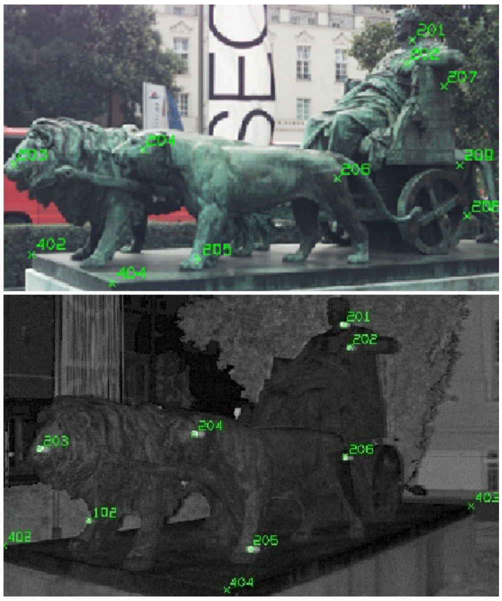

Fig.6: Marc Anton monument (Above: Kodak DCS image. Below: Laser intensity image). Retroreflecting tie point targets are numbered.

For the block adjustment the ORPHEUS/ORIENT software has been used. Gross errors in the original scans (especially in the coarse laser scans) could be eliminated with the help of rough residual analysis, robust estimation, and data snooping. The balance of observations vs. unknowns of the joint adjustment (laser observation plus photos) is listed in Table 2.

Number of	
observations in 20 laser intensity images	819
observations in 22 photos	508
fictitious observations	6
intermediate TOTAL	1333
eliminated after gross error analysis	-95
observations TOTAL	**1238**
unknown orientation parameter (6 per sensor position)	192
unknown coordinates of 30 tie pts (3 each)	90
datum parameters (3 pts) (3 each)	9
unknowns TOTAL	**291**
Balance = Redundancy	***947***

Tab.2: Balance of observation vs. unknowns in bundle block

In the course of data snooping a variance component analysis has been carried out. The results show clearly what has been expected. The variance of the measurements of the coarse scans are about 50% worse than those of the fine scan. The accuracy of the photo coordinates has been estimated with 0.4 pixels.

In order to be able to estimate the improvement induced by the additional use of photographs, the entire block has also been calculated with laser measurements alone. Table 3 lists the comparison of the a posteriori accuracies as result of the joint adjustment and the sole laser scan adjustment, respectively.

In this project the usage of photographs was not explicitly required because the smooth and complex shape of the monument, which hardly bears any texture is a ideal object for laser scanner measurements. Photogrammetric compilations needed much more effort and probably artificial texturing in order to be able to find an appropriate number of points for proper surface modelling. Nevertheless, the photographs affected the overall geometric quality positively, thus improving also the laser measurements. Points on the object, which are of specific interest, of course, have an improvement in accurary of a factor of 3 (see Tab.3, row "Tie pts (statue)") where the mean location accuracy of one point could be reduced from 3.6 mm to 1.2 mm.

	Laser Sc. Adjustment			Joint Adjustment		
Units in [mm]	dX	dY	dZ	dX	dY	dZ
Laser position	2.1	2.1	3.2	1.9	1.8	2.9
Camera position	n/a	n/a	n/a	2.4	2.2.	2.8
Tie pts (statue)	**1.8**	**2.2**	**2.3**	**0.7**	**0.7**	**0.7**
Tie pts (periph.)	3.9	3.6	5.1	3.3	3.1	3.5
Tie pts (mean)	2.5	2.6	3.2	1.5	1.5	1.5

Tab.3: Comparison of adjustments: Laser scanner alone and laser scanner + digital photos

4. CONCLUSION

The examples above demonstrate the usefulness of combining laser measurements with photographic pictures for a series of reasons. *Firstly*, the photographs bear important and very detailed information about the radiometric characteristics of the object. One must also not forget a further advantage: a photograph captures the object at a very short moment so that in most cases motion effects caused by moving objects or moving sensor platforms can be neglected. As typical examples the dynamic acquisition modes of the CityGrid scanner have been presented. *Secondly*, the information content of surfaces with intricate intensity or colour textures can be reconstructed from high resolution images. *Thirdly*, photos support the interpretation of the object under investigation as a human operator, who possibly controls the compilation process interactively or at least evaluates the quality of the results, is used to this sort of images. *Fourthly*, even if photographs are not needed for fulfilling the requested surveying task, the high spatial quality of image information can even help to improve the quality of the laser measurements if used in combination, as the example in 3.2 could prove. On the other hand, the advantages of the laser measurement principle are apparent too: *Firstly*, the laser scanner delivers a dense point cloud of polar measurements with an rather high distance accuracy almost independent of the surface properties. The surface need not be textured. *Secondly*, at one single instrument position the entire hemisphere (or even more) can be surveyed. *Thirdly*, laser measurements can penetrate vegetation to a certain extent so that the reflected pulse becomes a complexly shaped time-dependent signal. Many of current instruments register either first pulse and last pulse or even the full wave form which bears enough information to derive object structures behind vegetation such as tree or bushes even in urban environments. *Fourthly*, laser scanning is an active technology and, therefore, does not daylight or optimum illumination conditions. Laser does not care of heavy cast shadows or severe brightness contrasts. Of course, photo cameras too could be equipped with flash light, but the usable range is rather limited. *Fifthly*, the laser scanner almost immediately delivers a 3D data set, no further complicated and time consuming compilation process like image matching needs to be taken into consideration.

Each of the instruments has its great advantage. Technically it is absolutely no problem to combine both acquisition techniques. Modern digital cameras are of high quality and are available at very low costs. If a laser scanning equipment is owned by company, upgrading with a digital camera is highly recommended. Ideally the camera should be integrated in the laser scanner but, as the example above showed, cameras may also be used independently. In any case, the reconstruction process will benefit as far as the completeness, the reliability and the accuracy, briefly, the overall quality is concerned. Nevertheless, we are still at the beginning of the new technology as far as the instrument developments and data compilation is concerned. A further step forward will be the full integration of photos and laser scans in the object reconstruction process where also a higher degree of automation can be expected – A great challenge for researchers in photogrammetry, computer vision and surveying in general.

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