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INTEGRATED SENSORS FOR IMPROVED 3D INTERPRETATION

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ABSTRACT

The use of GPS and Inertial Navigation Systems in combination with topographic sensors are discussed. Topographic data are acquired using scanning laser range finders and high-resolution digital cameras. The use of reflectance data from the laser scanner is also mentioned. Characteristics of laser range data is described and a strategy for automatic interpretation is derived from that characteristics based on a TIN structure. Results focused on visualisation, interpretation and accuracy are presented from two different test areas. Automatic procedures for separating ground surface and objects are developed. Algorithms for classification of laser range data in the three classes ground surface, buildings and vegetation using the Minimum Description Length criterion are also discussed. Results are presented for urban and sub-urban environments.

1. BACKGROUND

The increased use of georeferenced data for various purposes and applications has put new demands on the ability of fast acquisition of accurate and reliable data. With the introduction of GPS and inertial navigation systems, INS, for position and attitude determination, it is now possible to acquire such georeferenced data from various types of sensors.

Airborne laser scanners, or laser range finders, LRF, is such a new type of sensor that is emerging as one of the most important new techniques for surveying. Laser scanners produce digital surface models, DSM, of high local and global accuracy and it is in areas where such data are useful as it will compete with, or complement, traditional photogrammetric techniques. Examples of such areas are 3D city modeling, road networks and civil engineering tasks like surveying of electrical power lines. A limitation of the laser scanning technique lies in the nature of the technique: it gives elevation data and elevation data only. This need to be combined with other types of sensor data, of which images in some form is the most convenient for interpretation purposes. Images can be in the form of scanned aerial images, digital images from the same sensor platform as the LRF or reflectance images from the LRF system itself.

The laser scanner systems on the market are now in a fairly mature phase, where most of the technical hardware problems have been solved. What very much remains is the development of algorithms and methods for the interpretation and modeling of data to useful representations and formats for the end-user.

2. SENSORS AND SENSOR DATA

In the presented study, data from the Saab TopEye system have been used. The primary sensor of the system is the laser range finder, LRF. The sensor measures distances between the aircraft and the ground at a frequency of 7 kHz with up to four distances

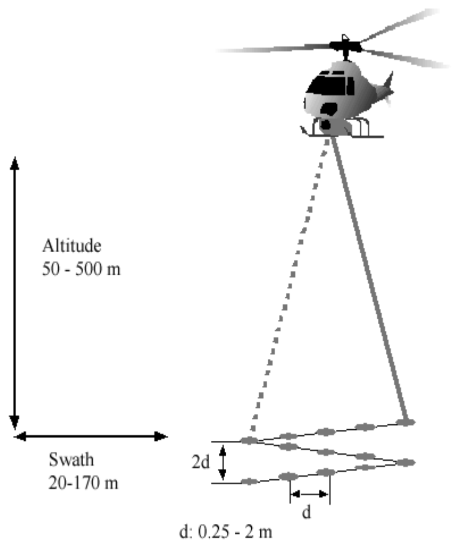

Figure 1 Normal flying and data acquisition conditions for Saab TopEye

recorded by each laser pulse. It detects objects down to 0.1 m in diameter and has a sampling density of 0.25 - 2 m at flying heights of 50-500 m. The pulsed laser beam is scanned across the track of the helicopter, creating a Z-shaped pattern, *figure 1*. The position and attitude of the helicopter is determined by differential GPS and INS. Ground points are measured with an nominal accuracy of 0.1 m.

Recent development of the TopEye system makes it possible to register the amplitude of the returning laser pulse. The amplitude depends of the reflectance properties of the surface objects and together with elevation data, the result can be seen as a “3D image “ in a very narrow wave length band, *figure 2*.

Reflectance data will probably be of great importance in the future, but have not been investigated in this study mainly because of its late development. The use of reflectance values is also available by some other laser scanning systems and has been investigated in *e.g.* [Hug 97]. Reflectance images give the ability of interpreting the LRF data even in flat areas with smooth elevation changes between different surfaces, e.g., paved surfaces and grass.

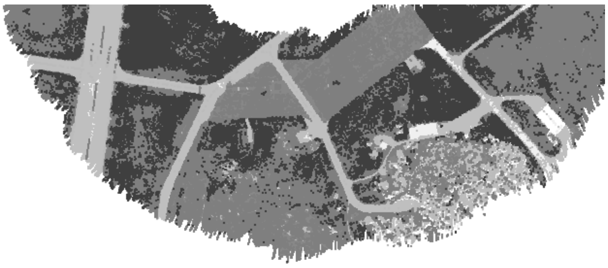

Figure 2 Example of reflectance data covering parts of airfield

Other sensors can be mounted on the same oriented platform as the LRF and a test flight was carried out with a Daedalus digital frame camera having a resolution of 2Kx2K pixels. The advantages of having the LRF and camera mounted on the same oriented platform are twofold: there are no temporal changes between images and elevation data and, secondly, images are oriented without any external orientation procedures.

In some examples given in the article, LRF data has also been combined with scanned aerial photographs. Elevation data and image data in those cases not from the same time epoch.

3. A STRATEGY FOR INTERPRETATION OF LRF DATA

A laser scanning system produces data which can be characterised as sub-randomly distributed 3D point clouds. These point clouds may contain more information than a 2.5D surface model, in which the elevation has a unique z-value as a function of x and y. This means that vertical walls in some cases can be seen as truly vertical, surface points beneath bridges can be measured and volumetric estimations of vegetation can be carried out. Some of this information is lost if data are interpolated into a regular grid DSM, and original data should therefore be used in the classification and interpretation process until an object dependent representation and generalisation can be made.

Most applications will require special algorithms and strategies for the classification and interpretation of LRF data but one task can probably be seen as general to all of these and this is the separation of objects from the ground surface. Once the objects are separated from the ground surface, they can be treated by algorithms according to application.

Following these ideas, a strategy for the interpretation of LRF data is formulated based on elevation data but with the possibility of adding other types of sensor data if available. The strategy can be summoned as:

- Use original LRF data as long as possible, preferably in a TIN structure for easy access
- Separate surface and surface objects with application independent algorithm
- Develop application dependent algorithms for object classification and generalisation. Other data types, as reflectance data or image data are used in this part if available.

3.1 Separating surface and surface objects

Several strategies for identifying the ground surface have been presented, *e.g.,* morphological filtering [Lindenberger 1993]. Here, a method is developed where a surface is connected from below to the point cloud, *figure 3*. The surface is allowed to fluctuate within certain values. These fluctuations can be controlled by, *e.g.*, constrained spline functions, active contour models like snakes or geometrical thresholds for elevation differences. Some characteristics of the approach is:

- A ground surface of connected points in a TIN is created
- The surface goes through the original data points
- Low ground surface points will always be included

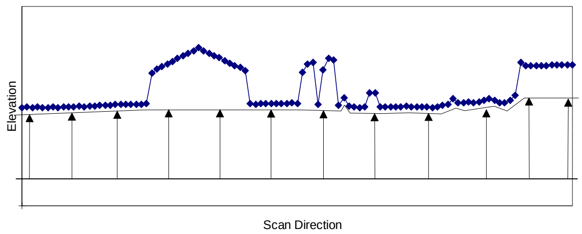

Figure 3 Connecting ground surface to LRF data

An implementation of a simplified version of the approach was carried out. The implementation analyses each scan line at the time and not a whole surface. The implementation fails if no ground surface is present in a scan line, but works satisfactory in most cases, *figure 4,5*. Since the result is promising, a surface based implementation based on TIN will be done.

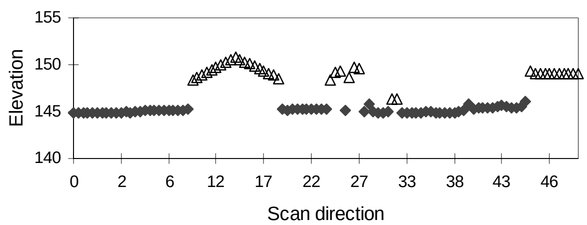

Figure 4 Separating ground from objects

3.2 Classification of buildings and vegetation

Delineated surface objects consisting of unstructured point clouds linked to a TIN are processed by area based methods looking at one object at a time. A classification tool is developed that classify surface objects in the two classes buildings and vegetation. The ability of the laser to penetrate vegetation and thus giving echo from several heights makes it possible to distinguish between the two classes man-made objects and vegetation, *c.f. figure 4*. The classification procedures is based on the Minimum Description Length, MDL, criterion [Rissanen 83] A cost function is formulated for the two classes buildings and vegetation based on the second derivatives of the elevation differences:

***Buildings*:**

Geometric model: Connected planar surfaces

$$\begin{cases} \dfrac{\partial^2}{\partial^2 x} = 0 & \text{Planar surface} \\ \dfrac{\partial^2}{\partial^2 x} \neq 0 & \text{Breaklines between surfaces} \end{cases}$$

***Vegetation*:**

Geometric model: Randomly distributed points

$$\frac{\partial^2}{\partial^2 x} \neq 0 \qquad \text{Randomly distributed}$$

The cost function of the building model contains three parts:

- A constant parametric model for the horizontal plane of the second derivatives
- A statistical model consisting of the assumed gaussian deviations from the parametric model
- A statistical model for the breaklines which are assumed to have random behaviour (similar to that of vegetation)

The cost function for the vegetation model contains only one parts:

- A statistical model for the vegetation which are assumed to have random behaviour (similar to that of breaklines)

A minimum is located for the building model where the optimum number of breakpoints is balanced against the gaussian deviation. The minimum cost is compared to the cost of the vegetation model and a classification is made depending of which value is lower.

An implementation of a simplified version similar to that of ground separation was carried out. The implementation analyses each separated object only in the scan line direction. Examples of the classification can be seen in *figure 5,6*. A surface based implementation based on TIN is planned.

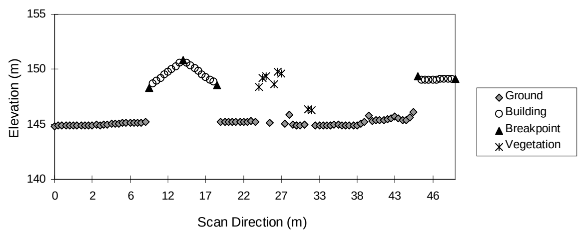

Figure 5 One classified scan line of suburban area

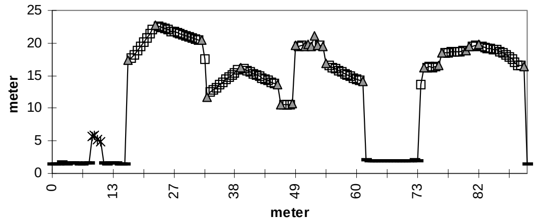

Figure 6 One classified scan line of urban area, see also figure 12 and 13.

4. PRACTICAL RESULTS AND EXAMPLES

Two test sites are used for evaluation of laser scanner data obtained by the Saab TopEye System. The first set covers central parts of Gothenburg. It is combined with scanned aerial photographs taken at a different occasion. The second set covers parts of Borlänge and is combined with digital images acquired from the same sensor platform as the laser measurements.

4.1 Test site 1 - Gothenburg

The area is situated in the central part of Gothenburg. It contains some water areas, but consists mainly of streets and buildings. Elevation data were acquired at approximately 0.5 m distance. Digitised aerial images from a traditional photogrammetric block flown at a different time were used in combination with the LRF data.

Data from the LRF were primarily transformed to WGS84 coordinate system. Since they were to be combined with aerial images, the coordinates had to be transformed to a common coordinate system. In this case the local coordinate system of the Gothenburg region was used, as ground control point coordinates were given in this system. Transformations between different datum definitions is a delicate matter involving, *e.g.*, different referens ellipsoids and different geoid models. Somewhere an error was introduced, causing a constant error of approximately two meters in elevation. The plane coordinates remained correct. The origin of the error was never discovered and the data set was translated to the correct elevation.

There was no digital camera available at the time for acquisition of LRF data. Instead, six aerial images with a 60% side and strip overlap were used in the study. Flying height was 800 meters and the images were triangulated in a Helava photogrammetric workstation. The mean residuals after adjustment were 3 cm in plane and 4 cm in elevation.

4.2 Test site 2 - Borlänge

The second test site is situated outside the city of Borlänge. It is dominated by a large crossroad and used by the Swedish Road Administration as a test area. The area is well documented both by geodetic and photogrammetric measurements which make it well suited for the purposes of this study.

A digital high-resolution frame camera, 2Kx2K, was

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installed on the same platform as the LRF and images were taken at regular time intervals, creating strips and blocks with approximately 70 % overlap. The camera was not calibrated prior to the installation and together with a suspected error in the time tagging of the images, the original idea of using triangulated images for evaluating GPS and INS did not seem applicable. Instead, the GPS positions were used in the triangulation of the images, making it possible to calibrate the camera [Burman 98].

5. VISUALISATION

The amount of data generated by a laser range finder can very large. For visualisation, they must be presented in a readable manner for the user. Traditional presentations of data are, *e.g.*, contour maps and orthophotos while perspective views with image overlays are more recently developed techniques. The example in *figure 8* shows contour lines as overlay on an image. LRF data from *site 2* was imported to a Helava photogrammetric workstation and processed together with a digital image acquired simultaneously. By using GPS and INS as orientation data for the image, it could be combined with the LRF data without any triangulation or matching procedure.

5.1 Orthophotos of Urban Areas

An orthophoto is an orthogonal projection of an image, *i.e.*, usually to a defined map projection. Before transforming images to orthophotos, they must be oriented to a common coordinate system. Elevation data, normally in the form of a regular DEM, must also be available for the ground surface. Orthophotos of high quality over urban areas are difficult to obtain, since detailed 3D information of buildings and other constructions must be at hand. In *figure 9*, LRF data were used to produce an orthophoto over *site 1*. The results show that it is possible to use LRF for this purpose with fairly good results. Some effects of shortcomings of the software is shown very illustrative in the figure. Since only one image is used for producing the orthophoto, areas that are occluded in

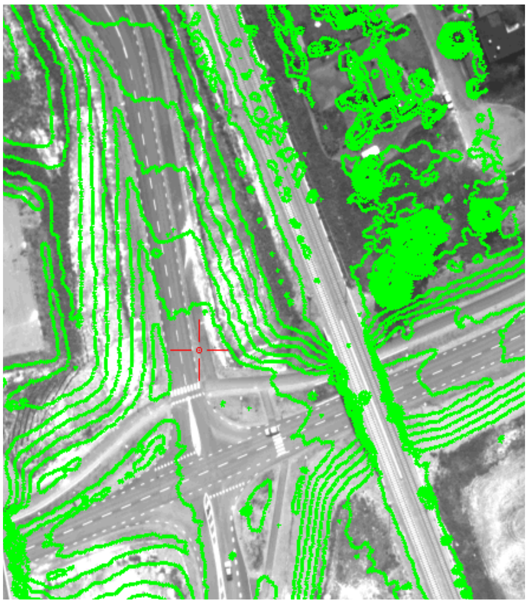

Figure 7 Contour lines as overlays on image

the image will get its image information from the occluding area.

5.2 Perspective views

Another way of presenting elevation data is to generate perspective views of elevation data in combination with an image. An aerial image in combination with LRF data were used for creating the perspective view at *site 1* shown in *figure 10*. Since aerial photographs are close to vertical, the image information, or numbers of pixels, for a facade is usually very low. Only at the borders of an image is the viewing angle enough non-vertical to project facades in the image, *figure 9*. If more detailed images of facades are needed, the aerial images can be complemented with other types of close-range images.

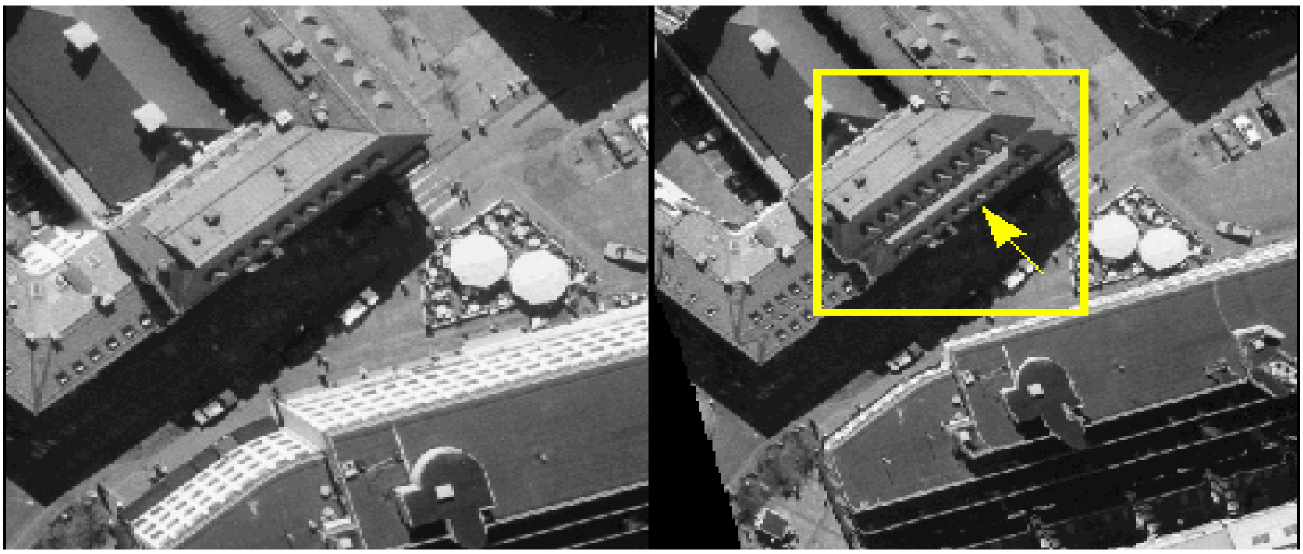

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Figure 8: Original perspective image to the left and generated orthophoto to the right. The vertical walls of the buildings have disappeard on the rectified image. The area of the street that is occluded in the middle of the image results in a projection of the roof on the street that looks like a double row of roof windows.

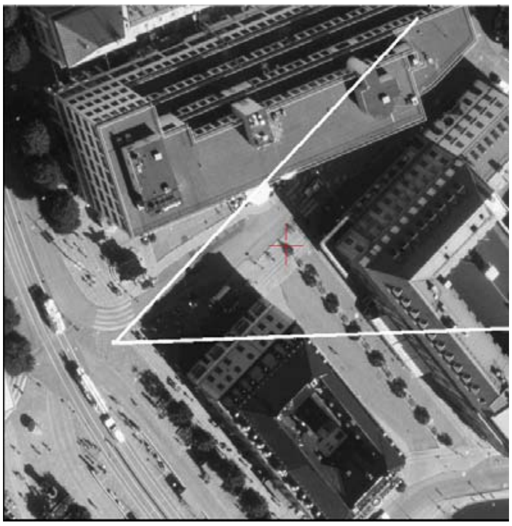

Figure 9: Original image for the perspective view with approximate viewing angle for the perspective scene

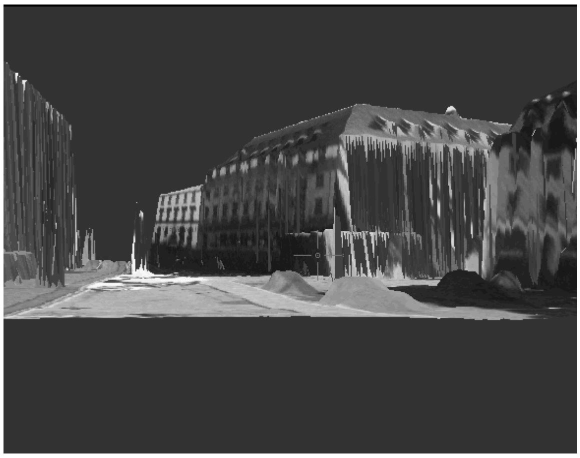

Figure 10: Perspective view of DEM together with image information. Note that the form of the roof windows is preserved fairly accurate. The windows on the houses on the right side is visible while the left ones are occluded in the image, see figure 5. The bumps in the foreground are cars.

Perspective views can also be used as a very illustrative tool for giving a more realistic appearance to landscapes and larger areas. In *figure 11* a perspective view of *site 2* is shown. The view was created in a similar procedure as *figure 7*. Orientation data for the image was taken from GPS and INS measurements and the image could then be combined with a DEM generated from the LRF data. Difficulties can be seen at the railway bridge over the road. The close-to-vertical side of the interpolated DEM is very sensitive to errors in elevation and image data.

6. INTERPRETATION OF LRF DATA

The two test areas has been processed using the algorithms described in 3.1 and 3.2. From *site 1* a detail is shown, picturing a block in typical city area, *figure 12,13*. The roof structures are complex and would be very difficult to measure and model by automatic image matching techniques. The dense LRF grid of elevation points captures the roof with enough accuracy to make a classification possible, *figure 6*.

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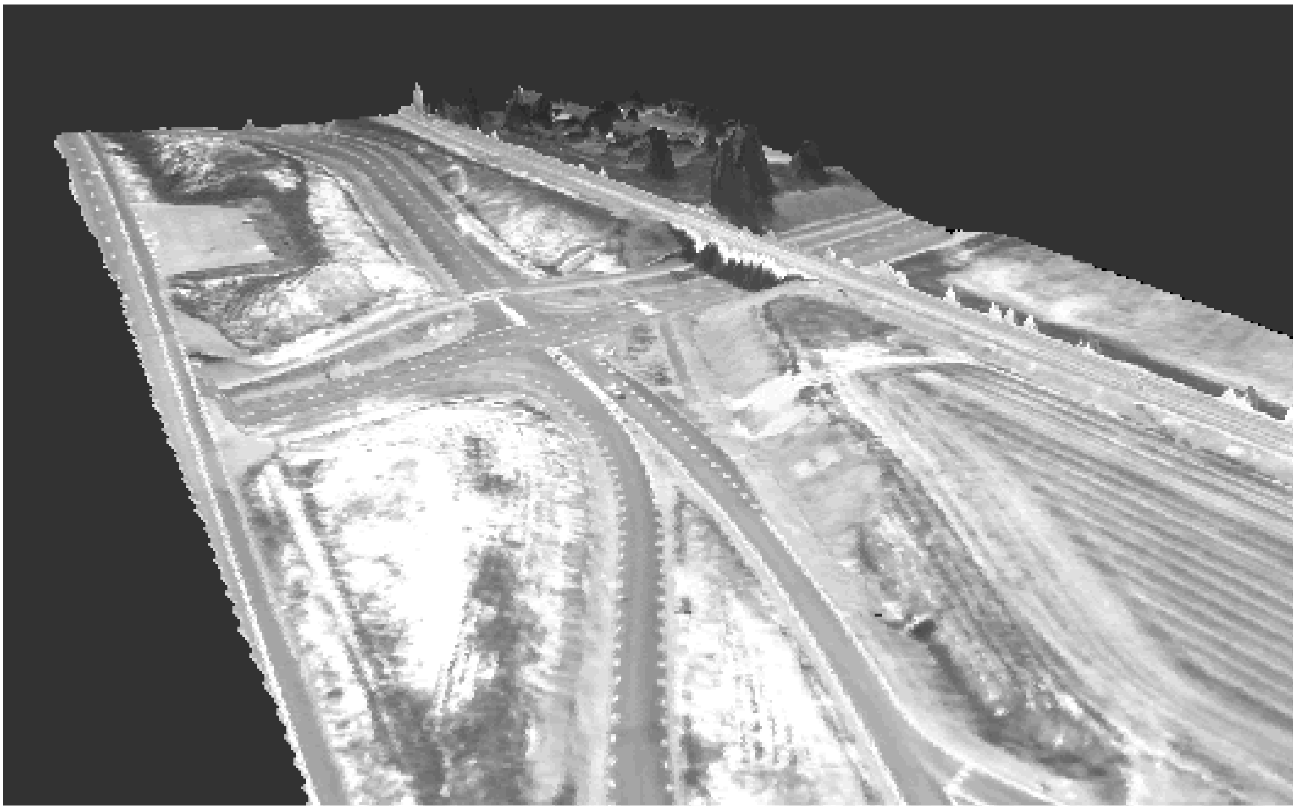

Figure 11 Perspective view from site 2

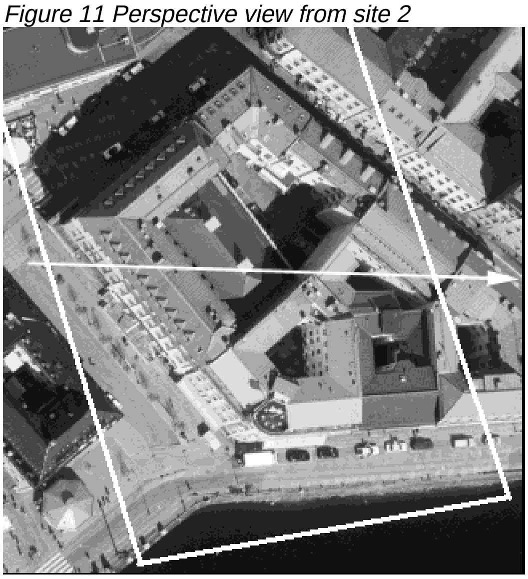

Figure 12 Scanned aerial photo of the surveyed area. The arrow indicate the scan shown in figure 6.

Figure 13 LRF data automatically labelled by MDL using the cost function described in 3.2 as ground, vegetation and buildings with breakpoints.

Points classified as breakpoints indicate the roof structure and will be used in the following modeling process of data.

A strip of *site 2* is shown in *figure 14*. It shows a road with classified buildings and vegetation separated from the ground surface. The MDL classifier manages to distinguish between buildings and vegetation even though the two classes has similar heights and size.

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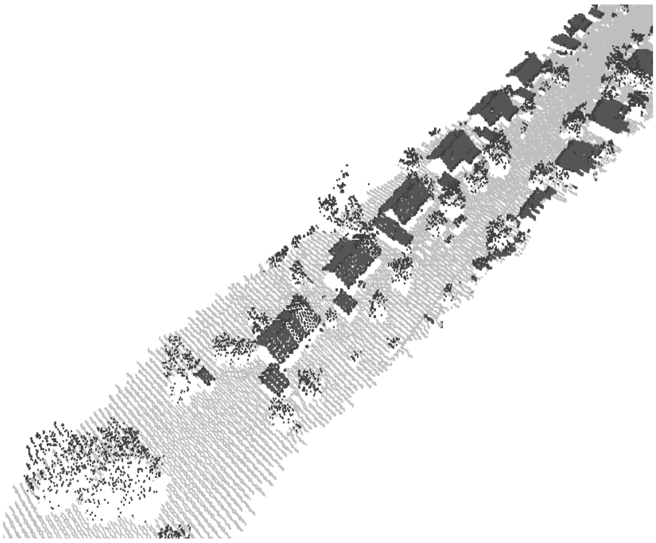

Figure 14 Classification of site 2. The separation of the three classes is fairly successful. Single scan lines erroneously classified can be seen at some buildings. Some of them are due to chimneys and other objects disturbing the statistic variables.

7. ACCURACY EVALUATION

The evaluation of the accuracy at *site 2* is not completed but preliminary figures give an indication of the final result. The area of *site 2* is covered by a DEM with 1x1 m resolution. The DEM was automatically computed by digital matching of aerial images using an Intergraph Image Station at the Swedish Road Administration. Flying height for the images was 600 m using a 30 cm normal lens. Control points for the triangulation were measured with an nominal accuracy of 0.01 m.

As an initial test, points measured by the LRF on a street were selected for comparison with the photogrammetrically derived DEM. The street was chosen in order to minimise the error introduced by the distance between the randomly distributed LRF points and the evenly distributed DEM. A total of 1880 points were compared on an area of approximately 10x100 m. The results are shown in *table 1*. The accuracy of the photogrammetrically derived DEM is mainly dependent of the conditions of the image correlation. A road surface is not ideal regarding, *e.g.*, texture, and some trends visible in data are probably due to variations in the DEM and not in the LRF data. This can be seen when looking more closely at the DEM which have some unlikely variations in elevation. More details will be reported in [Johansson 98].

The digital camera was calibrated in an adjustment calculation using both ground control and GPS positions of the helicopter. The deviations between the calculated and given positions and attitude angles are given in *table 3.* The result from strip 1 indicates an error in the positioning of the images that have not been solved. Strip 2 shows a result more in accordance with the accuracy obtained for the LRF data in *table 2*. The accuracy requirements for position and attitude depend on application, but for large scale cadastral mapping the following requirements are suggested by [Schwarz 95]: Position 0.05-0.1 m and attitude 15''-30''. When comparing these figures with the results in *table 3* the attitude angles are found to be acceptable. The position is more sensitive to time errors and calibration parameters, but for a metric camera carefully calibrated, it seem likely that the requirements can be fulfilled. A more detailed report of the calibration is given in [Burman 98].

Average of differences:	-0.05 m
Standard deviation of differences:	0.05 m
Max deviations from average:	-0.19, +0.13 m

Table 1 Comparing photogrammetrically derived DEM and LRF data

	X (m)	Y (m)	Z (m)	roll	pitch	headi
Strip 1	2.3	1.8	0.4	25''	23''	23''
Strip 2	0.17	0.10	0.14	23''	10''	19''

Table 2 Deviations between calculated and given orientation data from INS

8. DISCUSSION

The usefulness of airborne laser scanner systems has been shown by other authors in a number of applications where the generation of DEMs with traditional photogrammetric methods fail or become too expensive, *e.g.,* DEMs over areas with dense vegetation [Lindenberger 1993] or 3D city models [Kilian et al 1996], [Haala et al 1997]. High quality DEMs with sampling distances of 0.25 - 2 m are provided, depending on the application and system, within a short time limit.

The limitation of laser scanner systems lies in the fact that they are providing coordinates and coordinates only. On one hand, this allows fast and highly automated data processing. On the other hand, the interpretability of data is limited due to the fact that no object information is provided [Ackermann 1996]. Experience shows that it is in many cases impossible to interpret LRF data unless oriented images is available in the same coordinate system. This is illustrated in *figure 15* where two types of interpretation problems are found.

The first problem concerns the truck and the two cars beside it that obviously were standing at the traffic lights when the LRF data were acquired. Even though the truck is not seen in the image, the image information gives enough support for, at least, a manual interpretation. The second problem relates to the strange high elevation points detected in a couple of places on the road. What first seem to be erroneous data points are actually laser reflections from wires hanging over the street. These wires and especially the wire poles are visible in the image. Both of these examples show the need of high quality georeferenced image information for a good classification and interpretation of LRF data.

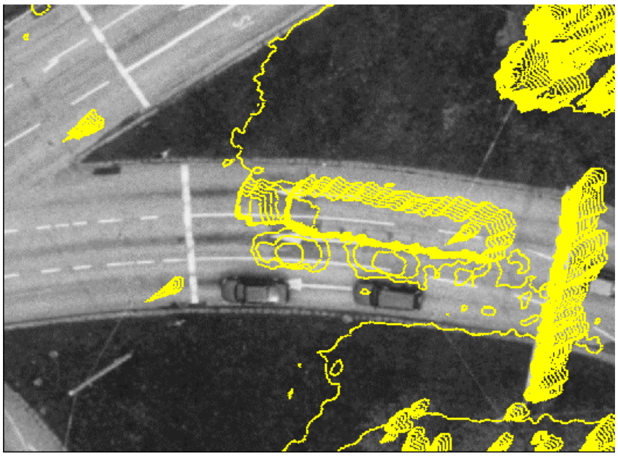

Figure 15 Range data of truck visualised with contour lines.

Automatic procedures for interpretation and classification of laser range data can be fairly successful for many applications using statistical classification methods. For a more general classification approach other sources of information should be used in order to raise the success rate of the procedure. One such source of information is images as used in this study. Other types can be existing 2D GIS data-bases, land-use maps etc., adding valuable facts for the classification tool.

If laser range data are to be used more extensively for mapping purposes it is therefore reasonable to believe that they need to be merged more closely with image information. This can be achieved either by using oriented images from photogrammetric image blocks or supplied directly from the same platform as the LRF data. This can be accomplished by combining the laser system with high quality image sensors, *i.e.,* aerial cameras, image scanners or high resolution digital cameras. Another very interesting alternative is to use reflectance data from the laser measurements which are available in some systems. Even though the ground resolution and radiometry is limited compared to aerial photographs, it can still give valuable information for some applications. This direction of development has also been confirmed by different system manufacturers now presenting systems with both laser range finders and high quality image sensors. When such a system is carefully calibrated and tested it will provide a highly self-contained mapping unit providing image and elevation data without any, or very limited, ground control.

9. ACKNOWLEDGEMENTS

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