EXPERIENCES OF LASER AUTOSCANNING FOR ARCHITECTURE: THE DOMUS AUREA IN ROME AND THE SAN GIOVANNI'S BAPTISTERY IN FLORENCE

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KEY WORDS: Laser, Autoscanning, Architectural Survey, Archaeological, DSM, and cupolas.

ABSTRACT

We describe two experiences of laser autoscanning survey, the Domus Aurea in Rome and in the San Giovanni's Baptistery in Florence. In the first case we surveyed the so called "sala ottagonale" that is the central room of the Domus Aurea. We employed the Quarryman MDL LaserAce. This is a motorised theodolite that can measure 3D co-ordinates along a regular grid up to 15000 points. In this way for the two domes a DSM (Digital Surface Model) of about 12000 points has been produced in less than 5 hours. The instrument is designed mainly for quarries and large areas and it has limitations for its architectural employ; nevertheless the results are quite interesting, providing some corrections to the angular and distance measurements. We describe the performed tests on the instrument. MDL works properly when the laser ray beats almost perpendicularly the surface: this is just the condition for a cupola. In Rome the accuracy was not very satisfactory, while on the contrary it was higher than the one declared by the manufacturer in Florence. We think that in this last case the smoothness and regularity of the surface allowed better results and more reliable checks.

Introduction

The laser technology modifies our habits of surveyors and photogrammetrists, providing a new powerful tool; it is indeed a real breakthrough in the surveying sciences, together with GPS and digital photogrammetry. The main applications have been made from the airborne, (laser profiling and DSM – Digital Surfaces Models). We had the opportunity to use and test a laser auto-scanning MDL System (quarryman). This one is similar to a theodolite, designed for large surfaces, such as quarries etc. Two motors along horizontal and vertical axes drive the sensor. It can scan a regular grid, whose span can be selected. The problem is that the machine can record a great amount of points, but it can hardly detected the most significant lines, like corners, vertices, etc.
We describe two experiences: the dome survey of the "sala ottagonale" in the Domus Aurea in Rome and the dome survey of the San Giovanni's Baptistery in Florence. The MDL Ace300 has limitations for architectural employ; some corrections to the angular and distance measurements were necessary to work properly.

1. THE INSTRUMENT

The **MDL** laser autoscanning (ALS), Ace300, Quarryman[1] employs laser time of flight measurement technique to measure range to the object without the need to place reflectors at the target. This allows 3D measurements to be made of inaccessible points. Quarryman can observe up to 3600 points per hour. The range of MDL 300, the model we used, is up to 400 metres. The measurement beam is 4 cm in diameter at the starting and has a divergence of 2 milli radians, which are 2cm per 10 meters of distance.

[1] The instrument is manufactured by Measurement Devices Engineering Limited, Siverbum Crescent, Bridge of Don Industrial Estate, Aberdeen, AB23 8EW, Scotland UK.

The features declared by the factory are as follows:

- Motorised on two axes
- Distance measuring by laser
- interior recording
- 2 points/sec
- max distance 400m
- distance accuracy: 6 5cm
- angular accuracy 6 0.02g

1.1 The instrumental checks and corrections

The instrument has been designed for quarries survey mainly, therefore the architectural survey is an improper application, but, provided some corrections, it becomes fully suitable to this task.

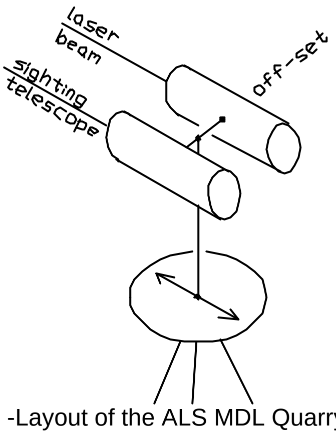


Fig. 1 -Layout of the ALS MDL Quarryman

The instrument is composed by two telescopes, the laser telescope and the laser beam (figure 1). As both of them are ex-centric respect to the vertical axis or the rotation axis, it is necessary to apply reduction to the:

- collimator readings,
- distance measurements,
- horizontal directions.

It exists a similar instrument equipped with the **DISTO** as distantiometer, produced by the same manufacturer, but without any eccentricity. It is characterised by greater accuracy but lower speed, and a smaller range of application.

1.2 Correction of the collimator

Being l the angular reading to point P, and e the eccentricity, d the distance to the point, the corrected reading l' is obtained (figure 2):

$$l = l' + e \qquad (1)$$

where $$e = \frac{e}{d} \qquad (2)$$

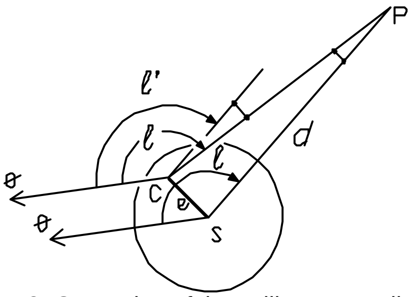


Fig. 2- Correction of the collimator reading

1.3 Correction of the distance

The corrected distance d*, from the measured distance d and the eccentricity e is (figure 3):

$$d^* = \sqrt{d^2 + e^2} \qquad (3).$$

The two distances d and d* in practice coincide after few meters.

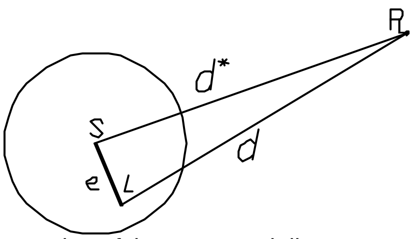


Fig. 3 – Correction of the measured distance

1.4 Correction of the direction

We want to substitute point P* with point P_L, the one where the distance is taken (figure 4).

$$l' = l + e \qquad (4)$$

with $$e = \frac{e}{d} \qquad (5)$$

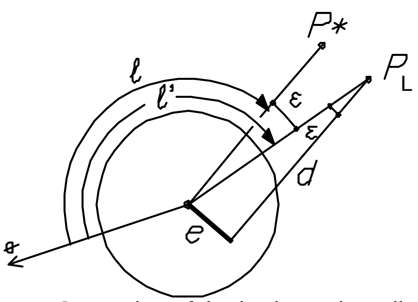


Fig. 4 – Correction of the horizontal readings

1.5 Test of the vertical wall

The correctness of equations (4) and (5) have been verified by the following test. We placed the instrument at a distance of about 1 m from a vertical wall and then we made a horizontal cross section. The obtained section, without corrections (4) and (5), looks like in figure 5 and is not aligned. The point P corresponding to the angular measure is not point P' the one where the distance d_L is taken. On the right hand side the measured distance d_L is greater than d while, on the left-hand side this is smaller (figure 6). We want to take point P_L instead of P and this is done by angular correction (4).

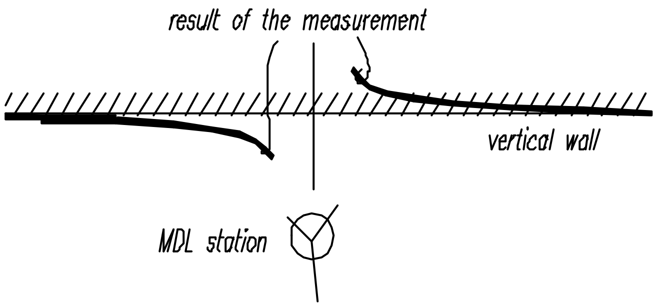


Fig. 5 - Test of the vertical wall

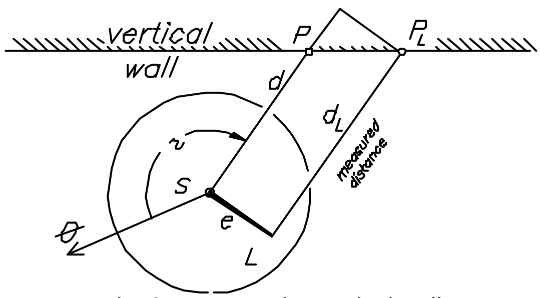


Fig. 6 – Test on the vertical wall

1.6 Test of horizontal cross-section

The MDL instrument does not make possible the transit, say the angular readings from both sides (right circle and left circle).

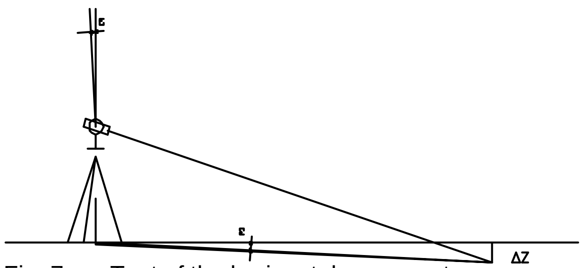


Fig. 7.a – Test of the horizontal pavement

Fig. 7.b -Test of horizontal pavement

The operator cannot check the vertical readings and eventually correct them for the zenith error. In order to assess the correctness of the vertical measurements and to establish the amount of the error, we made two measurements (figure 7.a and 7.b) in an about horizontal floor. The medium slope of the two reciprocal sections is the correct one, and the difference from it is just the hunted vertical error.

1.6 The autoscanning mode

The autoscanning of the MDL takes place in an area defined by two points: point A upper right, and point B, lower left. The amount of the scanning interval must to be input: cord or arc, horizontal or vertical scanning (figure 8).

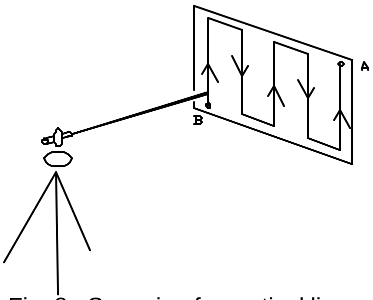


Fig. 8 - Scanning for vertical lines

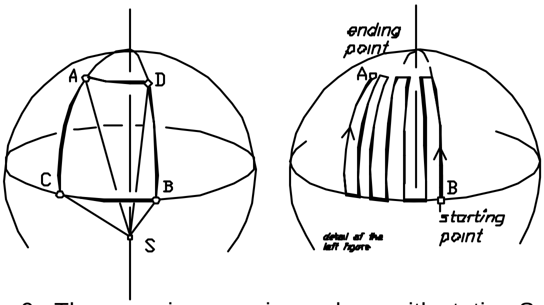


Fig. 9 - The scanning zone in a sphere with station S on the z- axis

1.8 Smoothing sharp edges

As explained in paragraph 1 the laser beam is, as a matter of fact, a cone instead of a straight line. The consequence of this is a smooth of the sharp edges as shown by our tests.

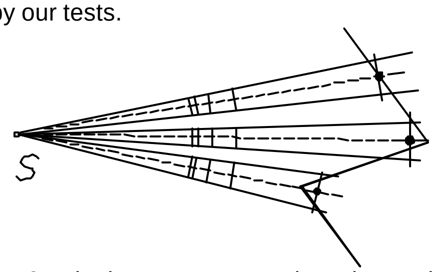


Fig. 10 - The instrument smoothes sharp edges.

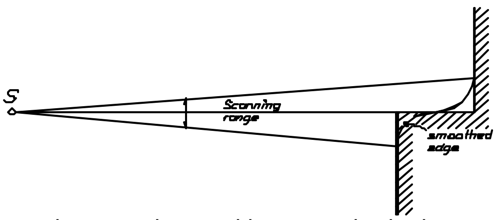


Fig. 11 – The resulting smoothed edge

The distance is the average of the points included in the cone (figure 10 e 11).

2 DIGITAL SURFACE MODELS: PRACTICAL EXPERIENCES

We present here two practical experiences

- the dome of the “sala ottagonale” in the Domus aurea in Rome
- the dome of the Baptistery in Florence

The presentation is limited to the use of MDL autoscanning.

2.1 - The Domus Aurea in Rome – The “Sala Ottagonale”[2]

The Domus Aurea in Rome was built in the years around 60 ac. by will of Nerone, one of the first roman emperors. It was very much extended in surface, and one of most significant room was the so-called “sala ottogonale”. We carried out a laser survey with MDL autoscanning, which was limited to this hall and its nearing rooms.

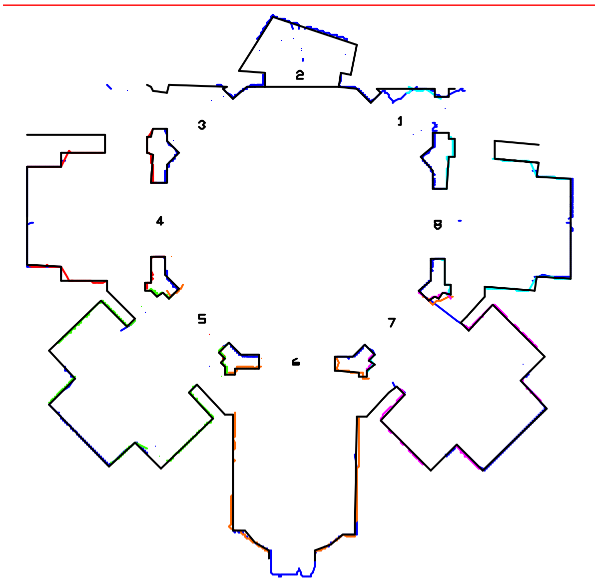
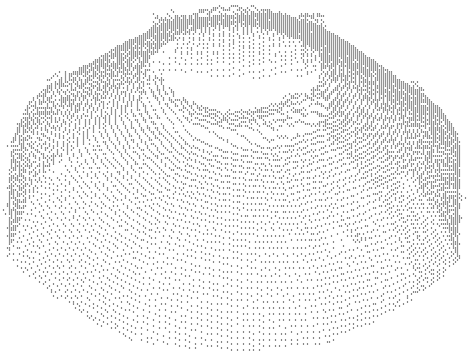


Fig. 12 – Map of the octagonal hall with its nearing rooms. The points 4, 5, 6, 7, 8, 10 are the ground stations of the surveying network.

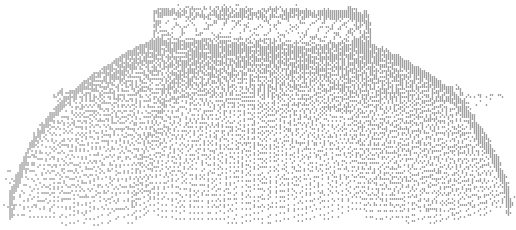
The plan is an octagon. The ceiling is a vaulted dome, with a large hole in the centre, 6.0m of diameter. The diameter of the circle inscribing the plan of the sala is 14.60m, the dome ranges from an elevation of 5.05 over the floor to 9.76 m for a depth of 4.71 m. The digital surface model of the dome was obtained by scanning divided in three zones, each of them having an angular amplitude of 120°, taking care that each zone has an overlapping area with the next one. The scanning interval was set to 20 cm, for a total amount of about 12.000 points.
About 60 target points have been stuck on the surface of the dome. They have been intersected from at least two

[2] The project derives from an agreement between CISTEC, the Rome University “La Sapienza” and the Soprintendenza Archelogica of Rome.

stations by a theodolite equipped with a laser disto. We made a comparison of the targeted point with the interpolated corresponding point on the digital surface model. The surrounding four points have been interpolated by bilinear surface enabling us to compute the surface point corresponding to the target. The accuracy obtained has been in the range of 5 cm.



(a) Axonometric view



(b) Frontal view

Figure 13 Digital Surface Models of the dome

In addition to the digital model of the dome, we determined some horizontal cross sections, from station points 4, 5, 6, 7, 8, 10 (figure 12), setting the laser beam to the horizontal. A map of the room has been obtained. The figure 14 shows the difference between this map and the one produced by a detailed survey with an accuracy of 2 cm.
The difference can reach values of 10 cm. It is important to underline that the surface of the room is highly irregular.

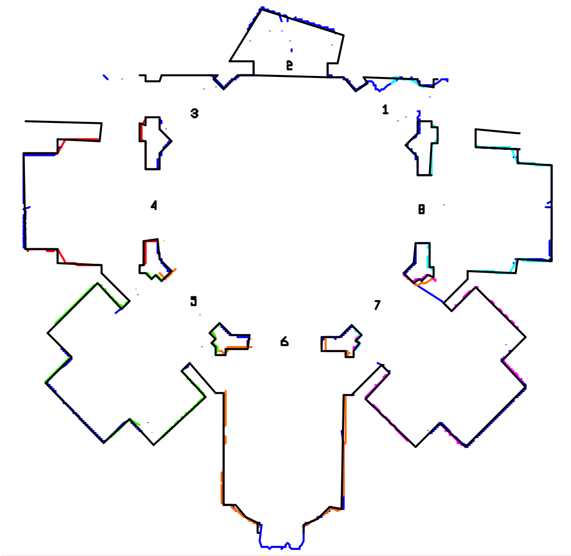


Fig. 14 – Difference between the map produced with MDL and the map taken as reference derived by a classical survey

Some other vertical cross sections were derived from the station placed in the centre of the room. Other cross sections were obtained as intersection of the dome with a cone, giving a constant inclination to the telescope. Figure 15 shows the reconstructed cupola with these sections (16 vertical and 10 horizontal)

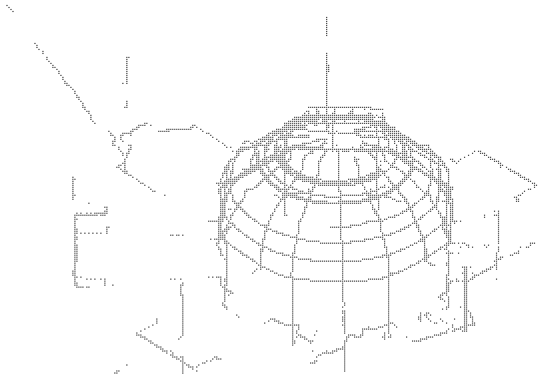


Figure 15 – Merge of vertical and oblique sections.

2.2 The San Giovanni's Baptistery in Florence[3]

The plan of the San Giovanni's Baptistery in Florence is an octagon. The dome was built in 1226. The top of the vault has an elevation of 33.26 m while the starting horizontal plan is 15.35 m elevated, for a depth of 17.91 m. The octagon is inscribed in a circle of 13.95m of diameter. For the digital surface model the scanning was divided in four zones, each of them having an angular amplitude of 90°, taking care that each zone has an overlapping area with the next one. The scanning interval was set to 50 cm, for a total amount of about 12.000 points (figure 16).
Some other vertical cross sections were derived along the 8 corners intersection of the sides. In addition 8 vertical cross sections were obtained along the midpoint of the 8 sides (figure 17).

[3] The project is leaded by Pisa University.

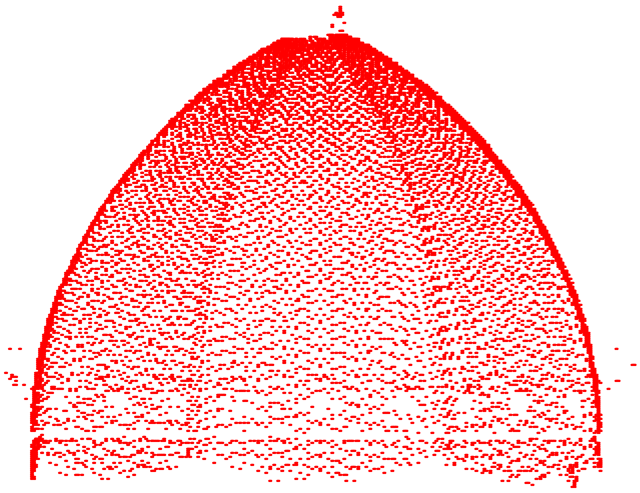


Figure 16: Digital Surface Model

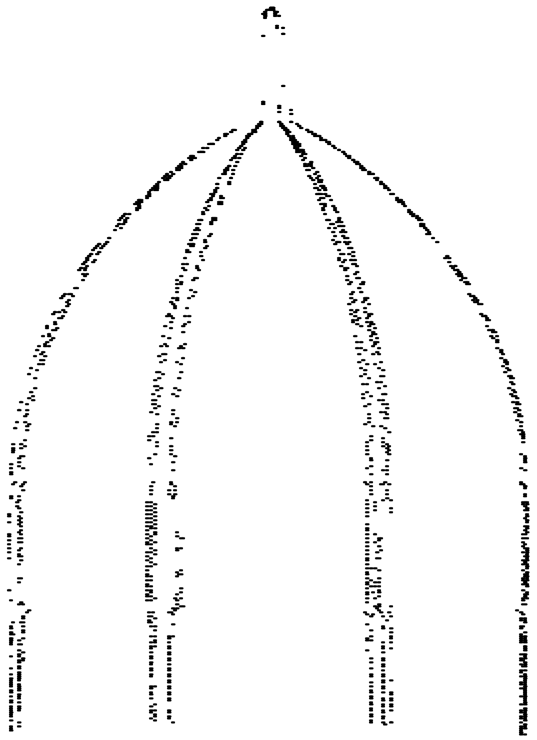


Figure 17 Vertical cross-sections along the corners

2.2.1- Test on repeatability. Three vertical cross sections were repeated. The average on absolute differences on the repeated co-ordinates is 1.0 cm with 409 points compared. Figure 18 shows the differences along 3 cross-sections; the difference vectors are amplified 50 times.

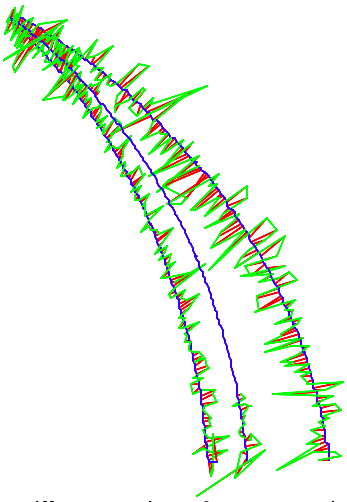


Figure 18 - Difference along 3 cross-section between repeated measurement

2.2.2 - Test on differences. The vertical cross section directed toward south (called "scarsella") was also derived by GTP1002 total station. The test was performed with the suitable 20 points taken with GTP1002.

The distance d is regarded as positive when the interpolated MDL point H is farther than the GTP1000 point P (figure 19). The average of the distances is 0.0165 m while the average of the absolute value of the distances is 0.0173m.

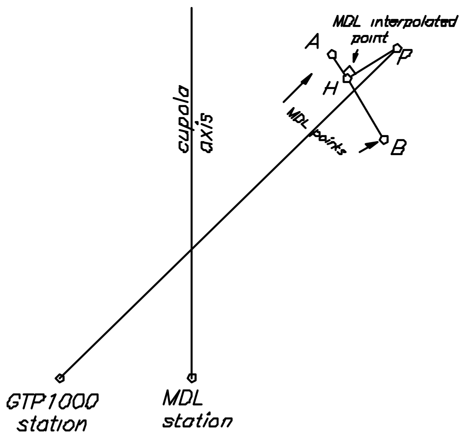


Fig 19 – Distance from MDL points and GTP1000 point, taken as reference

The figure 20 shows the differences, computed in the manner just described, amplified 50 times.

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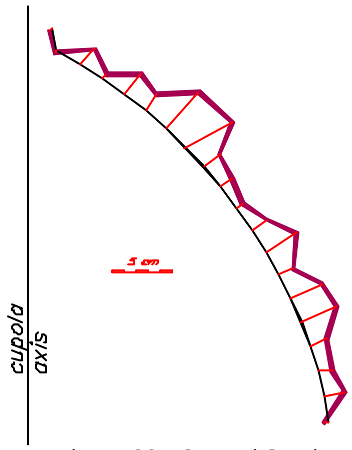

Figure 20 - Control Section by GTP1002 Topcon

Conclusions

In general the laser shows great possibilities in surveying. For the architectural survey there are still many problems to be solved, but also from now it is possible to use laser instruments like MDL quarryman, provided some measure corrections. The more suitable application seems to be in the production of Digital Surface Models. The best results in terms of accuracy are obtained when the surface is regular and smooth. In particular the instrument is suitable mainly for vaulted surfaces like cupolas, where traditional methods like photogrammetry are difficult and time consuming to use. Here the efficiency of MDL cannot be compared with any other method.

Acknowledgements

We tank Geotop s.r.l., Ancona, distributor for Italy, for having made available the MDL instrument.

References

1. Bacigalupo C., Cessari L., Fangi G., (1997) - Experiences of Geometrical Monitoring and Survey of Defects by Using Laser Technologies and Photogrammetry, CIPA International Symposium 1997 Goteborg 1-3 1997, pp 168, 174 ISPRS Archives Volume XXXII part 5C1B

2. Balletti C., Pilot L., Brumana R. (1988) – Plan, execution and representation of an architectonic survey: the torrazzo of Cremona, Italy ISPRS Archives Vol. XXXII part 5 pp 507- 512

3. Brenner C., Haala N., (1998) – Rapid acquisition of virtual reality city models from multiple data sources - ISPRS Archives Vol. XXXII part 5 pp 323-330

4. Hug C., (1992) - Concept of Airborne Laseraltimeter Proceedings of the 2nd International Workshop on High Precision Navigation, Stuttgart /Germany Nov. 1991 Ferd. Dummlers Verlag, 1992, pp. 137-148

5. Lohr U. , (1997) – Digital elevation models by laserscanning: Principle and applications. In: Third International Airborne Remote Sensing Conference and Exhibition, Vol. I Denmark pp. 174-180

6. MDL Quarryman ALS Rockface Laser Profiling System – Operator's Manual

7. Pritschow G., Hartl Ph., Ioannides M., Weher A. (1992) – 4D-Laser Scanning Followed by Internal Computer Model Generation. ISPRS Archives XVI Congress, B5, Commission V (1992), pp. 522 - 527

8. Suzuki S., Kamijo K. (1998) – Development of Three-Dimensional Measuring Technology at High Speed and at High Resolution – ISPRS Archives Vol. XXXII part 5, pp.805-810

9. Takada K., Akiyama Y. (1988) – The possibility of water surface slope measurement with airborne laser profiling method - ISPRS Archives Vol. XXXII part 5 , pp. 284-290

10. Wehr A., Hug C. (1993) – New Laser Technology to Derive Surfaces in Proceedings ISPRS Commission I Workshop – Trento pp. 177- 193