Mobile Mapping – The StreetMapper Approach

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ABSTRACT

Mobile mapping using laser scanning is now a well established survey technique and usage of this technology is becoming more widespread. Although mobile mapping can be a very efficient way to capture high resolution LIDAR data, especially of a highway environment, there are still challenges for system manufacturers and users in maintaining high accuracy in conditions of variable GPS quality.

The StreetMapper approach to mobile mapping is to focus on maintaining high accuracy so that “survey grade” data can be delivered to the end users. This paper examines the workflow and performance issues of the mobile mapping system ‘StreetMapper’ with particular reference to maintaining high quality results.

1. INTRODUCTION

Mobile mapping has been around for many years using various photogrammetric techniques. In recent years, there has been an increase in the number of mobile mapping systems using laser scanners available in the commercial market. The improvement in the performance of GNSS/INS for direct georeferencing has broadened the range of applications for these mobile mapping systems.

Terrestrial 3D laser scanners are commonly employed for highway and building surveys; however, these instruments are slow and therefore costly when large areas need to be surveyed. Mounting a 3D scanner on the roof of a vehicle can improve the speed and productivity but there are still disadvantages such as uneven point spacing and the time taken to accurately geo-reference each 3D scan. For large surveys, over 100 individual scan positions must be geo-referenced which in turn causes significant data management problems.

Highway surveying using videogrammetry, supported by GNSS/INS systems, has also been well used in many parts of the world. However, there are significant challenges in creating 3D data products with minimal human data processing. Some of these systems are now adding laser scanners to improve the data processing workflows.

The StreetMapper mobile laser scanning system was initially developed to meet a demand for measurement and recording of highway assets, but has since been developed for other applications. The system is easily deployed on a range of different vehicles and the first StreetMapper system has been operating since early 2005. This was the first fully integrated, commercially available system of its type

The significant commercial advantage of the system is that no traffic management is required to complete highway surveys and an accuracy of 30mm can be achieved.

The performance objectives of the mobile mapping system “StreetMapper” are:
- Complete eye safe operation;
- Operational speeds up to 80 km/h;
- Full field of view;

- Operation in urban environments and under tree cover;
- Survey grade mapping;
- Operation of additional sensors (for example, video and digital imaging).

It is however, noted that there are potential limitations of such a mobile mapping system and these are described in Section 2.

2. PERFORMANCE ISSUES

In order for the StreetMapper system to be attractive in the commercial market and perform well in real world projects, the performance limitations of each element of the system must be understood.

2.1. LIDAR system performance

Unlike airborne laser scanning, the mobile mapping sensors will be operating in a cluttered environment where the field of view is limited by buildings, vehicles and vegetation. The sensor field of view must be as wide as possible so that the final point cloud is as complete as possible.

For the end user, the point density is a key issue as this controls the resolution of the point cloud. This also defines the minimum size feature that can be seen in the point cloud. Point density varies with:

- rotational speed of sensor head;
- points per scan line measured by the sensor;
- sensor mount (angle and location on vehicle);
- height of sensor above road;
- driving speed;
- distance from the vehicle;
- overlap from adjacent scans.

Some of these aspects are controlled by the selection of the LIDAR sensor and others are controlled by the survey mission planning.

2.2. Imaging system performance

The interpretation of the LIDAR point data is improved by moving or still imagery. The StreetMapper offers three types of imaging system to allow for different modes of use:

The *StreetMapper video system* uses consumer video cameras on a flexible and adjustable mount, usually inside the vehicle, looking through the front window. Although the rigid connection to the GNSS/IMU is missing in this case, the information about the position and orientation of the camera is still good enough for the given task.

The *StreetMapper imaging system* uses 4 MPixel digital cameras recording JPEG format frames at 7.5 frames per second. Each frame is time tagged by the TERRAcontrol system and can be synchronised with the laser scanner data. To take the full benefit of the orientations from the GNSS/IMU system, this camera is mounted together with the other sensors on the rigid platform. The camera image is calibrated and overlaid on the LIDAR point cloud using the software PHIDIAS from PHOCAD Ingenieurgesellschaft mbH, Aachen, Germany. Additional software is available for colouring LIDAR points from the images.

The *StreetMapper camera system* uses a digital SLR camera (typically 12Mpixel resolution) with each frame time tagged by the TERRAcontrol system. This provides high resolution images but the maximum frame rate is limited to 2 frames per second (or less) depending on the model of camera. This system is mostly used when travelling at slow speed in urban areas.

2.3. Navigation performance

The GNSS conditions in a land vehicle are deteriorated by multipath effects and by shading of the signals caused by trees and buildings. This is a challenging environment for maintaining high positional accuracy. However, the distance between the scanner and the measured object is typically some ten meters, compared to several hundred meters for airborne laser scanning. Therefore the contribution of the GNSS positioning error to the overall error budget is much larger than the contribution of the error from the attitude determination.

Figure 1 shows the typical performance of the GNSS/INS along a typical highway with a good view of the sky. It can clearly be seen that passing by trees and under bridges causes the number of visible satellites to drop significantly. The effect of this can be seen in the average INS position plot (Figure 2), which is an estimate of system accuracy after processing GNSS and INS data together.

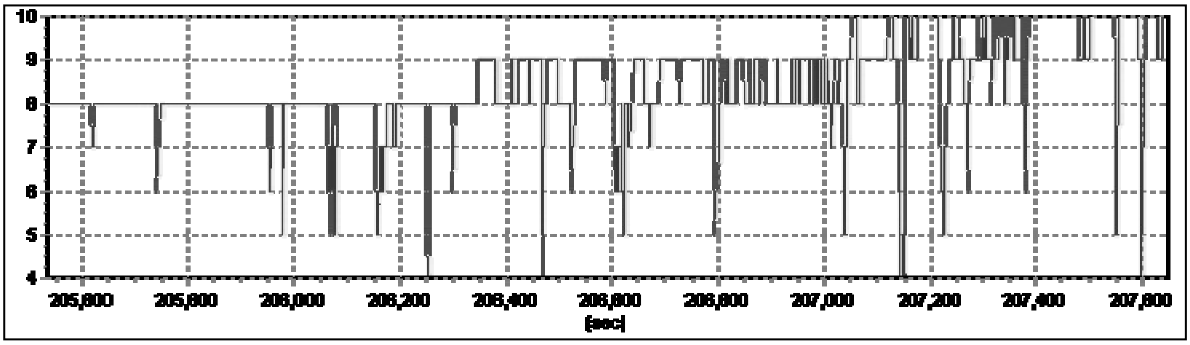


Fig. 1: Number of GNSS satellites visible vs. mission time.

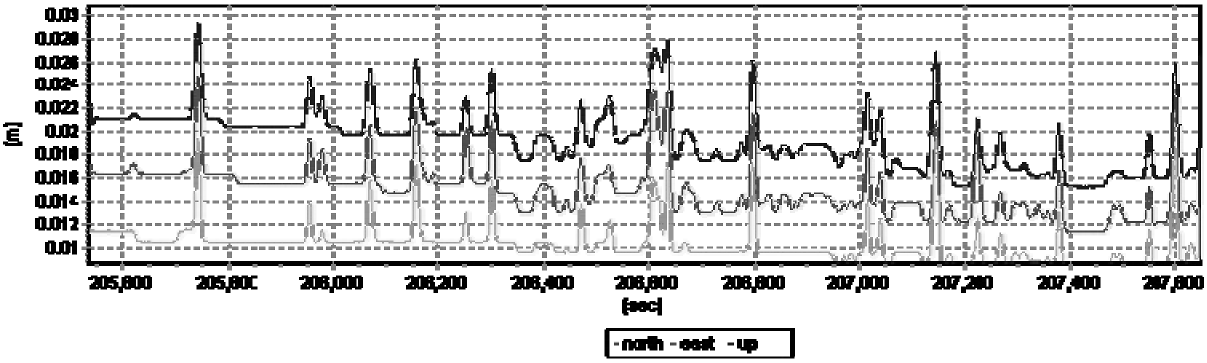


Fig. 2: Average INS position RMS vs. mission time.

The TERRAControl navigation system has been upgraded especially for StreetMapper applications where there is reduced GPS visibility due to tall buildings and obstructions. Using a technique called Direct Inertial Aiding, an inertial navigation system assists the GPS receiver in areas of poor GPS signals. After losing the GPS signal when passing a tall building, the receiver can rapidly lock on to GPS signals again and maintain positional accuracy. Initial tests have confirmed that typically the GPS receiver will get back to a high positional accuracy up 5 seconds sooner when using the

Direct Inertial Aiding after losing the signal. The overall result is higher positional accuracy across the whole survey.
A recent test in Germany has proven the ability of the Direct Inertial Aiding system to reduce the mission time with reduced GPS quality due to tunnels and trees. A test was conducted by driving the StreetMapper system through a tunnel with two GNSS/INS systems installed: one with Direct Inertial Aiding and one without. The route is shown in Figure 5 below.

The improvement is clearly shown in Figure 3 below, where the reacquisition time (to 80% quality) is achieved 5 seconds faster using Direct Inertial Aiding.

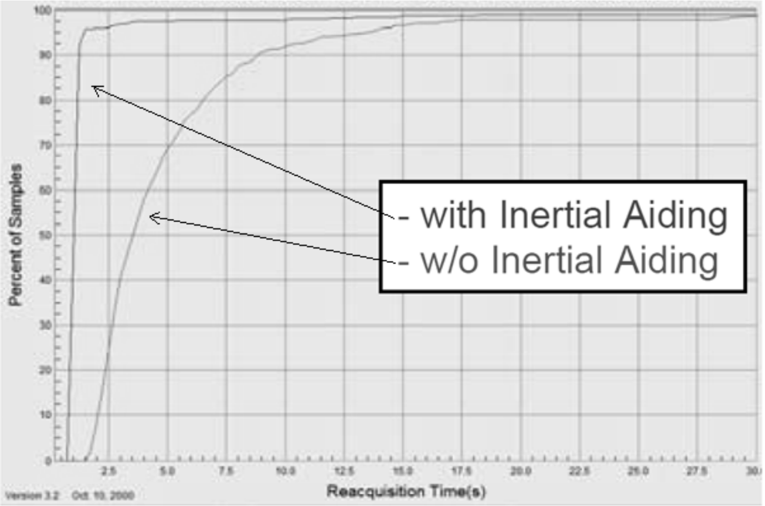
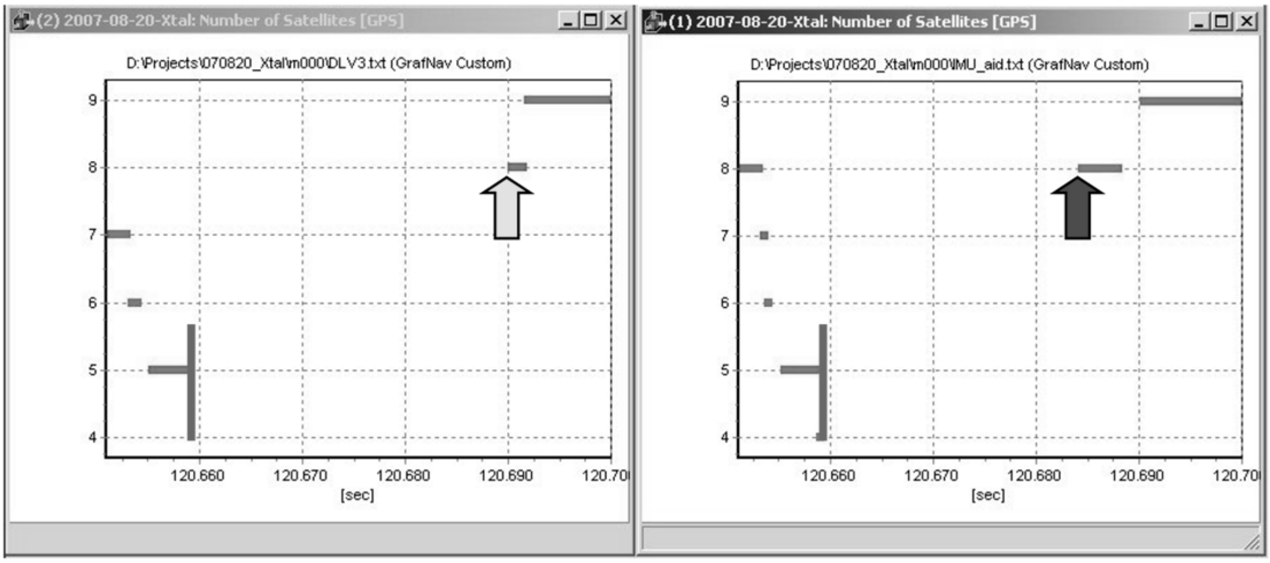


Fig. 3: This graph shows the reacquisition time for the GNSS L1 signal after coming out of the tunnel.



without inertial aiding

with inertial aiding

Fig. 4: This graph shows the difference in number of satellites visible vs. time
(after exiting the tunnel at time=120.660).

Fig. 5: Plan view of the test area showing tunnel exit lines and arrows showing points where 8 satellites are visible with (dark arrow) and without (light arrow) Direct Inertial Aiding.

2.4. System calibration

The relative position of the different sensors to the IMU can be measured directly at the sensor assembly. The relative orientation, or misalignment, has to be determined from the data. For this misalignment calibration, features like street markings or house corners are captured in multiple passes. Certain target structures allow separate determination of the three misalignment angles. Due to the rigid mounting of the laser scanners and the IMU, the misalignment calibration does not change noticeably between different missions.

2.5. Mission Planning

In order to maintain high accuracy, the GPS visibility for the time and location of the survey must be checked and times with poor GPS visibility must be avoided. The number of driving passes must also be determined based on the point density requirements, the GPS visibility and the desired accuracy. In airborne surveying, it is normal to expect overlapping flightlines (either with LIDAR or photogrammetry). Good survey practice for mobile mapping is to also generate overlapping survey passes which will allow detection of blunders/poor GPS quality, adjustment by matching flightlines and a check of overall system calibration. This might decrease the overall mission efficiency but the benefits of driving each road twice will be seen in the accuracy and reliability of the final data product.

2.6. Mounting

The sensor mounting platform is critical to the success of StreetMapper. The StreetMapper 360 system uses an innovative lifting sensor platform that has significantly improved the protection of both equipment and personnel during installation, use and routine maintenance. The scanners are protected from the weather during operation, and can be removed from sight when not in use. In addition there is no requirement for personnel to work at height, which can be a significant risk to health and safety.

Fig. 6: Lift mount with extra height bars.

Fig. 7: Hydraulic lift inside vehicle.

Extra height bars can be added for applications where extra visibility is required to the side of the highway (such as into drainage channels on the side of the road).

Many users of StreetMapper will not require a fixed vehicle installation and prefer a portable system that can be easily mobilised around the world. The StreetMapper Portable system can be transported as normal checked-in baggage with an airline with two people travelling. This system mounts onto normal roof bars and is designed so the sensor and IMU can be easily removed when necessary.

Fig. 8: StreetMapper Portable system in action.

3. FEATURE EXTRACTION

The end user of the StreetMapper data will normally create the following final products:

- Digital terrain models, especially for rapid volume determination;
- Highway surveying where level, gradient and edge of carriageway information is extracted;
- Asset Management Databases for highway authorities (for example, sign posts and street furniture) or utilities (for example, heights of wires over the road);
- 3D city models with detailed façade and street level information;
- Change detection for military and security forces.

For a survey grade mobile mapping vehicle, like the StreetMapper, the results will normally be presented as CAD lines and points as well as a GIS database. Two examples of feature extraction are described here.

3.1. Highway linear features and terrain model

Most highway survey information is used by highway engineers for design or construction calculations. They require 3D CAD information such as lines, points and terrain models. These need to be extracted from the point cloud.

Some tools are available for simple automated extraction of lines, but for large projects with rigorous quality checks users will prefer to use a semi-automated technique so that regular quality checks can be made during the processing workflow. The TerraScan software (by Terrasolid of Finland) is one of the best applications for efficient extraction of CAD features from point cloud data.

Fig. 9: StreetMapper point cloud data with extracted CAD data.

3.2. Highway point features

Some features such as road signs can be easily extracted from the image data. The StreetMapper feature extraction system searches the image database for matches with a library of images (for example, road sign images). The result is a list of matches with object name and geographic coordinate. The matches can be overlaid onto the images to assist validation of the results.

Fig. 10: StreetMapper feature extraction showing two results, with only one validated as correct.

The StreetMapper system uses point cloud data alongside image data. The images are searched with a low selection threshold which generates a high number of false positive results (and a low number of missed objects). The point cloud data is then used to validate each of the results. Figure 10 shows an example where two image matches have been found: one is a sign and the other is on the front of a vehicle. The software then uses a set of rules along with the 3D point cloud data to determine that the match on the front of the car does not have the correct flatness, geometry and location to be a valid sign.

4. STREETMAPPER ACCURACY TRIALS

4.1. Project "Simulated Tunnel"

A test was performed to determine the performance of StreetMapper's inertial navigation system after driving through periods of sustained GPS outage due to tunnels of various lengths.

Since it is very difficult to establish accurate control points within tunnels, it was decided to simulate the effect of tunnels by driving on a regular road and removing GPS epochs from the differential GPS (dGPS) solution files for each of four simulated tunnel lengths and comparing the data to a control run that utilises all GPS epochs.

The StreetMapper was driven along a 3 km stretch of the A52 in Bingham, UK. Between 6 and 7 GPS satellites were available during the mission, producing an average PDOP of 2.5.

Trajectories were produced for a control run using all the available GPS epochs, and additional trajectories produced for 4 different simulated tunnel lengths by removing a series of epochs from the dGPS solution as outlined in Table 1.

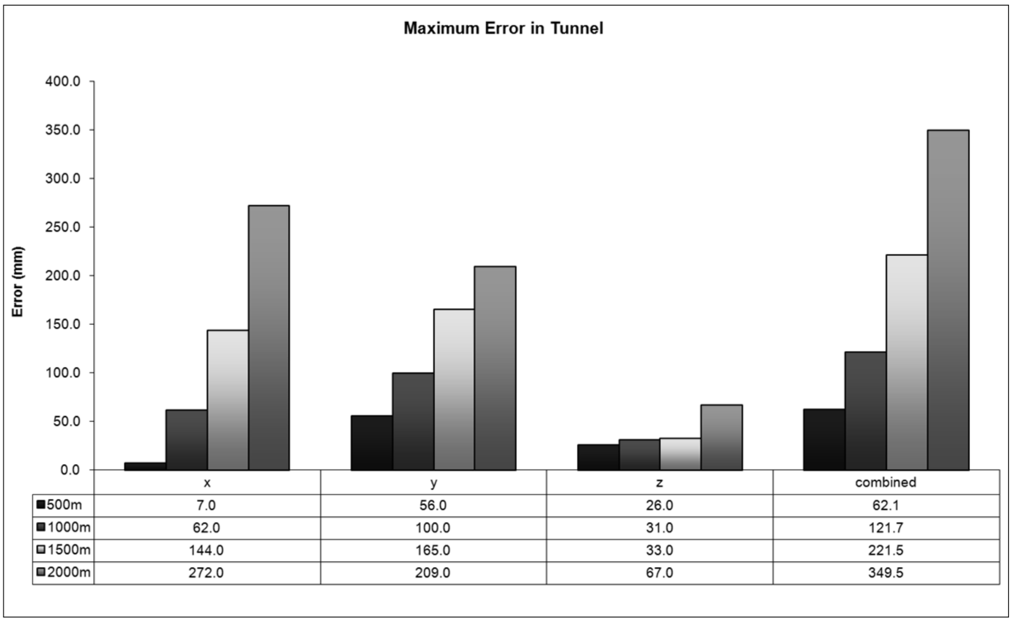
dGPS solution	First Epoch (secs)	Start of tunnel (secs)	End of tunnel (secs)	Last Epoch (secs)	Tunnel length (secs)
Control	382004	n/a	n/a	382906	n/a
500m	382004	382489	382520	382906	31
1000m	382004	382489	382547	382906	58
1500m	382004	382489	382575	382906	86
2000m	382004	382489	382603	382906	114

Table 1: GPS epochs used for each trajectory.

In the StreetMapper processing workflow, 1 Hz trajectories for the four tunnels were output, and their coordinates compared to the 1 Hz control run trajectory. The RMS positional error, due to the lack of GPS, was determined for each tunnel. The estimated RMS position of the INS, as determined by TERRAoffice software, was output for the control run and for the four tunnels. The estimated INS RMS position of the control run was subtracted from the INS RMS position's of the tunnels to take into account any positional error in the control run (hence assuming perfect accuracy in the control run).

4.1.1. Results

Figure 11 shows the maximum error in the four simulated tunnels. As expected the accuracy gets worse with increasing tunnel length. The error in elevation (z) has the least error and is not affected by tunnel length as much as the errors along the driving path (x) and perpendicular to the driving path (y). Coordinates on the y-axis show the greatest amount of error, rising to almost 30cm in the 2000m tunnel.



	x	y	z	combined
■500m	7.0	56.0	26.0	62.1
■1000m	62.0	100.0	31.0	121.7
□1500m	144.0	165.0	33.0	221.5
▨2000m	272.0	209.0	67.0	349.5

Fig. 11: Results of simulated tunnel test showing INS accuracy.

The maximum estimated error (the INS positional RMS) was also calculated for each case and compared to the maximum actual error. In most cases the estimated error was far greater than the actual error, with the exception being the y axis in the 500m tunnel where the actual maximum error was 11mm greater than the estimated maximum error.

The tunnel tests have shown that StreetMapper can achieve better than 35cm positional error in a 2000m tunnel that takes about 2 minutes to drive. Most obstructions along a highway due to bridges and buildings will be equivalent to a tunnel less than 500m, and this shows that in these cases a positional error of better than 6cm can be expected.

4.2. Project "Washington DC"

A test of the StreetMapper accuracy was a comparison of a StreetMapper 2 system against terrestrial 3D scanning measurements. The project was 6,600ft length of 4 lane divided urban highway with traffic signals and turning lanes. This was a high density commercial district with access roads on either side of the highway.

The terrestrial 3D scanning was undertaken with a truck mounted Riegl LMS-Z390 scanner using survey control targets (mounted on a bi-pod) every 50m. A 5 man crew was required for all scanning and surveying of control targets. There were known problems with the movement of system due to wind, settlement of the scanner/vehicle and traffic vibrations. Due to the length of the survey period, it was not possible to avoid all busy traffic periods, which caused unwanted shadow areas in the scans due to traffic. The survey took 7 days (with 5 man crew) with 88 scans and using 132 target control points.

By comparison, the StreetMapper mobile mapping system took 1.5 hours with a 2 man crew to survey the same area. Due to the short survey period, it was possible to schedule the survey for a time when traffic volumes were lowest. A GPS base station was placed near the survey site and 50 ground truth control points were measured using conventional techniques.

The accuracy was compared between the two techniques by comparing a simplified terrain model (including digitised breaklines) generated independently for each technique. The accuracy results are shown below:

Sum of (Elev Diff) Squared	0.0572 m
Ave of (Elev Diff) Squared	0.0000 m
Root Mean Square Error is	0.0062 m
National Standard for Spatial Data Accuracy (NSSDA)	0.0122 m
Points PASS the 95% confidence test based on 1.96 Chi Square Value	
User defined Tolerance	1.0000 m
Maximum difference BELOW	-0.0094 m
Maximum difference ABOVE	0.0390 m
Total number of points	1482
Points are below the TIN Surface	836
Points are above the TIN Surface	627
Points are equal to the TIN Surface	19

Fig. 12: StreetMapper system on location in the USA.

5. CONCLUSION

An understanding of the limitations of any system is fundamental to its successful deployment and application. This paper has highlighted the performance issues associated with the StreetMapper mobile mapping system yet has also clearly demonstrated the potential for the system for widespread adoption for a variety of surveying and mapping tasks. Accuracy levels of better than 30mm, in good GPS conditions, and achieved in real world projects, demonstrate the suitability of the StreetMapper system for highway surveying, asset management and urban modelling for example and it is expected that it will become as tried and tested as it's laser scanning relatives the fixed terrestrial and airborne mounted systems.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Haala, N., Peter, M., Kremer, J. and Hunter, G. (2008): Mobile LIDAR mapping for 3D Point collection in Urban Areas -a Performance Test, XXI ISPRS Congress, Beijing.

Hunter, G. (2006): Accurate Terrestrial Laser Scanning from a Moving Platform, Geomatics World, PV Publications, July/August 2006

Hunter, G., Cox, C., Kremer, J. (2006): Development of a Commercial Laser Scanning Mobile Mapping System – StreetMapper, Second International Workshop The Future of Remote Sensing, Antwerp, October 17-18, 2006

Kremer and Hunter (2007). Performance of the StreetMapper Mobile LIDAR Mapping System in "Real World" Projects, PHOWO, Stuttgart 2007