EXTRACTION OF SPATIAL INFORMATION IN THE ENVIRONMEN OF IRISH ROADS USING AIRBORNE LASER SCANNING

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ABSTRACT:

This paper describes the first phase of a three year PhD research project which aims at extracting road and roadside information accurately and robustly from airborne sensor data and assessing its suitability for integration in a spatial analysis system. The context for this research is road safety and the requirements of the European noise directive for noise mapping. Phase 1 concentrated on using existing and widely available software and techniques for extracting spatial information from LiDAR data. Geometric and raster approaches were used. Results are encouraging indicating that existing systems and techniques can yield roadside objects successfully with appropriately designed workflows. However the degree of automation is limited. Phase 2 of the research, which has just begun, will address the combination of LiDAR with other sensor data and attempt to improve the degree of automation through the development of specialist algorithms.

1. INTRODUCTION

Airborne laser scanning (LiDAR) is investigated for its possible use in extracting spatial information about Irish roads and objects in its environment using automatic and semi automatic techniques. It forms the first phase of a three year PhD research project which aims at extracting such information accurately and robustly and its integration into a spatial analysis system. The context for this research is twofold – 1) the requirements of the European noise directive for noise mapping and 2) road safety. These two areas require constant monitoring of road objects and LiDAR, in combination with other sensors, can ease the work load on National Road Authorities (NRA) with responsibility in these areas.

1.1 Background

LiDAR can provide detailed 3D information cost effectively and efficiently in a very short time without any hindrance to traffic. Moreover the information can be collected in the day or at night time, which is not the case with traditional surveying and photogrammetry. National authorities responsible for surveying and mapping are increasingly adopting this technology for generating precise DTM's. Vertical accuracy of ±15 cm and horizontal accuracy below one meter can be achieved (Leica Geosystems, 2003). New sensors claim to have absolute vertical and horizontal accuracies of 10 cm and 20 cm (FALCON III, TopoSys) which is time consuming to achieve in digital photogrammetry. LiDAR data, acquired for road surveys, can also be used for various other purposes such as locating the path of a new road and extracting information about other existing topographical features.
Road safety and noise mapping requires an examination of two different aspects of roads.

1. Road Geometry

2. ROAD ENVIRONMENT

Road geometry means the parameters used for the geometric design of the roads such as design speed, stopping sight distance, passing sight distance, line of sight, number of lanes, lane width, side foot path for pedestrians, longitudinal and transverse slope, road pavement material (bitumen or concrete) etc. Roads which have been constructed recently follow modern geometric design parameters and such data is available in Computer Aided Design (CAD) files that can be used by the NRA's. However for older roads this data is not available or unusable.
Road environment means whatever comes in the neighborhood of the road, i.e. approximately 200 m on either side. It includes buildings, tress, vegetation, electricity and traffic light poles etc. The hypothesis for the current research is that LiDAR has the potential to provide the required information for noise mapping, road safety assessment or upgrade quickly, efficiently and economically with an acceptable degree of robustness.

2.1 Related Work

The focus of using LiDAR data is in the preparation of digital elevation or terrain models (Brüggelman, 2000; Hyyppä et al., 2000; Kraus and Pfeifer, 1998; Kraus and Otepka, 2005) and the extraction of buildings and building outlines (Haala and Brenner, 1999; Vögtle and Steinle, 2000).
Research on automated road objects extraction has been fuelled in recent years by the increasing use of Geographic Information Systems (GIS), and the need for data acquisition and update for GIS (Hinz and Baumgartner, 2003). Basically, only a few approaches exist which rely primarily on height data in order to identify roads within a DTM or their extraction from a DSM. A road surface is defined by means of a homogeneity measure and break lines are described as linear structures that show discontinuities perpendicular to their shape. This concept has

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been used by many researchers (Brügelmann, 2000; Briese, 2003, Wild et al., 1996). Clode et al. (2004) proposes a method based on hierarchical classification in order to extract roads from DTM data. A number of preliminary studies have been made of road planning: laser based elevation data for highway drainage analysis (Hans et al, 2003), forest road planning (Coulter et al. 2001) and the extraction of road geometry parameters from laser scanning and existing databases (Hatger and Brenner, 2003). Shrestra et al. (2001) have used laser data for highway mapping and DTM generation.
Major motivation of this research is to explore the capabilities of LiDAR processing tools in extracting objects represented in the form of point clouds and their integration into spatial analysis software, otherwise LiDAR use will be limited only to surface modeling and terrain visualization.

2.2 NRA Requirements

For noise mapping NRA Ireland is interested in features that influence how the noise is dispersed from the road surface. It is important to know the location and height of the purpose built noise barriers (concrete/wooden/bunds), any wall, ditch along the road side, buildings within a specified distance of the road in conjunction with embankment information and overall ground model. Using a road based camera system trying to capture some of these features has proved unsuccessful because of the occlusion of the objects and secondly because of limited field of view of camera.
For road safety, interest stems from trying to identify road side features that offer little margin of error in the event of driver error i.e. should a car run off the road and strike a telegraph pole, the possibility of a fatality is much greater than if there were no obstruction within a specified run off zone. Major interests lies in identifying telegraph poles, trees, roadside inventory (signs etc) with no barrier system, ditches, walls etc.

3. PROBLEM STATEMENT AND JUSTIFICATION

Except for the 3D point coordinates, and in some cases intensity and multiple return data, no other direct information about the point is provided by LiDAR data. It is not feasible to classify all LiDAR data manually every five years to extract objects of interest. However, the true problem, indeed, starts when the point clouds have to be turned into consistent, topologically correct, true 3D models. Currently available automatic and semi automated techniques need to be evaluated and refined further for extracting spatial information. It is commonly agreed that (on average) the data processing needs a factor of 10 more time than raw data acquisition and preprocessing (Gruen, 2007).
A further important aspect of the generated 3D model is its proper utilization and that is only possible if it is integrated, together with other national data, into one spatial analysis system. Point cloud processing tools are available which classify the point on the bases of position, intensity and multiple returns. These classified points can not be used directly for spatial purposes unless they are transferred to a 3D Model. Still the point classification techniques are not mature enough to classify all the points that belong to one object – hence the motivation for this research.

4. DATA & SOFTWARE

4.1 Data

The area selected for the project is located in Bray, County Wicklow located on the south side of Dublin, Ireland covering an area of about 25 Km^2. Data consists of a good variety of diverse regions, coastal, urban, rural, industrial, and forestry with a topographic height profile ranging from sea level to high ground. The available LiDAR data is of two types.

4.1.1 Fixed-Wing Data:

Three LiDAR data sets are available which were acquired at different flying heights and therefore have different point densities. They have an average point spacing of 2, 1.5 and 1 m with multiple returns. Data was captured in February 2004 by a Leica GeoSystems ALS40 scanner.

4.1.2 Helicopter Data:

Another high density data set with an average point density of 16 point/m2 along with the intensity of the returning pulse was acquired by the Fugro FLI-MAP II scanning system mounted on a helicopter. This scanning system consisted of two scanners, one primary 7o forward looking and one secondary 7o backward looking. The flying height is 200 m and the system is not capable of recording multiple returns. Video and aerial images were recorded. The data was captured in December 2004 in a corridor mapping project.

4.2 Software

4.2.1 Flip 7:

Flip 7 is developed by Fugro to visualize LiDAR data along with photographs captured using its FLI-MAP II system. It also has some good point cloud classification tools and data can be exported in .LAS the ASPRS (American Society of Photogrammetry and Remote Sensing) LiDAR data exchange format (Samberg, 2007).

4.2.2 TerraSolid:

One of the leading software for processing LiDAR data, it works as an additional module in MicroStation. It consists of four major modules: TerraScan, TerraMatch, TerraPhoto and Terra Modeler.

4.2.3 LiDAR Analyst:

It is developed by Visual Learning System Inc. as an extension to ArcGIS 9.x. It has some good classification routines for the extraction of building boundaries, trees and forest areas. LiDAR data is displayed in raster format instead of point clouds.

5. METHOD

Phase 1 of this two-phase project has yielded promising results for the extraction of buildings and other roadside objects. This phase concentrated on using existing and widely available software and techniques and is illustrated in figure 1. The three approaches used combine a geometric and a raster approach.
The geometric approach uses point clouds and available information such as intensity, number of return. In the raster approach points are converted into a NDSM (normalized digital

surface model) and the objects are extracted using segmentation and classification.

The left column in Figure 1 represents the point cloud classification of high-density FLI-MAP data in TerraSolid. Objects of interest are extracted from the point cloud and integrated into a DTM and a DSM consisting of the selected objects. A NDSM is created and contours are generated from it to identify road boundaries, longitudinal and transversal slopes. The closed contours also represent trees and building boundaries. All this extracted information is than imported into spatial analysis software where further attributes can be calculated. TerraSolid provides good routines for point cloud classification based on multiple returns and intensity of the retuning pulse however limited possibilities to automatically or semi automatically extract 2D or 3D objects with attributes. TerraSolid can efficiently handle large LiDAR files.

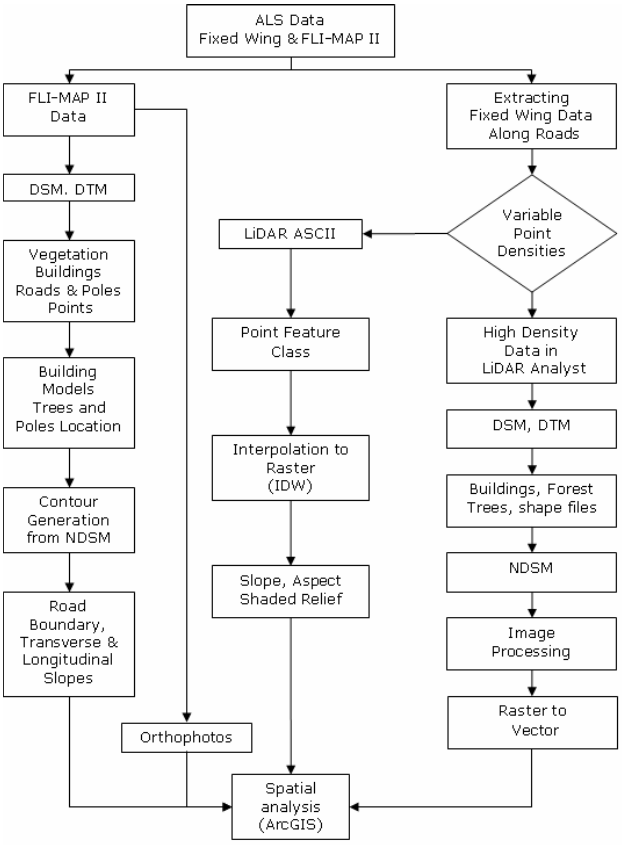

Figure 1: Adopted Method

The middle column in Figure 1 represents processing in ArcGIS 9.2 which supports the visualization of .LAS data file which can be imported as a space delimited ASCII (American Standard Code for Information Interchange) file. A general workflow and the outcomes of ArcGIS processing are shown in Figure 2.

ArcGIS provides very limited options for dealing with point clouds. It can not handle large LiDAR files. Points are stored in 2D shape files with Z as an attribute. The DTM and NDSM have to be created first from the DSM and then they can be imported into ArcGIS. Extensive customization is needed to process LiDAR data. Some commercial software companies have developed extensions for processing LiDAR in ArcGIS such as LP360, LiDAR Analyst, Feature Analyst and LiDAR explorer.

LiDAR analyst capabilities have been used for extracting objects directly in spatial analysis software with attributes. The workflow for processing in LiDAR Analyst is represented in the right column of Figure 1.

It can detect buildings with the following attributes: FID, Shape, Class ID, Roof type, Average Height above ground, Minimum Height above Ground, Maximum Height above Ground, Deviation in Height, Area, Perimeter, Length, Width and orientation angle.

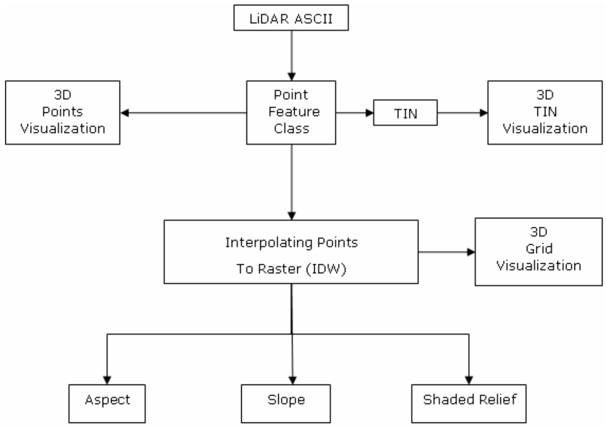

Figure 2: LiDAR Processing in ArcGIS 9.2

Trees and forest patches are also extracted with the following attributes. Trees: Shape, Tree Height, Crown Width, Stem Diameter. Forest: Shape, Area, Number of Trees, Tree Density, Average Tree Density, Canopy Height, Average Crown Width, Average Stem Diameter. Obtained results need further editing to delete the wrongly identified objects. LiDAR Analyst does not provide the opportunity to classify only the point cloud or extract other objects of interest. It has semi automatic techniques for extracting trees, forest and buildings with the option to change some of the variables in the algorithm settings. It automatically creates separate layers for DSM, DTM, NDSM, buildings, trees and forest patches with pre defined attributes.

6. RESULTS

The following section outline the progress made in Phase 1 of this project. A combination of semi-automated techniques and manual editing has yielded promising results for the extraction of roads, vegetation and buildings from LiDAR data. Orthophoto, DTM's, DSM's and NDSM's have been generated from high density helicopter data and fixed wing lower density data.

6.1 Orthophoto:

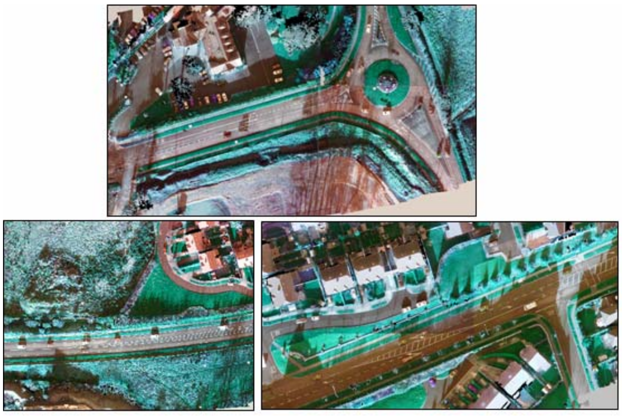

Figure 3: Generated Orthophotos (Pixel size 5 cm)

Flip7 can generate orthophotos with high resolution using LiDAR data and the images captured at the time of data acquisition. These images are exported in GeoTIFF format and can be visualized in ArcGIS along with LiDAR data. The images are created by assigning colour from the digital images to the point cloud. Images captured by FLI-MAP II system are in native Flip7 format and cannot be used in other software such as TerraSolid which also have a module TerraPhoto for the generation of Orthophotos.

6.2 DSM, DTM & Enhanced Intensity Image

FLI-MAP II data is processed in TerraSolid for the extraction of a DTM from the DSM. The DTM is the essential layer for further extraction of objects from the LiDAR data.

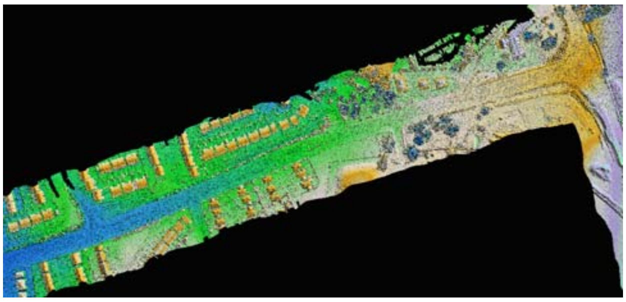

Figure 4: DSM (16 points\m^2)

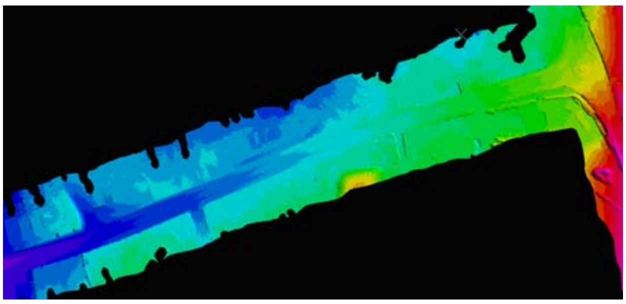

Figure 5: DTM

The intensity of the returning pulse has been enhanced for better segmentation and classification based on intensity values.

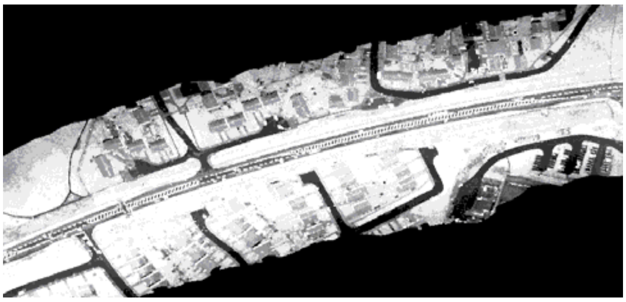

Figure 6: Enhanced Intensity Image

Figures 4 to 6 represent a narrow strip of LiDAR data covering approximately 80 m on either side of a road. Although point density is high, the classification algorithms not work correctly near the edges (Figure 5). Fixed wing data with a highest density of 1 point/m^2 covers a larger area and provides a better opportunity for testing raster based object extraction algorithms and gives more closed contours. A point density of 1 point/m^2 or higher is recommended for raster based object classification (Rao, 2008).

6.3 Buildings and Vegetation

Based on height, vegetation was classified into three classes i.e. 0 to 5 m low vegetation, 5 to 10 m medium and above 10 m as high vegetation. Building points also exist in the medium and high vegetation classes. Here intensity values were used and building size to separate building roofs from vegetation. Intensity values of building roofs and road pavement lie in the same range (0-20). But roads are part of the DTM so they are classified based on zero height difference to the DTM which is not the case with buildings.

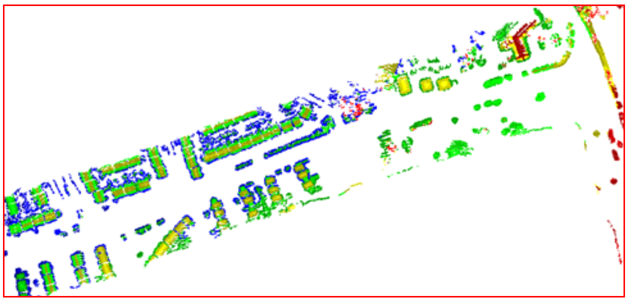

Figure 7: Buildings & Vegetation (Medium to high)

Figure 8: Refined Buildings

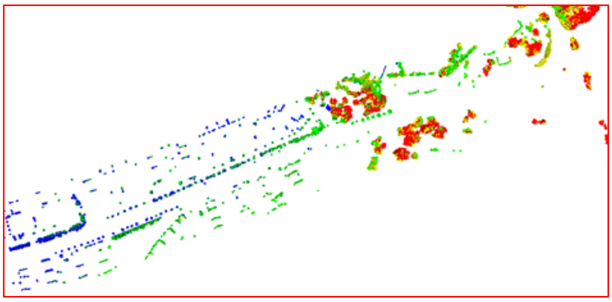

Figure 9: Tree Extraction

Three different types of tree models were used to further classify tree points. These models can be modified based on the vegetation in the project area.

6.4 Roads

Roads were separated successfully from footpaths upon further classification of intensity. Roads are more prominent in the range of 0-6 on a grey scale of 0 to 256.

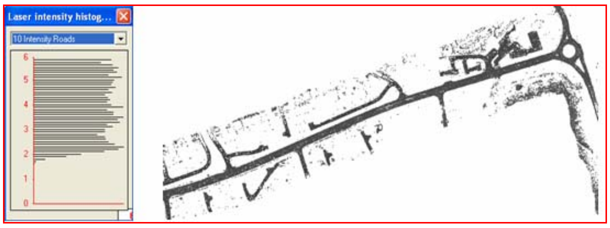

Figure 10: Road Extraction

6.5 3D Building Models

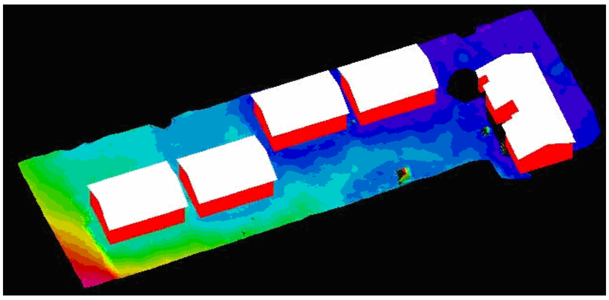

Figure 11: Simple Building Extraction

A NDSM (Normalized Digital Surface Model) is created by subtracting the DTM from the DSM. Classified building points are displayed over the NDSM and building roof planes are detected and combined together to form one single polygon. The process requires an operator to remove the false detected planes and combine multiple planes to form a single one. These models are exported from MicroStation to ArcGIS.

6.6 Poles and Wires

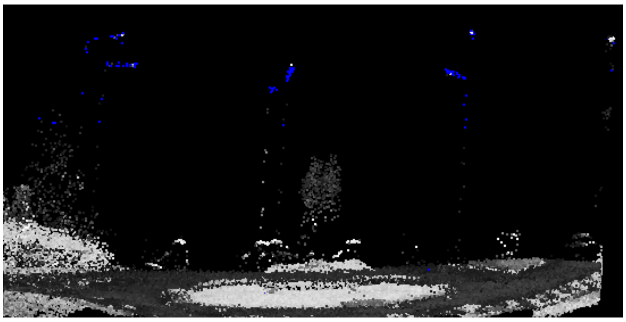

Figure 12: Light Pole Extraction

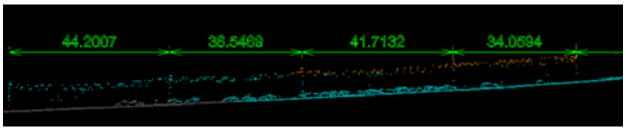

Figure 13: Electricity Poles & Wires

Electricity, light and traffic poles are important from a road safety point of view. Over hanging poles (Figure 12, blue colour) have been automatically detected from high density helicopter data using a combination of filters in Flip7 software. The advantage of using two scanners tilted on a small angle is to have points on the vertical surfaces such as building walls and poles. Straight poles need to be identified manually and than the wires are digitized roughly. Wire extraction algorithms later detect the wires close to the digitized wires in 3D. These objects are difficult to identify in lower density data.

6.7 Road Gradient

Contours are generated from the NDSM which helps in identifying the change in the slope of the road (Figure 14, red lines). It is important to know the road gradient as noise of the vehicles increases because of rising gradient and from a road safety perspective. Figure 14 also shows building boundaries and tree locations as closed contours. It requires further editing, spatial analysis, attribute addition to make this information usable.

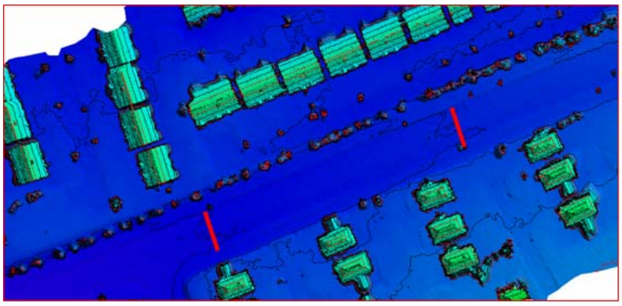

Figure 14: Contours Over NDSM

6.8 LiDAR Analyst

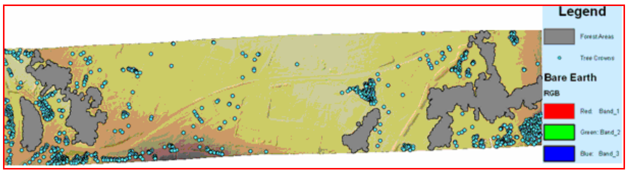

Figure 15: Tree and Forest Patches

LiDAR Analyst has been evaluated for extracting information out of the point cloud in ArcGIS. The extracted objects have attributes and can be used directly for the noise mapping software input such as LIMA extension for ArcGIS used by NRA, Ireland.

Figure 16: Extracted Building Boundaries

7. CONCLUSIONS

Advances in LiDAR and other data acquisition sensors are far more than the progress in automatic or semi automated methods for extracting information out of the acquired data. Currently LiDAR is mostly used for DSM, DTM creation and for 3D visualization of topographical features. Extracting useful information from the point cloud can widen its application areas. LiDAR is unable to provide all necessary information required for object extraction and the research has already been started in the fusion of LiDAR data with other sensor data. This will form a significance aspect of Phase 2 of this research project. Previously it was difficult to process a large LiDAR file which is no longer an issue because of the high computation speed of computers and their availability at low price.
Currently we are disposed to a great variety of sensors, with different properties and performances. The true challenge is to accumulate enough knowledge in order to be able to make optimal use of all these devices. In the history of measurement sciences there has never been just one sensor which could have served as the magic wand (Gruen, 2007).

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