High Precision Projects using LiDAR and Digital Imagery

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SUMMARY

This paper describes how low altitude airborne LiDAR in combination with digital imagery is used in a project, from data collection to final products. The dataset was collected with the TopEye system from 100 m flying altitude.

Results show that the combination of LiDAR and high resolution digital imagery can be used for projects that traditionally are considered to be typical terrestrial survey projects. Images are easy to interpret and their high resolution gives good planimetric measurement precision. LiDAR gives high coverage of precise height information and penetrates vegetation. If a good strategy for quality assurance throughout the project is used accuracies better than 0.02 m can be reached in well defined objects.

The technique shows good results and in many cases it can reduce costly and sometimes dangerous field work. High accuracy can be reached but also the possibility to use the LiDAR and image material in later stages for extracting complementary information, whenever needed.

The paper emphasize on data extraction, quality assurance and accuracy.

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1. INTRODUCTION

Airborne laser scanning, often referred to as LiDAR, has become a well used method for collecting height information. LiDAR has in many areas replaced photogrammetric methods, being more efficient and accurate. Also costly terrestrial measurements can be reduced when using low altitude LiDAR.

With good planning and quality assurance, High Precision LiDAR in combination with high resolution digital imagery can reduce costs and enhance information extraction for engineering applications. While airborne LiDAR provides excellent elevation measurements, high resolution images provide means for better visual interpretation and precise planimetric extraction. Experiences show good result in many areas of surveying and with better understanding and confidence in the technique there is a great potential in engineering applications.

2. QUALITY ASSURANCE

Quality assurance of a LiDAR project is a continuous process throughout the project [*Klang et al 2005*]. It starts with a well configured and calibrated system for data collection and continues with good planning, data capture, processing and delivery.

2.1 System Calibration

Airborne LiDAR systems are technical advanced systems with many sensors that have to be well calibrated and integrated with each other. As each laser pulse has its own exterior orientation, high demands are put on the georeferencing, i.e. satellite positioning and inertial navigation system (INS). With a poor inertial system one can never expect a good end result.

Other important system calibration issues are:
- Camera calibration
- Laser Range Finder (LRF) calibration
- Mirror scanner positioning
- GPS antenna lever arm positioning
- Time synchronization
- LRF/camera offset
- LRF/camera rotation - boresight calibration

2.2 Planning

In the planning process the foundation is laid for a good end product. Accuracy demands and end usage will influence the flight configuration, i.e. flying altitude, speed, overlap, etc.
For high precision projects high point density and high signal/noise ratio are essential. For most systems this means that a low flying altitude is preferred. Using a rotary wing will give more flexibility at low flying altitudes regarding speed and maneuvering of the platform.

2.2.1 Digital Imagery

Geometric ground resolution of the digital image is often easy to discuss as most people can relate to photographic images and interpretation possibilities in different image scales. In our case image resolution down to 0.02 m is possible, which will give excellent conditions for image interpretation. By making tie point measurements between images and image block adjustment, original GPS/INS image orientation can be improved to better match such high resolution images.

Figure 2.1 Example of a high resolution digital image (about 3 cm pixels).

2.2.2 LiDAR Points

LiDAR point density is not as intuitively understood as image resolution. While photogrammetric stereo measurements give worse height than planimetric precision it is the opposite with LiDAR. The main advantage with LiDAR is the high elevation precision. This is mainly due to GPS/INS georeferencing errors, poor planimetric point resolution and displacement within footprint.

To be able to detect and measure breaklines in LiDAR data very high point density is needed. For example, 10 points / m^2 corresponds to about 0.30 m between points while 25 p/m^2

corresponds to about 0.20 m between points. Taking into account that most systems do not give a symmetrical point pattern, these values are often worse in at least one direction.
When using strip adjustment to adjust for the remaining orientation errors, the result will depend on point density. It is well known from image matching that the precision will in best cases, at distinct features, be parts of a pixel. Assuming worse conditions matching LiDAR strips one could assume a slightly worse precision in matching. A reasonable assumption for LiDAR is that planimetric accuracy is about 2-4 times worse than elevation accuracy.

Combining LiDAR with high resolution digital images will give better interpretability and higher planimetric accuracy and therefore better conditions for high precision projects.

2.2.3 Ground Control

Ground control should be used both for elevation and planimetry. For elevation control of LiDAR data reference measurements are best placed on flat surfaces and the configuration should be a number of points representing a flat surface. The number of points representing the surface depends on accuracy in control and precision in LiDAR measurements.

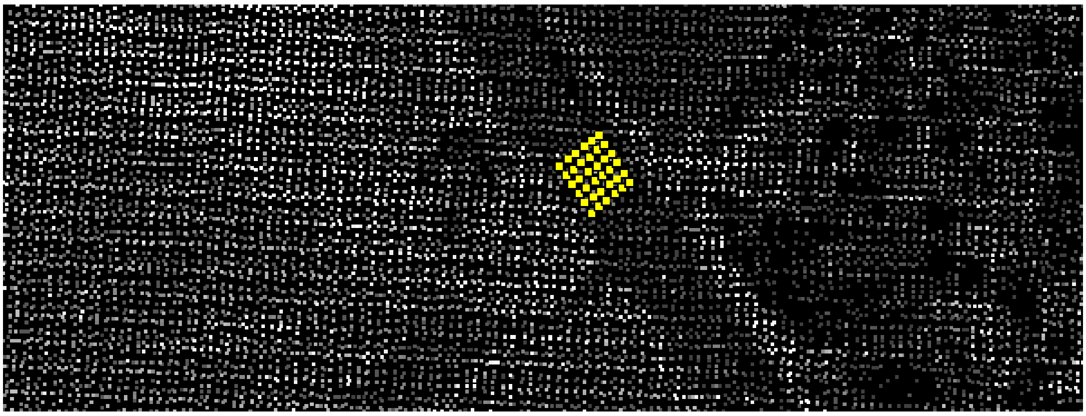

Figure 2.2 Example of one elevation control consisting of 6x6 points covering an area on the road.

Planimetric control points for LiDAR must have configuration where large gradients, either in intensity or elevation, is interpretable. Having high point density objects like painted road marks or similar are suitable as planimetric control. These can also be used for planimetric control of orthophoto. For lower point density, these might not be visible, and larger elevation gradients have to be used, e.g. building roofs or similar.

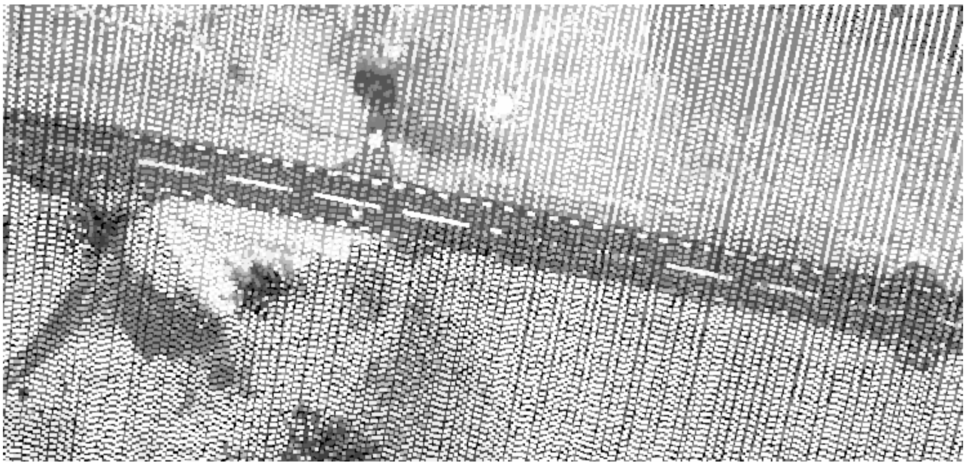

Figure 2.3 Planimetric control can be derived to the intensity of laser data, e.g. painted details on the roads. These can also be used as control of orthophoto.

2.3 Aerial Survey

Aerial survey must be done in good conditions. Good satellite configuration and atmosphere conditions are important. Avoid laser scanning after rain, as still water and wet materials give poor return. Crossing strips should be placed so that ground control is covered and to optimize possibility to discover and correct for mismatch between them. Flying must also be optimized for calibration and control of drift in the inertial system.

2.4 Primary Processing

Primary processing includes everything down to a quality checked LiDAR point cloud and developed georeferenced digital images:

- GPS/INS calculation, i.e. calculation of trajectory
- Deriving image orientation by combining trajectory and image exposure timing
- Developing images refining color balance and brightness
- Merging GPS/INS and LRF (Laser Length Finder) data
- Strip adjustment of LiDAR
- Adjustment towards control points

In GPS/INS integration these observations support each other to give a trajectory of best quality with highest possible frequency.

When merging GPS/INS trajectory and LRF data the first point cloud is obtained. At this stage all calibration parameters have been taken into account, like GPS lever arm, LRF boresight calibration, scanning device calibration and LRF waveform extraction.

Two methods are used to make final geometric quality assurance, strip adjustment and adjustment to ground control. In strip adjustment differences between overlapping strips are detected and corrected for [*Burman 2001*].

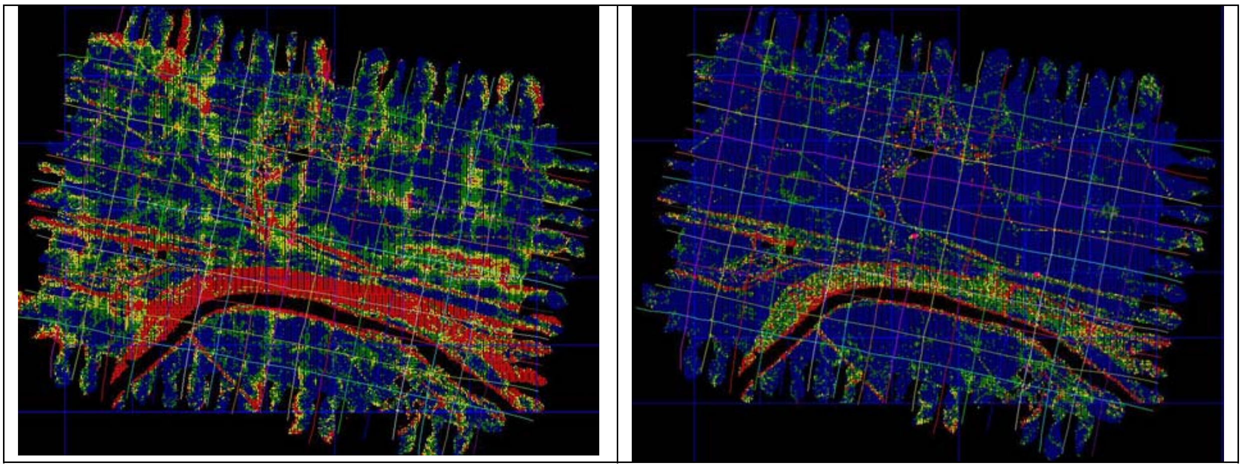

Figure 2.4 Example of differences between flightlines before (left) and after (right) strip adjustment. Images are taken from output from Blom's software TASQ, TopEye Area Statistics and Quality. Blue color is < 2 cm, green < 3 cm , yellow < 4 cm, orange < 5 cm and red > 5 cm differences.

2.5 Secondary Processing

Secondary processing includes classification of LiDAR points [*Axelsson 1999*], e.g. into classes ground, building and vegetation. Also mapping and modeling are likely to be included.

For many high precision projects, DEM (Digital Elevation Model) is one of most important products. To make a DEM of good quality will involve manual editing and refinement. A typical procedure would be:

- Ground classification
- Manual editing of ground classification
- Adding breaklines, either extracted from LiDAR data, digital image or terrestrial measurements
- Adding terrestrial measurements not measurable from air, e.g. ditch bottom
- Triangulation of all observation, both irregular points and breaklines
- Final control against ground control information

Most mapping might be done by monoplotting in orthophoto where the Z-value can be extracted from the elevation model.

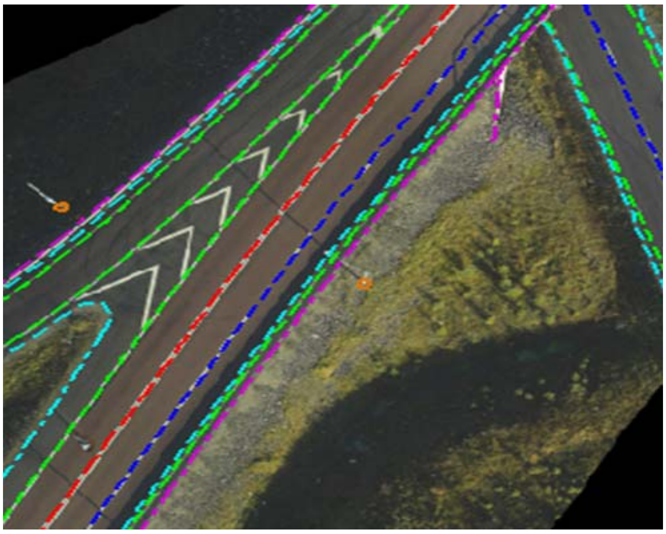

Figure 2.5 Example from monoplotting, mapping in orthophoto.

LiDAR point cloud can be used for modeling features like power lines and buildings.

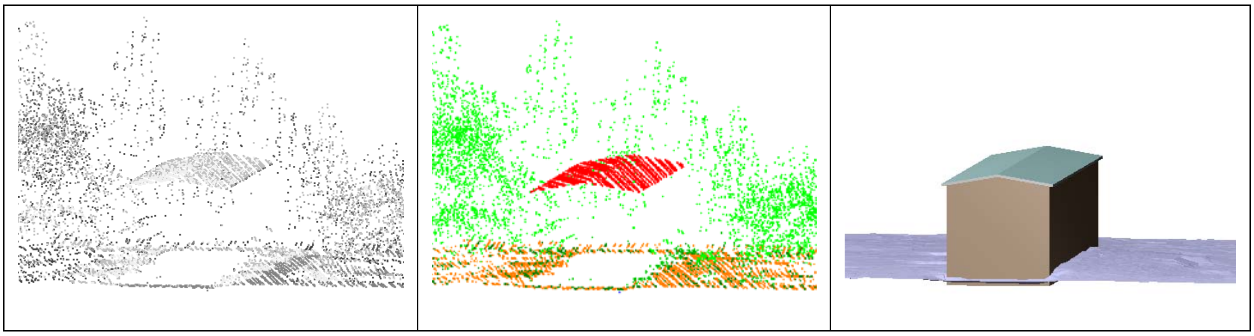

Figure 2.6 Building reconstruction from unclassified point cloud through classified point cloud till model of building and ground.

Mapping features above ground that is hard to interpret in orthophotos and LiDAR point cloud might be extracted in stereo using a photogrammetric workstation. This implies that the aerial photography has been captured with stereo overlap.

2.6 Delivery

What should be included in the delivery is of cause up to the customer and depending of what is included in the project. What can be suggested is that basic geometric quality should be presented. For evaluation of LiDAR data good measures are statistics of flightline overlap discrepancies and deviations against ground control. In combination with data coverage and point density over the area this will give a good idea of the overall geometric quality of the original point cloud. Both noise and systematic errors should be estimated. Equivalent measures can be presented for images, like tie point discrepancies and deviations against control points. Also geometric ground resolution and radiometric quality should be taken into account.

3. CASE STUDY – A14, Cambridgeshire, England

In October 2007 TopEye AB were requested by GeoSurvey Solutions to fly 37 kilometers of the A14 highway, near Cambridge, England. For 24 kilometers of the route high precision surface models were required for the asphalt area. The work was commissioned by the Highways Agency and was to form the bases for the planning and implementation of the upgrade and widening scheme.

3.1 Area

The A14 is an extremely busy road taking both commuter traffic from Cambridge and freight traffic from Felixstowe, the largest container port in the UK. As a result any traffic management required to carry out a topographic survey can only be done at night and so time consuming and very costly. A LiDAR survey of the site was deemed the most suitable option due to the remote access, speed or acquisition and the accuracies achievable from the enhanced high precision processing. Figure 3.1 below shows the site location.

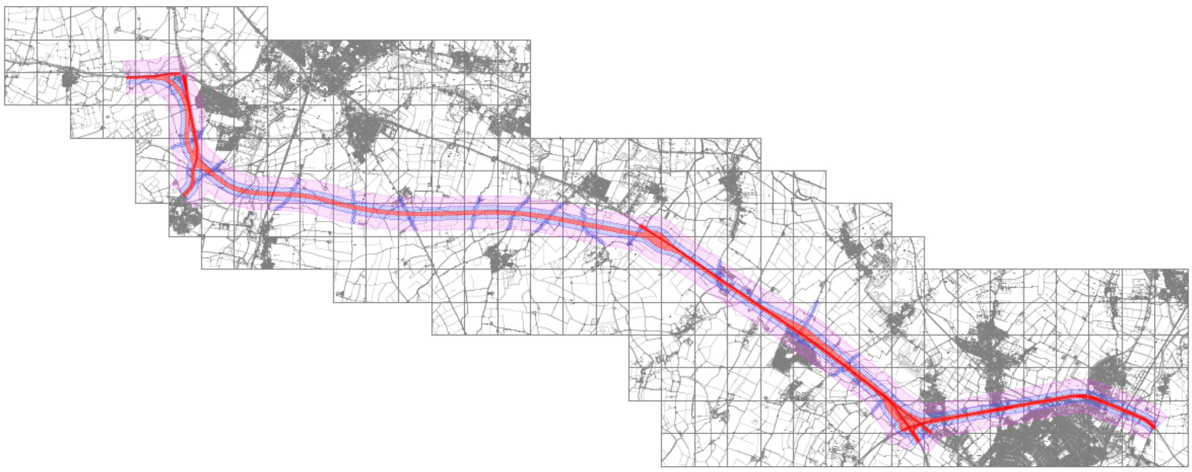

Figure 3.1 A14 Area of survey.

Data Collection

Data collection for the survey was acquired on 5th and 6th October 2007 using the TopEye Mk II helicopter mounted LiDAR system. A total number of 160 flight-lines were required to cover the area.
The nominal flying height was 100m (330 ft), flight speed was approx 30 knots and the resulting ground "hits" density better than 30 points /m^2 .

Prior to the survey a GPS network of 5 base stations had been installed and surveyed. This ensured that during data capture the helicopter was never more than 5 kilometers from a GPS receiver. During data capture a GPS receiver was set up on the stations, logging 1 second RINEX data. This data was then used in conjunction with the IMU data from the helicopter to calculate the precise trajectory of the helicopter.

The TopEye Mk II system is fitted with a Rollei AIC digital camera with 2 cm GSD. This enabled ortho photos at 4cm resolution to be generated.

To ensure a high precision model can be achieved it is necessary to have additional survey detail which can be used for analysis and checks of the laser data. On the A14 survey 34 topographic survey stations were established. From these white line detail identifiable in the imagery and point cloud was surveyed using a Leica TCRA total station.

3.2 Data Enhancement – Primary Processing

Point cloud was calculated with TopEye's program TEPP where GPS, INS, LRF (Laser Range Finder) and scanning mirror angle data are integrated. The geometry of the point cloud was improved in three steps:

1. TopEye's Palmer scanner gives an elliptic scan pattern which means that the same object is scanned from two angles in the same flightline, in forward (FW) scan and in backward (BW) scan. These two scans are treated separately as two surfaces and TerraMatch is used to check and correct for systematic Heading and Pitch errors.
2. Overlapping flightlines are matched together in TerraMatch by modeling Easting, Nothing, Z and Roll errors in trajectory.
3. Point cloud is checked against ground control and global systematic errors are corrected for.

Final statistical evaluation of deviations between flightlines is made using Blom's software TASQ.

Digital images captured with Rollei AIC with P20 EOB were developed in CaptureOne software and stored as color TIFF-images.

3.3 Data Enhancement – Secondary Processing

Once a good trajectory and a well matched point cloud has been ensured there are three basic steps to producing an enhanced dataset:

- Isolate and clean the data to be processed. On the A14 any laser data not inside the asphalt area was removed. All hits not on the ground were then removed, for example hits on vehicles and down drainage gullies. You are then left with a point cloud containing only hits on the road.
- Smooth the data. Using the functionality within the TerraScan software it is possible to apply a smoothing algorithm to the laserdata. This reduces the noise in the data, resulting in a smoother dataset.
- Compare point cloud to survey detail and shift accordingly. Analysis was done to the detail taken from the 34 topographic stations and corrections were made to the point cloud. The corrections varied from –4cm to +4cm.

Distance between topographic stations varied between 1 and 2 kilometers. At each station there were an average of 35 points (1190 in total).

Digital images were georeferenced by combining GPS/INS trajectory and time stamps, which gave exterior orientation parameters for each image. Georeferencing was refined using tie point measurement in TerraPhoto and final orthophoto was adjusted to control points.

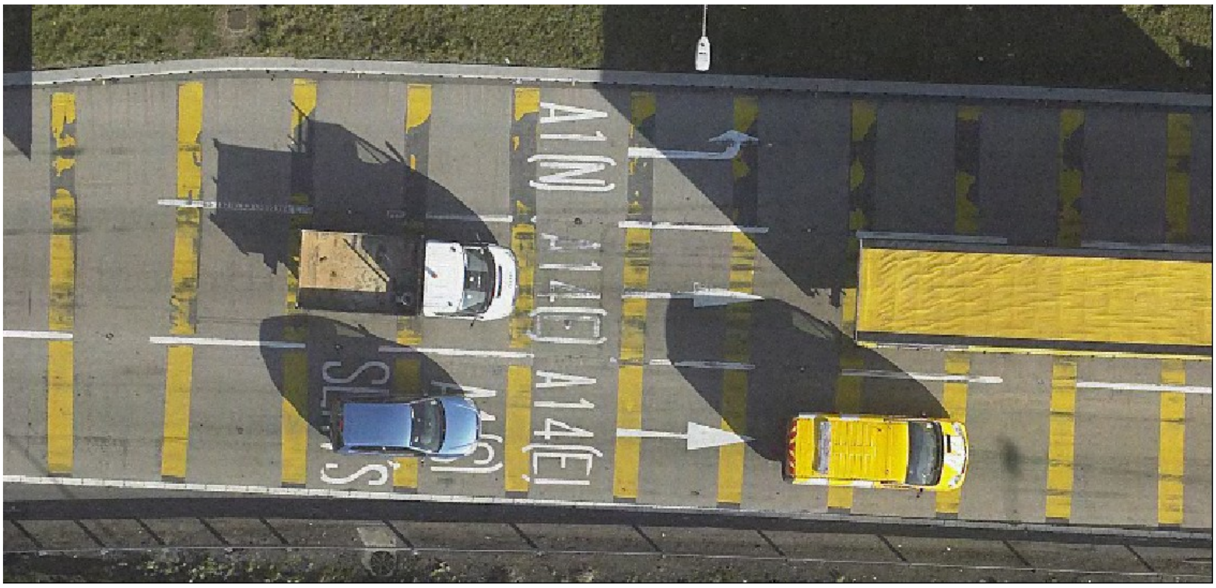

Figure 3.2 Example area of A14 orthophoto.

3.4 Result

Accurcay was checked using five points at five marker boards, i.e. a total of 25 points. The laser data at each board had been shifted to match the additional ground control.

At these check points an elevation accuracy of 13 mm RMSE was achieved, which was well with in the 20mm required.

Orthophoto was checked against the same marker boards and the result was 20 mm RMSE in Easting and 17 mm RMSE in Northing.

4. CONCLUSIONS

The work from the A14 proved that with careful planning and processing an enhanced high precision model can be achieved. However there are several things you need to be taken into consideration. The quality of the LiDAR point cloud is directly linked to the quality of the tools used. The system calibration, flight planning, data capture, GPS and survey data all need to be correct, should any one of them be incorrect then the whole data set is affected. Great care must be taken when collecting and processing the data. Enhanced models are not suited to all survey or surface types. Due to the smoothing applied to the data, small variations in the surface such as kerbs can be lost so it is best suited for smooth consistent surface types such as roads.

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BIOGRAPHICAL NOTES

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