QUALITY ASSESSMENT OF DTM AND ORTHOPHOTO GENERATED BY AIRBORNE LASER SCANNING SYSTEM USING AUTOMATED DIGITAL PHOTOGRAMMETRY

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ABSTRACT:

The approach of using an airborne laser scanning for DTM generation has made great progress recently. However, it is not always clear the reliability and the quality of the geometry that characterise the generated DTM. Thus, a special test was conducted to assess the quality and the reliability of the generated DTM via an airborne laser scanning system. To perform this test, an airborne laser scanner aligned with an airborne digital camera was mounted on a Helicopter (TopEye AB system). The test was performed in Italy and the flying height was about 200 meter. An overlap percentage of 50% were maintained between two successive images. The digital camera is a Hasselblad camera with 2Kx3K resolution. An INS/GPS system is integrated and used for position and orientation determination.

A series of tests were done to check the DTM quality. The main approach used is based on comparing it to the DTM generated from the digital aerial photogrammetry (automatic and semi-automatic matching approaches). Additional comparison is conducted between the Orthophoto created by stereoscopic model and the one created by the laser data and digital images. The test results will be presented and discussed.

1. INTRODUCTION

Airborne laser scanning, recently, is considered one of the best methods to obtain a reliable DTM with precision could reach one decimetre, (Kraus and Pfeiefer 1998, Axelsson 2000). Recent technologies such as the TopEye™ system - a system to capture topography and high-resolution digital images with high precision using scanning laser and digital images – is based on a multi-sensor system that employs a scanned Laser Range Finder, Digital Camera Systems combined with advanced GPS/INS system to capture 3D data in near real time. The system is installed on a Helicopter, which makes it feasible to fly at low altitudes and thus provides higher precision, and makes it flexible system to generate DSM (Digital Surface Model).

The laser scanner with the integrated GPS/INS provides a DTM, and with the aid of the digital camera, high quality Orthophoto can be produces. Normally, 20% overlap and laterallap is required to produce reliable Orthophoto.

Many factors could affect the precision of the laser system used, consequently, the precision of the produced DTM (Kilian et.al 1996, Kilian 1996, Huising et. Al 1998). The main factors are:

1. The range accuracy which is mainly could affected by:
   - Non-parallel alignment of the send and receive parts of the sensor, which generally corrected through calibration.
   - Inaccuracies in the measurement of the time of travel pulse.
   - Variation in the speed of rotation or oscillation of the mirror.
2. Position accuracy, which depends on, many factor such as satellite configuration, multipath and distance between reference-rover receivers.
3. . Attitude accuracy, this depends on the quality of the INS (Inertial Navigation System) (Ackermann 1996), which could be affected by:
   - Alignment errors.
   - Impurity in the accelerometer
4. Time offsets, to obtain a good and accurate three-dimensional positioning. Orientation, position and range are required to be taken at the same time in the same coordinate time system (all measurements should be synchronised) (Al-Bayari 2000).
5. Coordinate system, this depends on the transformation of the coordinates between WGS84 to National or local system and also depends on the Geoid measurements.

Naturally, there are relation between these factors and the flight height, scan angle, terrain topography, land cover, and control points used for transformation between WGS84 system to the national one. Due to all above mentioned factors, and new prospect field problems, it has been mandatory to perform some experiment at selected areas before perform entire surveying of whole area.

The aim of this work is to check the DTM quality in terms of the precision and of the geometry. A flight mission is planned such that 50% percentage overlap was maintained between two successive images of the digital camera. The digital camera is a Hasselblad camera with 2Kx3K resolution.

The results of comparing the DTM generated via digital Photogrammetry with respect to the one produced by the scanner is presented. Also, the results of comparing a cross-section of the surface produced via analytical digital Photogrammetry with the above resultant DTM is discussed. Other types of checks using ground GPS points and on-ground existing feature are presented. Finally, the differences between the orthophoto generated from the laser DTM and the Digital Photogrammetry are illustrated and discussed.

2. THE AIRBORNE LASER SCANNER SYSTEM

2.1 The Laser Scanner System

The testing system used is the TopEye laser system (www.topeye.com). The system is mounted on the Helicopter which gives possibility to perform different types of surveying at different altitude with different characteristic such as density of points per meter squared, different scan angles…etc.

The system scans the ground across the track of the Helicopter and measures the distance to the ground with up to 7000 laser pulse per second. The system could record four echoes for each laser pulses. Recording different echoes for a single pulses help to identify the heights of the objects on the terrain, such as building, trees, power lines...etc.

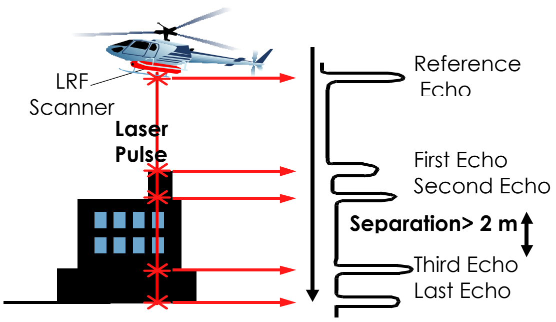

Figure 1 Laser Survey Principle (TopEye System, www.topeye.com)

Laser Range finder:	
PRF	7000 Hz
Returns echoes	4 with 2m object separation
Strength:	128 levels
Beam divergence	1 or 2 or 4 mrad
Swath	20º stabilized →20-340 m
	40º Not stabilized→ 40- 680 m
Absolute accuracy:	1 σ
	Depending on altitude above ground 10-30 cm
Video Cameras:	Sony Hi 8 PAL or NTCS
INS:	System H-764
GPS:	Trimble 4700
Pilot Guidance System	
Data Storage:	Exabyte
Mount External POD and cabinets in cabin	

Table 1: characteristics of TopEye Laser System

The TopEye system has two working modes, named FLA and FL2. In the FLA the laser collect First echo, Last echo and Amplitudes, in FL2 mode the laser collects first, 2nd , 3rd and last echoes plus their amplitudes (Axelsson 2000, Al-Bayari 2000). It is advantageous to use FLA- mode wherever possible as this gives higher laser pulse frequency and smaller raw data files, see Figure 1.

The system has also an integrated GPS/INS navigation system to provide position and orientation (Reid et. Al. 1996). The general characteristic of TopEye system is shown in Table 1, and the principle of surveying is illustrated in Figure 2.

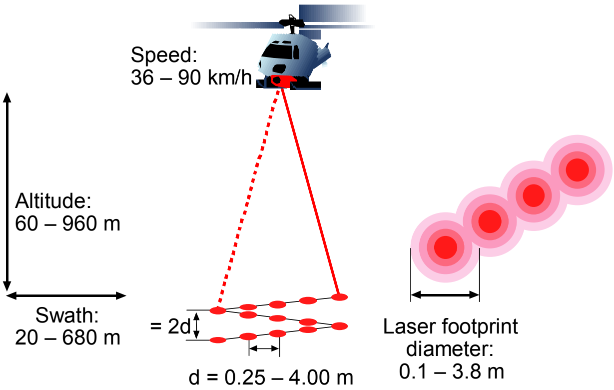

Figure 2 Laser Survey Principle Principle (TopEye System, www.topeye.com)

2.2 The Digital Camera

The TopEye system, additionally, has a digital Hasselblad phase I camera, calibrated at laboratory, which could be used to produce geocoded and mosaiced photos using attitude of camera and laser data. The pixel size is possible to vary between 2cm to 20cm covering an area of 40x60 m^2 to 400x600 m^2 depending on flight height.

3. FLIGHT MISSION AND DATA PROCESSING

3.1 Planning of Surveying

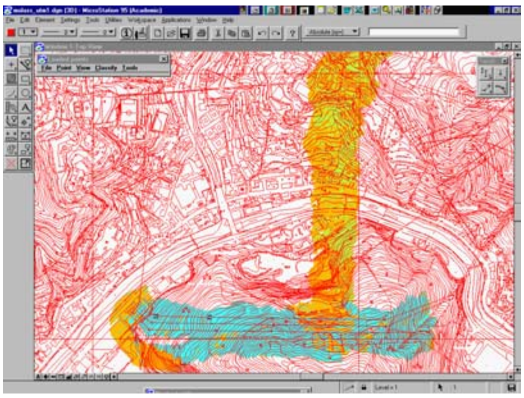

Figure 3 Flight area coverage,

The flight mission has been done in the *Molassana* area in *Genova City,* at flight height 195m above ground. The selected areas have different morphological characteristic, vegetation, building, versant …etc. The coverage of the flight is shown in Figure 3 with different colors. It corresponds to four flight lines vertically and four horizontally, which is about 1000 meter long and 200 meter wide.

The survey with TopEye system was planned using the Spectra Precision terraSat GmbH for the TopEye system. The coordinate of flight line is in WGS84 system, since the positioning is coming from GPS satellite in real time during the survey. TopEye Mission Planning Software (MPS) has the possibility to transform the coordinates from Italian national system to WGS84 system, but with low precision, which could cause flaying far-off the desired area more than hundred meters. To overcome this problem, IGM95 transformation parameters is used, published by IGM (Military Geographical Institute), based on using common known points between the two systems. Two reference GPS station had been used to determine the kinematics flight line trajectory. Six GPS ground control points were measured using Rabid Static Survey, from which two of them are shown in the covered area in Figure 4.

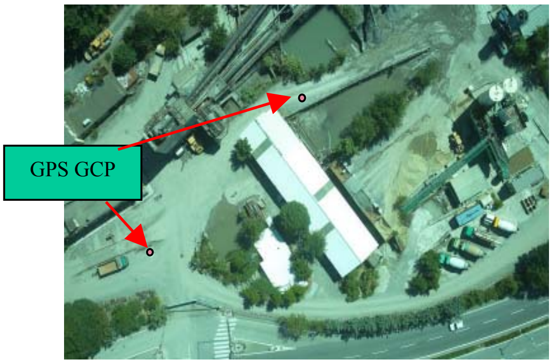

Figure 4: Location of Two GPS ground control points.

3.2 Data Processing

The first step of elaboration laser data is the processing of GPS data to obtain the Helicopter trajectory by using GPS processing software such as GeoGenius software. After that laser data is processed by TopEye software, which is developed for TopEye laser data. The programme combine GPS solution (position of Helicopter at 1 Hz), INS data (attitude at 50Hz), laser range and mirror scan angles to calculate the coordinates of the laser foot print on the ground for each laser pulse.

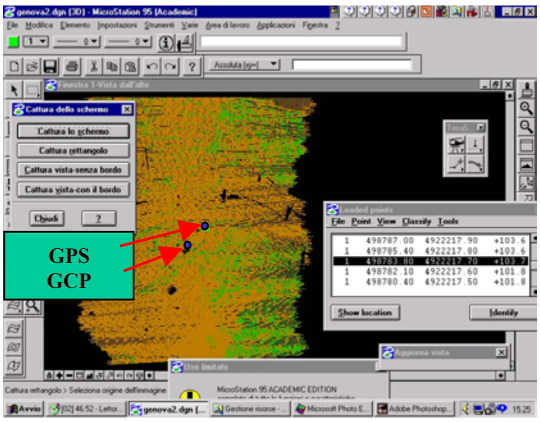

Figure 5: The two GPS ground control points on top of the generated DSM.

The final position is given in WGS84 geocentric coordinates. The final result of processing is cloud of three-dimensional coordinate points that represent the DSM of the surveyed terrain area. Figure 5 shows the generated DSM with the above two GPS ground control points. Then DTM is generated via the Terra Solid Software.

4. ANALYSIS OF RESULTS

During the performed survey, the laser system receives the echoes of laser pulses reflected from any object in its path, without distinguishing that the object is on the ground or above the ground. Thus the initial data point (DSM) will indicate all ground and non-ground objects together. To distinguish between the ground and non-ground data, terrascan software was used to classify captured data,– product of terra solid (www.terrasolid.fi).

All results and analysis in this work have been obtained by using GeoGenius software for processing GPS data, TerraScan programme for classification of laser data, and Terra Modeler for producing the final DTM, see Figure 6.

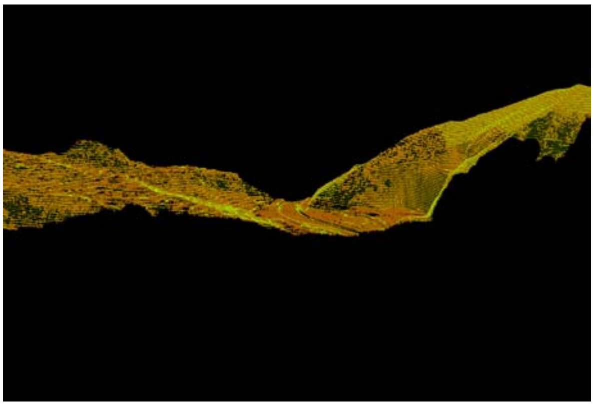

Figure 6: DTM generated from laser scanner data.

Figure 7 shows a cross section of the area of interest.

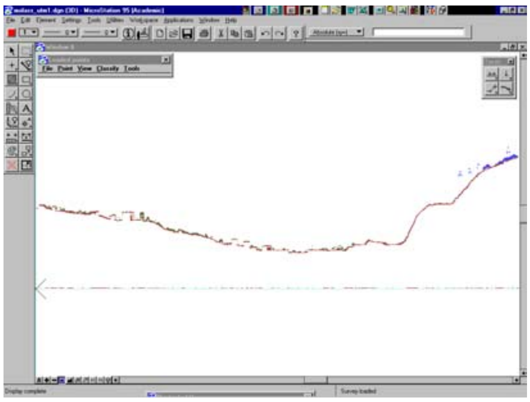

Figure 7: A cross-section of the area

Furthermore, PCI OrthoEngine software V8.2 is used for bundle adjustment and DTM generation from the digital photos. The DTM is generated using first tie and control points; Second, using the Epipolar photos. Orthophoto is also generated first from laser DTM with digital photos for radiometric values using the Terra Photo software. Second, the Orthophoto are generated from the Digital Epipolar photos based on stereo vision and using the PCI software.

4.1 Quality of the laser data

To check the quality of laser data and the DSM obtained. Some GPS points are survey in the area of interest using the rapid static technique. Two points were allocated as shown in Figures 4 and 5. The precision obtained could be considered as an indication of the external reliability of the method with respect to other surveying technique. In table 2 it has been shown the difference between the known GPS ground control point and the average of the Height component of the laser point strikes around the GPS verities. Table 2 shows the difference in height, which is within 2-4 cm.

Pt No.	GPS Ground Control Points		
	North	**East**	**Height**
1	**4922247.406**	**498824.960**	**102.776**
2	**4922214.584**	**498782.637**	**103.702**

Pt No.	DTM Laser coordinates			DH (m) At 195 height
	North	**East**	**Height**	
1	**..47.29**	**..25.00**	**102.76**	**0.02**
	..47.30	**..24.82**	**102.81**	**-0.03**
	..47.43	**..24.80**	**102.80**	**-0.02**
2	**..14.63**	**..82.86**	**103.74**	**-0.04**
	..14.43	**..82.86**	**103.73**	**-0.03**
	..14.52	**..82.19**	**103.73**	**-0.03**

Table 2: Height difference between the GPS GCP height compared to the nearest DSM laser points.

4.2 DTM Generated via Digital Photogrammetry

4.2.1 Tie Points and GCP and Bundle Adjustment Results:

DTM and orthophoto were generated for the vertical strip shown in Figure 3. It is a total of twelve photos. To adjust the strip, the exterior orientation taken from the adjusted laser data with large standard deviation were used, and also fifty-two laser points (with known ground coordinates) are used as a control points with standard error of 4 cm. In addition, each photo should have at least twelve tie points. The RMS values of the GCP laser points residuals resulted after the success of the bundle adjustment were 9 cm and 8 cm for the X and Y component, respectively. The RMS values for the tie points residuals were 2 cm and 1cm for the X and Y component, respectively.

The software used is OrthoEngine. The system did not have stereovision capability.

4.2.2 Epipolar Image:

Using the OrthoEngine software the epipolar image of all the twelve photos were created.

4.2.3 DTM Generation and Comparison Results:

DTM was generated vai the software in three methods. The first One is based on the laser points taken from Terra Scan software and found to be reliable with good coverage over the are without large gabs, See Figure 8. The other is based the tie/GCP points and epipolar image formation, however, the resultant DTM was not reliable. It has lots of gab/failed areas, points are scattered and thus was discarded.

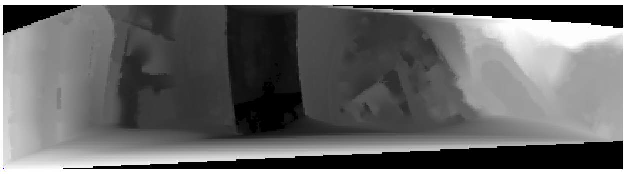

Figure 8: The DTM generated by OrthoEngine based on laser points

4.3 Orthophoto Generation

4.3.1 Orthophoto Generation from Laser DTM data:

To obtain the orthophoto in the terra photo programme, the laser point should be classified in the terra scan programme and then loaded with the digital images including the file that contain their attitude and position in the terra photo programme. Consequently and with using initial calibration parameters of the digital Hasselblade camera the initial orthphoto is produced. After all the camera calibration parameters should be improved by entering manual tie point, and semi-automatic tie points consequently the orthophoto created is improved.

Then, the area should be divided into tiles. The chosen tile size in our case was 1000X1000 pixel. The work should be continued with adding semiautomatic/manual tie points for all images and refine camera attitude and run the adjustment raw image attitudes until obtain the perfect adjustment. Orthophotos are then generated for each tile. Figure 9 shows the combined tiles to represent the area of interest.

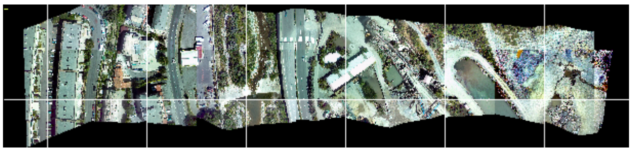

Figure 9: Orthophoto generated from laser DSM and digital photo.

4.3.2 Orthophoto Generation from Digital Photos and Stereo Vision:

Similarly, an orthophoto is generated using the OrthoEngine Software. The resultant adjusted photos from the bundle adjustment based on the tie/GCP points with the aid of the generated DTM are used to generate and orthophotos for each image. The pixel size of the generated orthophotos is 4 cm similar to the one generated via the TerraPhoto software. The automatic mosaicing is used to generate the orthophoto for the area of interest. See Figure 10.

Figure 10: Orthophoto generated from using OrthoEngine Software

4.3.3 Comparison Results:

The quality of ortho produced by the automatic mosaicing has better quality that one can see especially at the joining parts of the tiles. Figure 11 illustrates the water surface of the orthophotos. It shows that the TerraPhoto colour balancing still required more work to enhance it when compared to OrthoEngine.

(a) (b)

Figure 12: Lake Surface in the generated Orthophoto (a) using OrthoEngine Software (b) using TerraPhoto software.

Figure 11 illustrates how precisely the edged are matched in the case of Orthophoto compared to TerraPhoto.

(a) (b)

Figure 12: Edge matching in the generated Orthophoto (a) using OrthoEngine Software (b) using TerraPhoto software.

However, the projection of TerraPhoto/TerraScan software coincide perfectly with the laser data, more than the one produced via OrhtoEngine. The comparazone is done based on the selection of about 50 pionts. However, when distances are compred between the two generated orthophotos, the differences were with 4-8 cm and the RMS is about 5 cm, which is similar to the precision of the adjustment results. This shows that laser data provided by the system provide a reliable information that can be used for various types of applications.

5. DISCUSSION, CONCLUSION AND FUTURE WORK

In this work some experiments performed by airborne laser scanner at Genova City area have been discussed. Consequently some important points have to be noted:

- The lateral coverage used in laser strips should be taken in consideration to be at least 20%, due to the wind condition during perform survey by Helicopter;
- The precision of 10-20 cm of the DTM obtained is good enough for many engineering applications and that precision depends on the flight height;
- The problem of transformation of the ellipsoidal height to orthometric height should be examined carefully taking in consideration all factors that could affect the results such as distribution of control known points around the interested area and geoid undulation.
- The DTM obtained by airborne laser scanner could reach to 1 decimetre, and that is highly dependent on the precision of GPS solution and on the altitude of the Helicopter.
- In order to obtain a reliable solution it is suggested that the distance between reference and rover receiver not exceed 25 km (Acherman 1996, Al-bayari 2000).

The orthophotos generated by both the TerraPhoto/Scan software and the OrhtoEngine software provided very good precision and are comparable to the system precision (within 4-8 cm in x and y coordinates and 10-20 cm in height). OrhtoEngine software shows very good capabilities in color balancing and edge matching. On the otherhand, TerraPhoto/Scan software projected the laser points perfectly within 4 cm of its origin.

Within this paper some important aspects of airborne laser scanning are illustrated which show the success and the reliability of the laser data.

6. ACKNOWLEDGEMENTS

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