High-Resolution Environment Models to Support Rapid and Efficient Mission Planning and Training

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SUMMARY

Modern conflict situations set new requirements for mission planning and mission rehearsal systems Rapid and appropriate reactions to new situations require updated geographic information and intelligence information about the area of interest. In many cases, this information is inaccurate, outdated or even unavailable. Therefore, new data acquisition and automatic processing methods are required.

In this paper we present recent results from the Sensor Technology Division of the Swedish Defence Research Agency, where we have developed new methods for extracting terrain features from high resolution laser radar data and imager from airborne platforms. By using modern high-resolution sensors and new automatic sensor data processing methods, we are able to produce data that can be used in C2 systems for mission planning and for building realistic virtual training environments to gain mission critical local knowledge about the area of operations.

BACKGROUND

We face the challenge of a constantly changing battlefield. We have gone from massive force-on-force clashes on large battlefields to close quarters, often involving a third party in the form of non-combatants and civilians. The battle has moved from the fields into urban areas, where access to updated geographic information is critical for mission success. Peacekeeping operations are increasing in frequency, so the current military capabilities must be transformed in order to meet the new challenges. These new battlefield challenges and situations also set new requirements for turnaround time and geometric resolution for data acquisition for mission planning and mission rehearsal systems, making updated and high resolution geographic information a vital component in today's battle management systems. New sensors provide new possibilities for acquiring these kinds of data. Traditionally, satellite imagery and radar have been the main sources for acquiring topographic information, but with the advent laser scanners it is possible to acquire data with a much higher resolution. Aside from processing the data to find the actual targets, information about the Environment is becoming increasingly important, e.g. for manoeuvrability and intervisibility analyses.

Research on development of methods for processing laser data is growing and is strongly influenced by the increased interest of using laser radar systems for data collection in many mapping and remote sensing applications [1]. Results have been reported for many problem areas of which several are of interest for high-fidelity natural environment modelling, e.g. infrastructure mapping, remote sensing of forest and natural resources, city modelling including 3D reconstruction, etc [2] [3] [4] [5].

A fast data acquisition and processing system would make it possible to create updated terrain models for use in C2 and training systems. A realistic geospecific training environment used in simulations for training prior to a mission can give vital local knowledge and familiarity with the area of operations.

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OBJECTIVE OF WORK

The work at FOI Sensor Technology is aimed at developing methods for automatic transformation from sensor data to geographic information for use in mission planning, terrain database modelling, training, etc. These results have been obtained in a research program aiming for the development of methods for rapid and highly automatic construction of high-fidelity natural environment models from sensor data (www.sne.foi.se). We have used recent high resolution sensors (airborne laser scanning (ALS) systems and digital cameras) to acquire the data. Presently these systems are carried by aircraft such as helicopters and airplanes, but in the future we are likely so see them mounted on UAV:s and UGV:s. The long term goal is an automatic process from sensor data to environment models [6] [7].

DATA COLLECTION AND PROCESSING METHODS

In our work we have used data from recent high resolution airborne laser scanning systems (ALS) equipped with high resolution digital cameras.

An ALS system generally consists of a laser radar, some times also referred to as LIDAR (Light Detection and Ranging) and LADAR (Laser Detection and Ranging), a position and orientation system, realised by an integrated differential GPS and an inertial navigation system (INS), and a control unit. The laser radar consists of a laser range finder, an opto-mechanical scanner and a control unit.

The most frequently used scanners are line scanners which deflect the laser beam back and forth across the flight track using oscillating mirrors. The measured points on the ground form a zigzag pattern as the platform moves forward (Figure 1, middle). The distance between the laser radar and the point where the laser pulse is reflected is obtained using time-of-flight. This point may lie on the terrain surface or on some other natural or artificial object. Measurements are made on every kind of surface that reflects the laser pulse, e.g. buildings, trees, bushes, roads, fields etc. For each measured point the distance, position and orientation data are combined and a three dimensional coordinate in some suitable reference system is computed. The positional accuracy of the laser points can be as high as 10cm (4”) in XYZ in a given coordinate system. Current airborne systems can acquire data with a resolution down to 0.25m (10”) between laser points.

Besides distance measurement many ALS systems today also have the ability to register the intensity of the reflected laser pulse. This information can be used to form a monochromatic “intensity” image of the survey area, see Figure 1 (left) and Figure 2 (middle). Another feature found among many recent ALS systems is an ability to identify and record more than one distance if there are multiple reflections for one single laser pulse. Due to laser beam divergence the laser footprint will cover a non negligible area. Multiple distances are obtained when different parts of the laser footprint hit different objects at different elevations, see Figure 2 (right). For example, the footprint may be split by the edge of a roof and one part is reflected from the roof and the other part from the ground. The intensity and the multiple return data form an excellent source of additional information which together with the elevation data provide a good input to segmentation, classification and feature extraction tasks. Some systems can be equipped with IR and multi-spectral sensors for further information. The terrain surveying system we have used for capturing terrain topography and high-resolution digital images is the TOPEYE system. This system is operated by the service provider TopEye AB (www.topeye.com), a Swedish company providing worldwide services. Originally, the TopEye system was a pure ALS system. For some years, it has been extended with a high resolution digital camera.

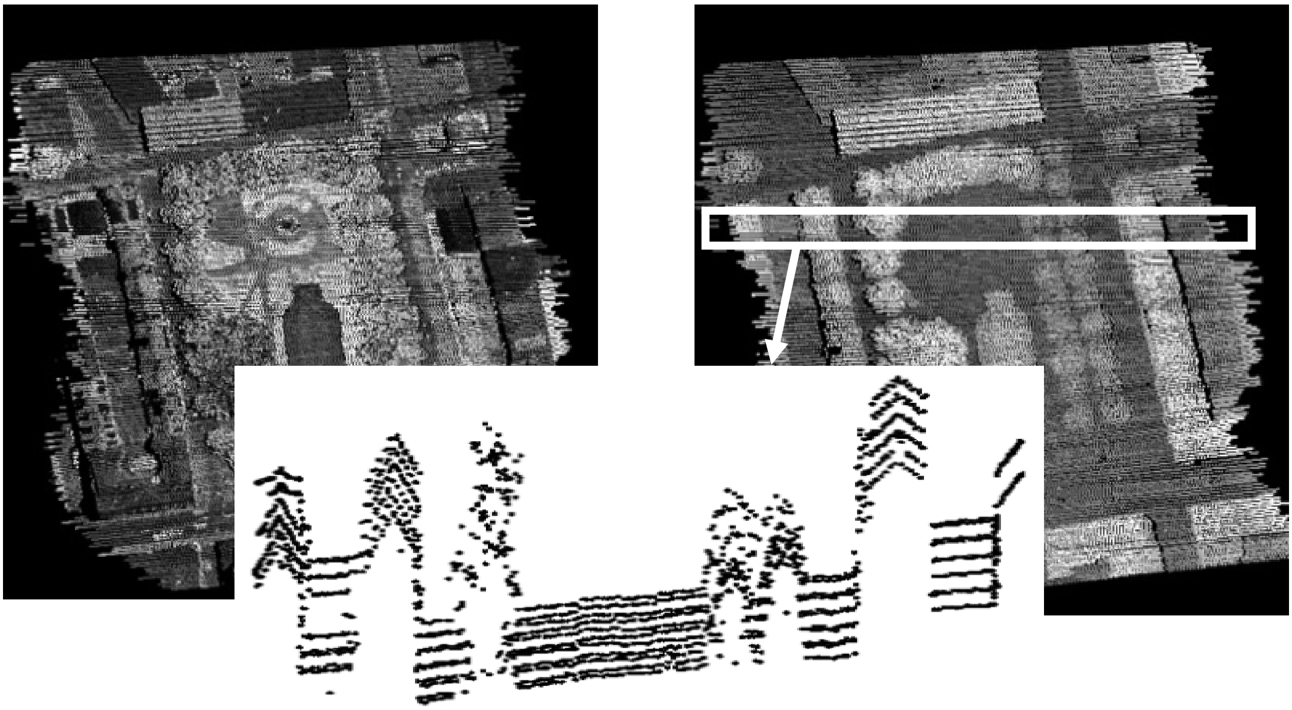

Figure 1: Sample ALS data. Left: Intensity, Right: Height, Middle: Illustration of zigzag pattern.

Pre-processing of laser radar data

The data points from the laser scanning system are irregularly distributed due to instability of the carrier platform and computational precision of the system. However, since most signal processing methods prefer regularly structured data, the laser data is often reorganised into spatially referenced grids of suitable size, making the data more "image-like".

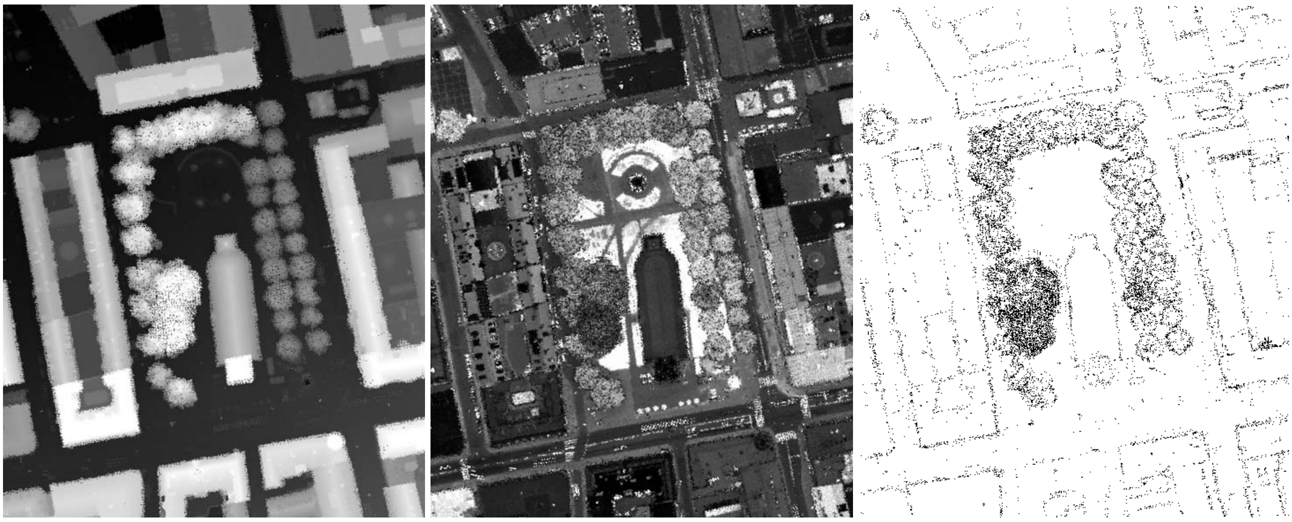

Figure 2: ALS data in regular grids. Let to right: Elevation, Reflection, Multiple returns.

Ground modelling

In many situations, information about the bare earth topography is very useful. We have developed new methods for estimating the bare earth surface from laser radar data. The methods are based on the theory of active contours [8], where an elastic "net" is pushed towards the laser points from below. The net sticks to the lowest laser points, and elasticity forces in the net prevent the net from stretching up into objects such as trees and buildings, thus creating a continuous model of the bare earth surface. This bare earth model is often referred to as a Digital Terrain Model (DTM). The DTM can be useful for detecting terrain features that are hidden from plain sight due to dense vegetation, such as ditches and slopes, which may have an effect on manoeuvrability. Figure 3 shows a DTM estimated from laser radar data.

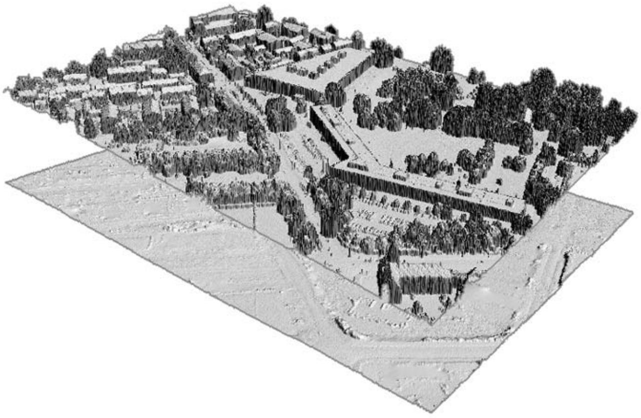

Figure 3: A Digital Terrain Model (DTM) extracted from ALS data of an urban environment.

Segmentation and classification

Classification of laser data [9] [10] is an important processing step towards feature extraction, tree identification and 3D model reconstruction. The ground points constitute a basic class for which classification is straightforward when a DTM exists. All points that are close to (i.e. within some given range) the surface given by the DTM are classified as ground points. Next, the remaining data can be further classified as e.g. buildings, vegetation, power lines, posts etc. For this purpose we have developed new methods which will be described below. Figure 4 shows an example of terrain feature classification.

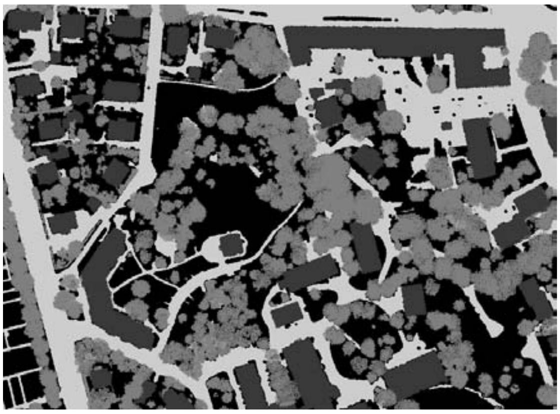

Figure 4: Laser data classification over a small urban area. Colour is used as follows: Black - ground, Dark grey – Buildings, Medium grey – Vegetation, and Light grey – Roads.

Vegetation processing

When processing the laser radar points classified as vegetation we are able to detect and estimate the position, height and crown area of individual trees. The individual trees are found using the same methods as in extracting the ground. Here, however, the elastic net is applied from above, creating a continuous surface. The trees are located by analysing the local height maxima in the surface. This way we can estimate the crown width of a single tree. Figure 5 below shows the classification results, individual tree positions and estimated crown sizes. These methods have been verified using real field measurements with very good results [11] [12].

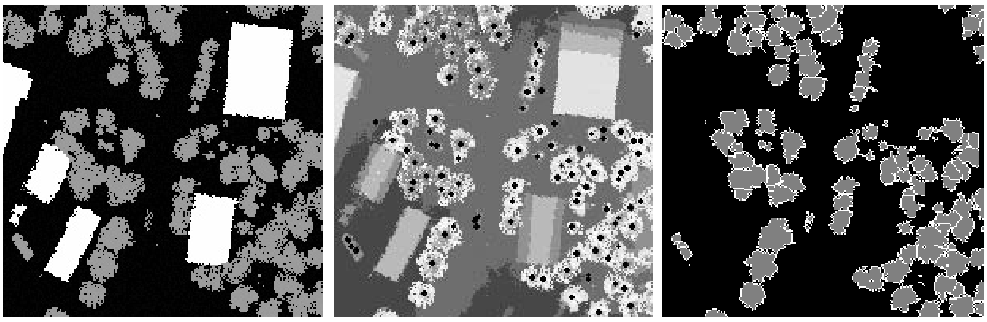

Figure 5: Vegetation processing. Left: Vegetation (grey), Middle: Tree positions (black dots), Right: Estimated crown sizes.

By further processing the laser data points inside the tree crown of individual trees, we can distinguish between different species of trees. This is done by examining the distribution of the laser points within the contour of a single tree. Figure 6 (below, left) shows sample point distributions from three different tree species. By analysing a number of variables within the point distributions we can identify the type of the individual trees. By using this information we are now able to specify the type, height and width of the individual tree at a specific geographic position. Figure 6 (below, right) shows the distribution of pine, spruce and deciduous trees in a sample area. Knowing which tree type is positioned at a specific location is useful for intervisibility, cover and concealment, as well as trafficability.

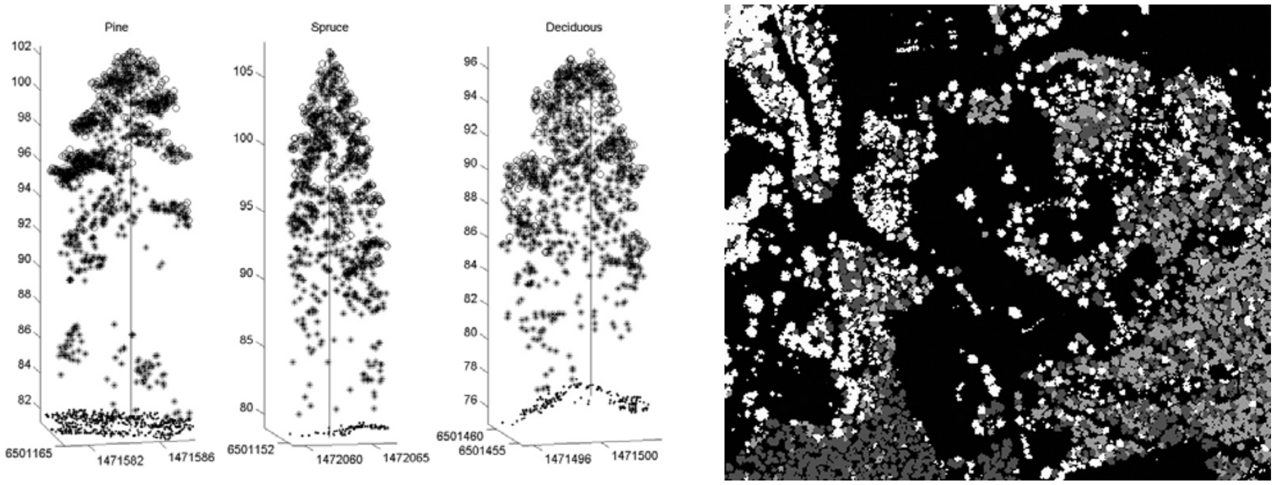

Figure 6: Left: Sample laser point distributions for different tree species, Right: Tree type positions.

Buildings

We have developed methods for automatic reconstruction of buildings. The laser data points classified as buildings are grouped into building footprints. By clustering the laser data points within the building footprint using different measures (e.g. slope, height, etc), we can distinguish roof segments. These segments are then expanded within the boundaries of the building footprint to form a complete roof. The roof patches are then made into polygons which are automatically adjusted to have right-angled corners, etc. The resulting reconstructed building models are then output as CAD models for further refinement, for use in visualisation packages or for integration in terrain modelling software, etc. Figure 7 shows the different steps from laser elevation data to reconstructed 3D model.

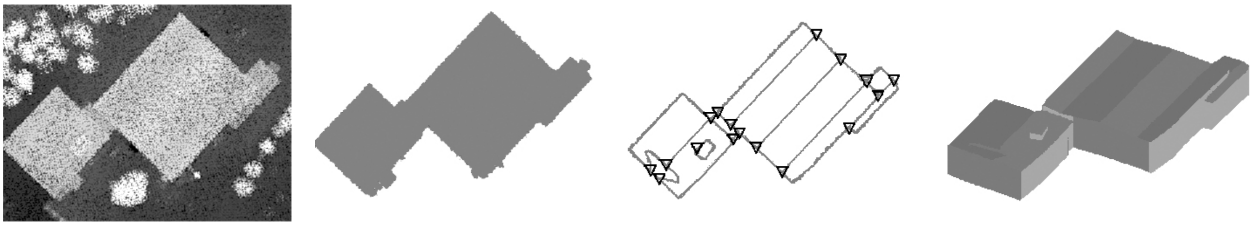

Figure 7: Processing steps for reconstructing buildings. Left to right: Height data, Building footprint (classification), Edge and surface analysis, reconstructed building as a CAD model.

Aside from the building geometry, the reconstructed models are also georeferenced, making it easy to position the models automatically. Figure 8 below shows a small urban scene where automatically reconstructed buildings are placed in the correct positions on a bare earth DTM.

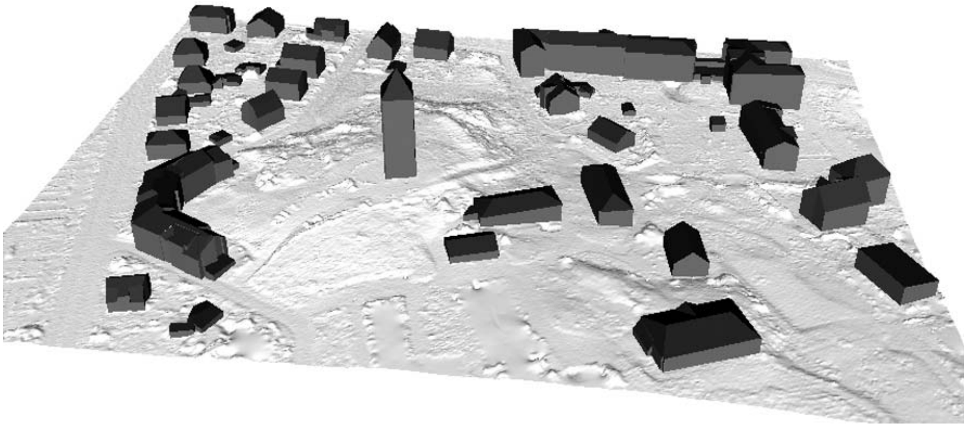

Figure 8: Sample scene from a small urban area with reconstructed buildings on a DTM.

Roads and water

By using more than one data source we are able to find paved areas such as roads and paths. This is done by first extracting the bare earth topography and then comparing it with the intensity image to determine what parts of the ground that actually represent roads.

The water surface usually is flat and specular, making light reflect away from the laser and never return to the sensor. This yields a sparser point distribution on water, a fact can be used to find water areas.

Power lines and street lights

Power lines have unique characteristics in both intensity and geometric structure, making it possible to detect power lines, slack of the cables and positions of the posts. Street lights also have special characteristics that make it possible to detect them, in that they are thin, high object that often lie close to roads.

Orthophoto mosaics

To obtain realistic models for e.g. environment visualisation, orthophoto mosaics are desired for ground texturing. For this we typically use the colour images obtained from a digital camera on the ALS system. Using these images, the camera orientation data and a digital terrain elevation model from the laser data it is straightforward to produce an orthophoto mosaic. An appropriate set of images is first selected such that such that all terrain areas to be textured are covered. This may result in a large number of images, often hundreds of high resolution images, even for moderately sized areas. The images are then orthorectified and a mosaic covering the area of interest is created. For orthorectification and mosaicking we use commercial COTS software.

ENVIRONMENT MODELLING AND VISUALISATION

For creating environment models for e.g. decision support systems, training systems, etc the extracted features need to be integrated in some (automatic) modelling system. Depending on the application, the information extracted when processing the laser data and the imagery can be output in arbitrary formats. For instance, the bare earth surface can be output as a regular grid of elevation values, whereas the individual trees can be output as vector points for GIS systems. The buildings can be output as standard CAD models. Figure 9 shows an example of a scene for real-time visual simulation generated from ALS data and high resolution imagery.

Figure 9: Sample environment model from ALS data and imagery.

Note that the shadows from the trees (which are part of the orthophoto) seem to have correct sizes and origins, indicating that the tree models have the correct heights and positions.

As an example, generating the environment model for the area in Figure 9 for a real time-visualisation application requires the bare earth DTM, an orthophoto mosaic, tree and building models and associated position and size information. The DTM is triangulated and draped with the imagery. The reconstructed building models are placed in the correct positions and instances of 3D tree models are placed in the correct positions, all properly scaled and with the correct model for the detected tree species. This process is illustrated in Figure 10.

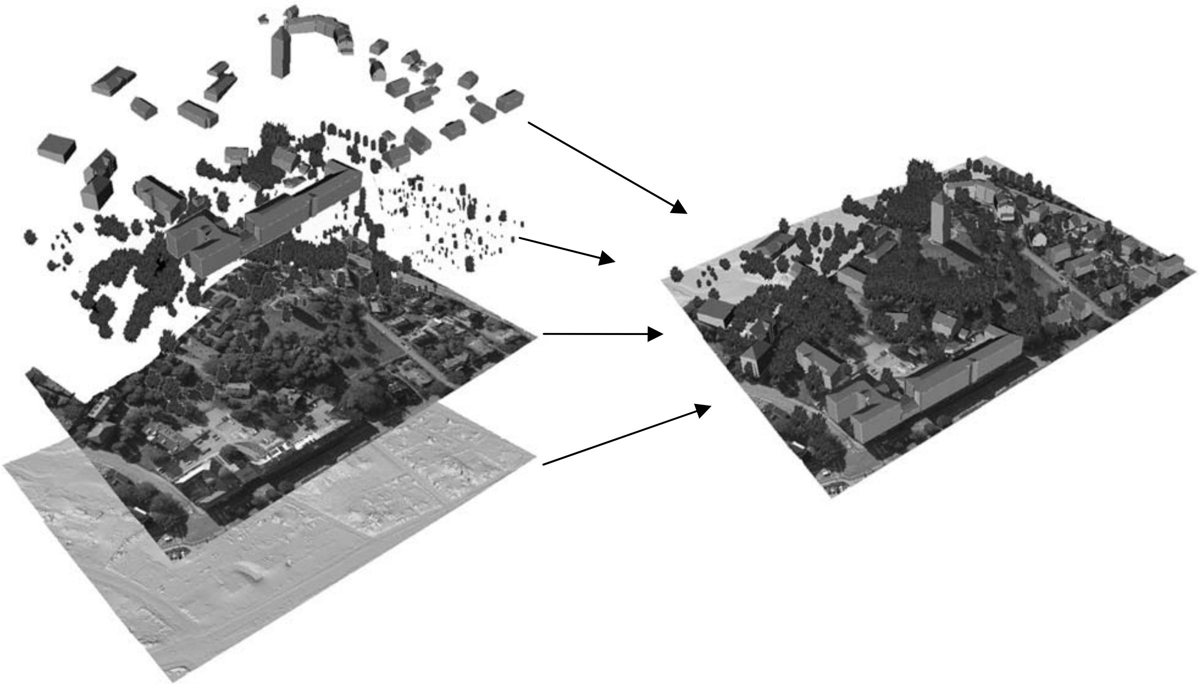

Figure 10: Integrating extracted feature and ground data into an environment model for visualisation.

APPLICATIONS

The data from these new data acquisition and processing methods can be used in many applications.

Dynamic update of geographic information

A fast process from data acquisition to environment model is also important to keep the information updated to accommodate for any changes. Changes in the environment can originate from natural causes (flooding, weather) or from battle damage or demolition, etc. As an example, blocked roads or damaged buildings cause problems for movement. By having an updated environment model in the mission planning system, new routes can be planned. The sensors detecting changes need not only be surveillance platforms. Updated information from personnel on location is increasingly important.

Mission planning

Updated high resolution geographic information will aid mission planning. The high resolution obtainable with modern sensors provides higher precision when doing LOS analyses for observation posts and when planning deployment of surveillance sensors. The ability to compute the line of fire or the area of observations for opposition positions helps to define safe and unsafe areas for movement. High resolution topography is also important when positioning short range radio transceivers or video surveillance equipment. Figure 11 shows the result of LOS calculations for an observer/threat in a high resolution urban area.

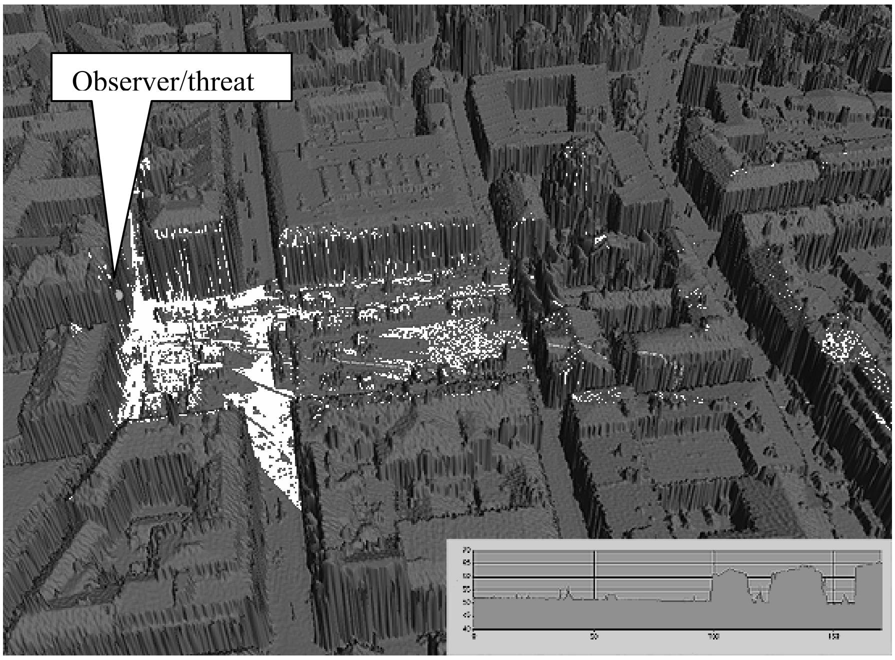

Figure 11: Detailed LOS analysis in high resolution surface model.

Risk assessment

Simulation of gas and smoke dispersion can benefit from having detailed topographic information of the environment, making the calculations more accurate. Figure 12 below shows an urban scene acquired using ALS data which can be used for wind flow computations for gas dispersion.

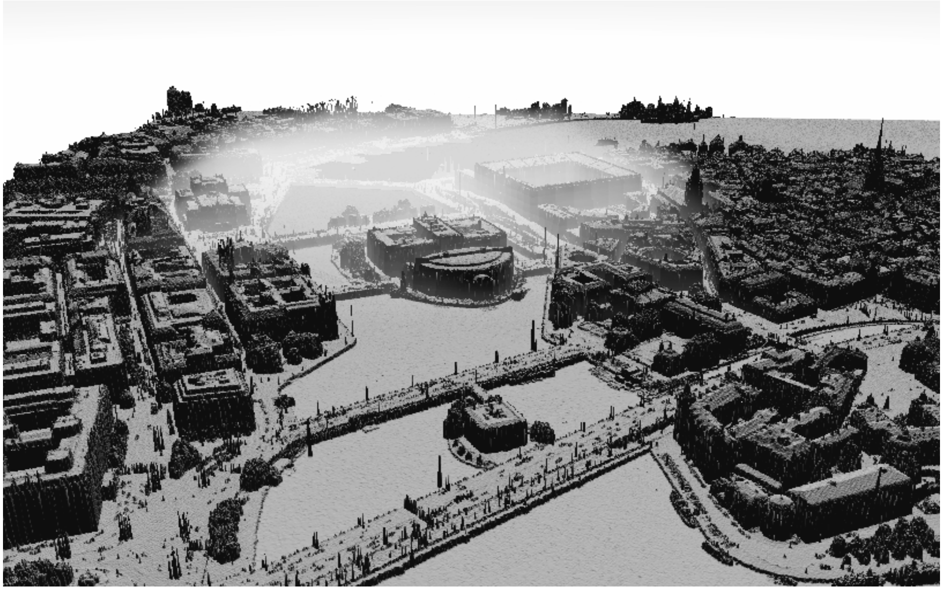

Figure 12: Gas dispersion visualisation in high resolution environment model.

Training in "real" environments for local knowledge

When training and rehearsing in a simulator prior to a mission it is vital that the environment is a good representation of the area of operations. This way, the soldiers will be more familiar with the surroundings, making them more prepared when the mission is actually executed. A geospecific environment model of an actual training area is shown in Figure 13.

The time from mapping the area of interest to training in a virtual representation of the environment should be as short as possible in order for the personnel to be able to familiarise themselves with the area. Therefore, a fast process from data acquisition to simulation environment model is critical.

Figure 13: Environment model for mission training.

Augmented reality and overlays

The high level of detail available from modern sensor systems combined with feature modelling and positioning make it possible to increase the situation awareness for people on location. For instance, georeferenced models of buildings can be overlaid on the soldier's helmet mounted display to indicate threats or risk. For low altitude flying, threats and safe passages can be displayed on the pilot's HUD.

After Action Review

High resolution environment models are a good aid for after action review, both for evaluating performance during training and during the actual operations. By logging the positions of people and vehicles using a positioning systems and recording any events that occur during the mission, detailed playback of the scenario can be made using the environment model. Due to the high level of detail, the effect of the topography can be accounted for and evaluated in the AAR system, for example to see if a steep slope or a blocked road affects mobility and thus the time needed for transportation.

CONCLUSIONS

There is an increasing demand for large and high fidelity environment models in many applications today. The high resolution data from airborne laser radar systems for 3D sensing provide an excellent source of data for obtaining the information needed for many of these models. In this paper we presented some progress on methods for utilising this type of data for environment model construction. We have shown that feature extraction and 3D reconstruction of real world objects is possible. A critical element in the data processing chain is time. Therefore, much effort is also put into making the methods automatic. We have also indicated how the result of feature extraction and 3D reconstruction can be used for the construction of high-resolution models for real-time 3D visualisation and for mission planning and training systems.

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