PHOTOGRAMMETRY AND GROUND-BASED LASER SCANNING: ASSESSMENT OF METRIC ACCURACY OF THE 3D MODEL OF POZZOVEGGIANI CHURCH

A. Guarnieri[1] F. Remondino[2] A. Vettore[1]

[1] Cirgeo – Interdept. Research Center of Geomatics
University of Padua – Italy (EU)
e-mail: cirgeo@unipd.it

[2] Institute of Geodesy and Photogrammetry
ETH Hoenggerberg - Zurich, Switzerland
e-mail: fabio@geod.baug.ethz.ch

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Contents

Introduction - 1

- Photogrammetry is a well proved and reliable technique for 3D object reconstruction.
- Advantages: accurate sensor calibration, analog or digital imagery, very portable surveying system, wide availability of commercial processing softwares.

- Laser scanning technology as promising alternative for many kind of surveying applications. Two branches: ALS and GBLS.
- Advantages: fast acquisition of a huge amount of 3D data, recording of intensity (gray values) and color data (digital images). High LOD of the representation combined with quite good metric accuracy (depending on employed laser scanner).
- Applications: cultural heritage, industry, land management, medicine.

Introduction - 2

- In the Cultural Heritage field 3D models are used for as-built documentation, restoration projects, generation of VR environments (*mix of image-based and laser scanner models*)
- Different content of 3D models from laser scanners for entertainment or scientific applications: visual appealing vs. geometric accuracy.
- Only a few works addressed so far metric and geometric accuracy of 3D models of Cultural Heritage objects. More interest towards texturing and viewing quality of generated models.

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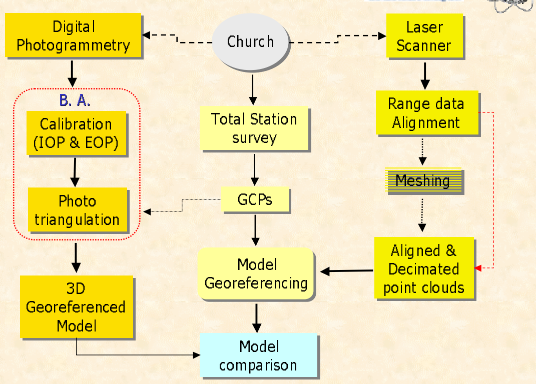
The aim of this work is to provide a method for the assessment of the geometric accuracy of a 3D model of a Cultural Heritage object by comparing aligned point clouds from GBLS range data with the results from image-based photogrammetric approach.

Case Study

Target object: the ancient church of Pozzoveggiani, located in the sourrounding of Padua (Italy).

Little church presenting simple geometry, composed by a unique hall and apse. Only the outside was surveyed because more interesting from architectural and historical point of view. Dimensions: 7m x 16m (planar), 8m - 17m (height)

Project framework



Hardware ....

Digital color camera Nikon Coolpix 5700: 5 Megapixels, 2/3" CCD sensor size. 80 images were acquired at 1024 x 768 resolution (8.6 mm pixel size)

Leica TCR 705 Total Station (Reflectorless)

Angle measurement	5",1.5 mgon
Distance measurement	3000m (with reflector); 2mm + 2ppm 170m (w/o reflector); 3mm± 2ppm
Measuring time	<1s (with reflector) typical 3-6s (w/o reflector)
Recording	>8000 measurements and coordinates 232 interface for external connection

Mensi GS 100 laser scanner, capable to record the intensity of reflected beam, as well.

Laser Wavelength (in nm)	532
Beam Diameter at Specified Distance (0.Y ft at X ft/Ymm at X m)	3 mm at 50 m
Distance Accuracy at Specified Distance (0.Y ft at X ft/Ymm at X m)	3.2 mm at 50 m/ 6 mm at 100 m
Data Acquisition Rate (pps)	5,000
Range (feet/m)	1 m to 150 m
Field of View (vertical angle / horizontal angle)	60° / 360°

... and Software

Polyworks Modeler/Inspector of Innovmetric Inc. (Quebec, Canada) was chosen as 3D Modeling software for the laser scanner data.

The modules comprised in Modeler were used for data alignment, meshing and editing, while model measurements and check point selection were performed in Inspector.

For the Photogrammetric approach, camera calibration and 3D object reconstruction were accomplished using Photomodeler.

Further processing steps were carried through a software developed at the ETHZ (**F. Remondino**)

Image-based Photogrammetry - 1

- 22 out of 80 digital images acquired with the *Nikon camera*, were used for the photogrammetric model.
- Image resolution was set to 1024 x 768, resulting in a pixel size of 8.6 µm in image space and 0.95 cm in object space.
- Camera calibration (IOP) was performed in *Photomodeler*, keeping the focal length fixed to its minimum zoom factor. Distortions were modeled taking into account 4 parameters: (k_1, k_2) for radial and (p_1, p_2) for tangential components.
- Approximated values for EOP were computed through a space resection algorithm, using a few GCPs measured semi-automatically with LS template matching.
- 170 GCPs were surveyed with the Leica reflectorless *total station* with a global accuracy of about 5 mm.

Image-based Photogrammetry - 2

Then 200 Tie points were extracted by means of interest operator, LS matching and the epipolar geometry.

Finally a self-calibrating Bundle Adjustment (**F. Remondino**) was run using previous extracted information along with 29 measured GCPs.

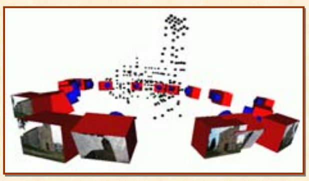
Image-based Photogrammetry - 3

A 0.9 pixel a posteriori standard deviation was obtained (σ_{priori} = 1), while tangential distortion parameters could not be reliable determined as during image capture the digital camera was kept, unfortunately, always in the same horizontal position.

- Theoretical precision of computed Tie points object coordinates:

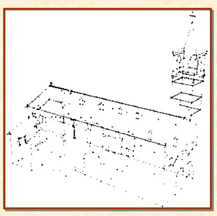
  0.030 m (X) 0.048 m (Y) 0.024 m (Z)

Parameter	Value	STD
Focal length	9.039 mm	0.019
PP x direction	0.132 mm	0.022
PP y direction	-0.086 mm	0.021
K1	-2.320e-03	1.4e-04
K2	2.143e-05	5.8e-06



Object modeling - 1

Tie points object coordinates were then imported in Photomodeler and used to generate the image-based 3D model of the church. These points were manually linked each other, defining edges, curves and surfaces in order to recover the geometry of the object.



Object modeling - 2

Digital images were also mapped onto the photogrammetric model using the dedicated tool provided by Photomodeler.

Major holes were filled by adding planar surfaces (roof, bell tower, etc.)

Model accuracy assessment

After Bundle Adjustment, 3D object coordinates were related to the total station reference frame.

Therefore, 21 check points, measured with the total station and well distributed all over the church were compared with the recovered object coordinates.

RMS X [m]	RMS Y [m]	RMS Z [m]
0.017	0.027	0.022

Laser scanner- based reconstruction

All processing steps, required to generate a 3D model of the church from the range data, were performed in Polyworks Modeler.

The church could be completely surveyed with only 5 scans given its small size and the rotating head provided by the Mensi laser scanner.

Scan resolution was set to 1 cm at about 4m distance, giving a global data set of 5.800.000 points.

Due to the interpolation routine implemented in ImAlign, each main scan was subdivided in smaller data sets, resulting in 5 scan groups.

A 2-passes alignment procedure was applied:

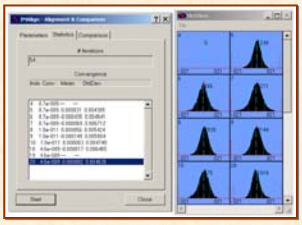
1) scans were roughly registered pair by pair, selecting manually N matching points on adjacent scans

2) Approximate tranformation matrices were then refined through application of a global alignment algorithm based on a modified version of well known ICP method (**Besl & McKay**)

Range data alignment - 1

All the scans were globally registered with a residual error of 5.5mm, i.e. the measurement sensor error.

However a few scans (6, 8, 10) didn't provide a well bell-shaped error distribution: low quality of corresponding scans and/or lack of useful data



Range data alignment - 2

Polyworks/Modeler provides a very useful tool to evaluate the residual alignment error throigh a color coded error map

Model georeferencing - 1

In order to be compared with the photogrammetric product, the laser scanner-based 3D model had to be georeferenced in a common reference frame (total station).

A decimated (simplified) model was used at this step. Decimation allows to reduce the model size and to eliminate overlapping points, i.e. redundant information useful for the alignment step only.

A model composed by 3.800.000 points was obtained. No triangulated model was used in further processing steps in order to keep as much as possible the original information about point position as acquired by the Mensi.

Precise model comparison should be performed using the same check points.

How to select the same check points extracted in the photogrammetric processing step ?

Model accuracy assessment

Measured GCPs manually signalized on digital images.

Only 43 out of 170 GCPs could be reliably extracted from the 3D model:

– most of measured points were located on corners or edges, critical features for laser scanning (laser beam ripple)

– tilting of some images provided high perspective effect, making difficult to correctly identify points located at large distance from the camera

Best selected check points were identified on surface discontinuities of the walls, apart from corners and edges.

9 out of 43 points were used to compute a 3D similarity (7 parameters) transformation (**F. Remondino**). These points were chosen among the sets providing the smaller RMS.

After georeferencing, remaining 34 check points were compared with corresponding measured coordinates, giving following results for the RMS:

0.044m (X) 0.015m (Y) 0.024m (Z)

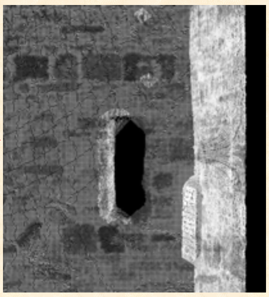
Conclusions

- Image-based and range data 3D models of an ancient church were compared in order to assess the metric and geometric accuracy of laser scanners when employed for Cultural Heritage applications.
- Differences between measured check points and corresponding 3D object coordinates extracted from the models show the same order of magnitude.
- While the range data alignment performed in Polyworks kept the global accuracy at the noise sensor level, the georeferencing provided worst results mainly due to difficult check point identification.
- Possible solutions: higher scan resolution and use of artificial targets, in order to help the point recognition.
- Care must be taken when using retroreflective targets as laser scanners sometime provide unexpected behaviour.
- Which is the best surveying technique ?

Photogrammetry and Laser scanning are not competitive but rather complementary. The former is most suited when the shape (geometry) of the object is required, while laser scanner is useful when higher LOD is needed.

Check point selection

Effect of noise (ripple) on edges along the range data 3D model



3D Laser scanning model