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Synthesis report: study on the potential of lidar data for the extraction of cartographic objects other than elevation

Canada Centre for Mapping and Earth Observation

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Abstract: Because of shrinking data-acquisition costs and increasing coverage of the Canadian territory, lidar technology has become integral to geomatics. In addition to its capacity to produce high-quality digital terrain models, lidar provides the opportunity to create new complementary data layers. The purpose of this analysis is to evaluate the potential of lidar data to extract cartographic objects other than elevation. Our results show that there is great potential in building extraction, as there are numerous related algorithms and tools. Extraction of the linear hydrographic network is equally promising, but it will require additional development effort. Surface-hydrography extraction yields mixed results, and requires significant development effort. The potential of transportation-infrastructure extraction is mixed as well, as no commercial or open-source solutions have been developed, and the additional development effort required is very significant. The potential of power-line extraction is moderate.

Résumé : Grâce à des coûts d'acquisition des données en diminution et à une couverture de plus en plus étendue du territoire canadien, la technologie lidar est devenue incontournable en géomatique. En plus de sa capacité de produire des modèles numériques de terrain de grande qualité, le lidar nous offre la possibilité de créer de nouvelles couches de données complémentaires. L'objectif de cette analyse est d'évaluer le potentiel des données lidar pour l'extraction d'objets cartographiques autres que l'élévation. Nos résultats montrent que l'extraction des bâtiments a un très grand potentiel puisqu'il existe de nombreux algorithmes et outils. L'extraction du réseau hydrographique linéaire est également prometteuse, mais elle demande un effort supplémentaire de développement. L'extraction de l'hydrographie surfacique donne des résultats plutôt mitigés et demande un effort de développement important. Le potentiel d'extraction du réseau routier est plus mitigé, aucune solution commerciale ni libre n'ayant été mise au point, et l'effort de développement additionnel requis est très important. Le potentiel est modéré pour l'extraction des lignes de transport d'énergie.

INTRODUCTION

Among Canadian users, national elevation data are by far the most popular of all the geospatial data distributed via the Geogratis and Geobase portals. A few years ago, lidar became the preferred tool for the acquisition of high-precision elevation data, which today are practically indispensable in several areas of activity such as forestry, flood risk management, urban planning, mineral-resource assessment, etc. In the coming years, Canada expects to acquire several million square kilometres of lidar data. Accordingly, it can be estimated that in the not-too-distant future, over 40% of the country will be covered by lidar data.

In addition to elevation data, airborne lidar can also be used to extract other themes such as critical infrastructure, hydrography, or vegetation. Natural Resources Canada (NRCan) is therefore looking at harnessing these data to update existing data layers while at the same time improving data quality and accuracy. However, lidar data have a particular structure and require adapted instruments and methodologies. To meet its needs and obligations, NRCan must develop reliable and effective tools that will enable it to manage and process this type of data in an operational environment.

To this end, AECOM was asked to conduct a study designed in part to review the methods of extraction of cartographic objects other than elevation (buildings, the hydrographic network, transportation infrastructure, and power lines) from data obtained from airborne lidar surveys. This literature review was divided into three sections clearly identifying the existing literature in the field of lidar on the basis of whether it pertained to basic research, experimental research, or operational applications. Bibliographic research was generally limited to the past ten years in order to describe current and recent results. An analysis of the maturity level of applications and technologies related to the selected themes was also conducted.

The study's other objective was to review the various available tools that are equipped to handle mass production, and to test them for the extraction of the different themes. These tools were analyzed and tested in order to establish clear recommendations to fill gaps that may impede mass production. Finally, the results were presented to the NRCan team, and training was provided on various tools that were tested and selected.

This document is an edited version of the summary report prepared by AECOM as part of its mandate from NRCan, in accompaniment to the full report (AECOM, 2016, "Étude sur le potentiel des données LiDAR pour l'extraction des objets cartographiques autres que l'élévation. Méthodes et outils d'extraction des bâtiments, du réseau hydrographique, des infrastructures de transport et des lignes de transport d'énergie", unpub. report presented to Natural Resources Canada, April 2016, 101 p.). It briefly presents the software selected for testing and a review of existing extraction methods. Also, a brief analysis of the various extraction tools is provided for each of the themes in the study (buildings, hydrographic network, transportation infrastructure, power lines). It is important to note that this study is not in itself a test bench of selected software; rather, it provides an overview of the tools available in a trial version, as well as a test of features.

The team that worked on this project included J.-É. Baribeau, D. Baron, T. Bergeron, and P. Hébert from AECOM, as well as P.-É. Bonhomme, M.-A. Daviault, G. Houle, and N. Sabo from the Canada Centre for Mapping and Earth Observation (Natural Resources Canada).

Lidar

Lidar is an acronym for Light Detection and Ranging. This recent technology, which reveals variations in altitude, is used to determine the shape of the land's surface, including both natural and artificial features. Lidar data are used to map topographic features as well as the height and density of objects in relief, such as trees and buildings. The raw lidar data, also called 'point clouds', are acquired from aircraft that project laser beams onto the Earth's surface. Lidar sources transmit pulses of laser light at visible and near-infrared wavelengths. The light hits solid objects and is then reflected back to the lidar sensor. Elevation data (object height) are calculated by measuring the time required for the signal to travel to the object's surface and return to the sensor. With this information, the actual height of objects in relief or topographical features can be calculated.

Each light beam emitted toward the ground can cause one or more reflections. A reflection (or a return) is defined as the part of a beam of light that strikes the surface of an object and returns to the sensor. In areas where some surfaces are smaller than the diameter of the beam, multiple reflections can occur. When the beam of light comes into contact with an object in such a way that the incident energy is partially reflected back to the sensor, the remaining incident energy continues to travel downward until it comes into contact with another solid object. All other objects in the path of the beam will be detected if they reflect enough energy from the incident laser beam toward the sensor. The first part of the beam that strikes an object, such as a branch, is reflected back to the sensor and is called the 'first return'. The part of the beam that strikes the final object (such as the ground) and returns to the sensor is called the 'last return'.

Pulses generating multiple reflections from a single beam allow for a detailed modelling of the ground surface. Part of a beam can hit a solid object and be reflected back to the sensor while the rest of the beam continues toward the ground. This usually occurs in forested or urban areas. Multiple reflections make it possible to define intermediate surfaces such as the canopy, providing elevation data for objects other than the ground surface. Generally, the first return corresponds to the reflection on the canopy's upper leaves, and the last return corresponds to the reflection on the ground under the canopy.

Each return of an emitted laser pulse is a data point with x, y, and z co-ordinates. Reflection intensity is routinely gathered with the other data. Data of good intensity produce an image comparable to a photograph in shades of grey. Intensity data can be used for viewing and for referencing prior to the extraction of objects.

EXTRACTION TOOLS

A number of commercial and open-source software applications are used to process lidar data in order to extract cartographic objects. The literature review conducted as part of the study helped guide the choice of software for testing. Software that had the potential for automating the extraction of map objects was preferentially selected for testing. Among these software systems, those that required numerous manual operations were not selected because of the timeframe allotted for the study's mandate as well as its main objective, which was a feasibility assessment of the extraction of cartographic objects using the most automation possible.

Table 1 presents a list of the main tools identified during the literature review for the extraction of cartographic objects other than elevation. However, the list of available software is much more comprehensive than the one presented in this table. Also, these systems were tested using their default settings for the most part, without any major adjustments. In this sense, it is important to note that this study is not in itself a test bench for the selected software; rather, it provides an overview of the tools available in a trial version, as well as a test of features. In addition, given the study's timeframe and scope, software and tools with automated extraction operations were prioritized.

The data used for testing were provided by NRCan. The lidar data sets have a density of 2.5 points/m^2 (mean density of first returns over 90% of area) and were collected above the Gatineau (Quebec) region.

Table 1. List of the main software applications identified during the literature review for extraction of the different themes

	Theme				
Software	**Buildings**	**Linear hydrography**	**Surface hydrography**	**Transmission lines**	**Roads**
ArcGIS + Spatial Analyst or 3D Analyst		√	√		
TerraSolid / TerraScan	√				√
Global Mapper LiDAR	√	√		√	
LiDAR Analyst	√				
GRASS		√			
Barista	√				
Trimble eCognition	√		√		√
LAStools - Las Classify	√				
ENVI / LiDAR	√		√	√	
R / MATLAB	√				
Whitebox GAT		√			
TauDEM – TauTopographie		√			
OPALS	√	√			
GeoNet		√			
LaserData – LIS	√				
LP360	√				
gLIDAR	√				

Software selected for testing

Key points from the analysis of the themes covered

The following sections summarize the observations and conclusions relating to each extraction theme addressed. At the beginning of each section, the key points covering the most important aspects of the analysis are summarized in a text box for the reader, as follows:

An assessment of the 'potential' of airborne lidar for the detection and extraction of cartographic objects in an operational context. Potential can be rated as 'excellent', 'very high', 'moderate', 'mixed', or 'interesting', depending both on the capacity of the current technology to produce satisfactory results without significant additional development and on the added value of using lidar compared to traditional data-capture methods. Potential is also assessed by taking into account certain operational aspects such as the density of the point cloud resulting from the lidar survey. Thus, in the case of a survey using 30 points/m^2, the potential for the extraction of a given object may be rated as 'excellent' following the literature analysis. However, in an operational context where the expected results from airborne lidar surveys will be approximately 1 to 4 points/m^2, the potential for the extraction of the same object may be given a lower rating, such as 'moderate', if tests have revealed limitations. Further, the 'interesting' rating for the potential of another system denotes a situation where a lidar survey would not necessarily lead to productivity gains compared to traditional methods but could provide a data source to detect objects that are barely visible, such as trails or paths in the forest.

The availability (or not) of commercial or open-source software solutions.

An assessment of the 'results' of the extraction tests conducted.

An assessment of the level of development efforts necessary to consider implementation.

A list of at most three software packages that stood out for the extraction of each theme during testing, if applicable.

BUILDING EXTRACTION

Review of methods

Very high potential

Many algorithms and commercial / open-source solutions

Promising results

Little development effort required

LAStools

TerraSolid / TerraScan

LiDAR Analyst

The detection of buildings by lidar is an application with very high potential. Among the various themes addressed in this study, the extraction of buildings by lidar is the one that will require the least amount of development effort for operationalization.

The mapping of buildings from airborne lidar has been carried out in a very large number of studies, and the existing literature is abundant. In addition, a large number of automatic-classification algorithms have been developed, and several commercial and open-source solutions exist.

The quality of the results obtained in the studies surveyed is very promising. A variety of methods and algorithms were used by the various researchers, including the following:

- algorithms applied directly to the lidar point cloud;
- algorithms applied to the lidar digital surface model (DSM);
- algorithms combining imagery and the lidar digital surface model; and
- algorithms found in the literature that relate to land use.

The scientific articles reviewed mentioned mainly methods and algorithms that are applied to the normalized surface model (nDSM) in conjunction with imagery. By contrast, the algorithms found in software are applied directly to the lidar point cloud without the input of imagery.

All of the algorithms are capable of achieving extremely high detection rates, often higher than 90%[1] (Rottensteiner et al., 2007). However, it seems important to mention that building footprints are not entirely accurate (approximately 70%)[2], which does not allow for the production of

[1]The detection rate refers here to the concept of completeness, which is the number of true positives divided by the sum of true positives and false negatives: (TP) / (TP + FN).
[2]This is an overlap of at least 70% between the generated data layer and the source data layer.

high-precision cadastral mapping. Aerial photography or satellite imagery is often used in conjunction with lidar to eliminate confusion with trees and detect buildings accurately.

The detection of buildings was carried out at the operational level in many applications. However, large national data sets generally do not offer users classified data that include a class for buildings. A building classification was created for Sonoma County, California (Watershed Sciences Inc., 2014, "Sonoma County Vegetation Mapping and LiDAR Program", unpub. report produced for Sonoma County, 44 p.). The county is fully covered with data at a density of 8 points/m^2. Only buildings with a footprint larger than 9.29 m^2 were selected, and a manual check was necessary. Slovenia is the only country found in our literature review that has been completely mapped with the aid of lidar and with the inclusion of a class for buildings.

The study by Tomljenovic et al. (2015) mentions that only two studies have focused on areas larger than 10 km^2. However, it is worth noting that there are some studies focused on land use that cover considerable areas and that were also designed to detect buildings.

Building-extraction tools

All the software applications used to perform the tests use as inputs the raw lidar point clouds in the native LAS format. Before using the preclassified data sets provided by the supplier, it is important to validate these data, since some land-classification errors may be present. For example, if some buildings have points on their roof classified as 'ground' in the data supplied, this will have an impact on the classification of buildings if it is not corrected. It is therefore important to note that reclassification may be necessary to optimize building detection.

Throughout the testing process for building generation, four major problem areas were encountered: large-area, flat-roofed buildings; confusion between buildings and overpasses; residential neighbourhoods; and the minimum-area criterion.

- Large-area buildings with flat roofs that are simply constructed are sometimes poorly distinguished from ground. Figure 1 shows an example of the results of tests conducted using various software applications for the detection of this type of building. Example 1 (Fig. 1a) illustrates a result that will require little correction work, while Example 2 (Fig. 1b) will require additional processing to achieve an optimal result.
- Overpasses conflict with buildings during extraction. Depending on the intended use of the representation of extracted objects, it is essential to determine the way overpasses are represented (as ground or other). Nevertheless, the detection of bridges and overpasses remains problematic.
- Residential neighbourhoods generally have the following two issues: sheds, trees, swimming pools, and power lines can sometimes be classified as buildings; and some software applications produce results that do not accurately represent the angle of buildings in relation to the street.

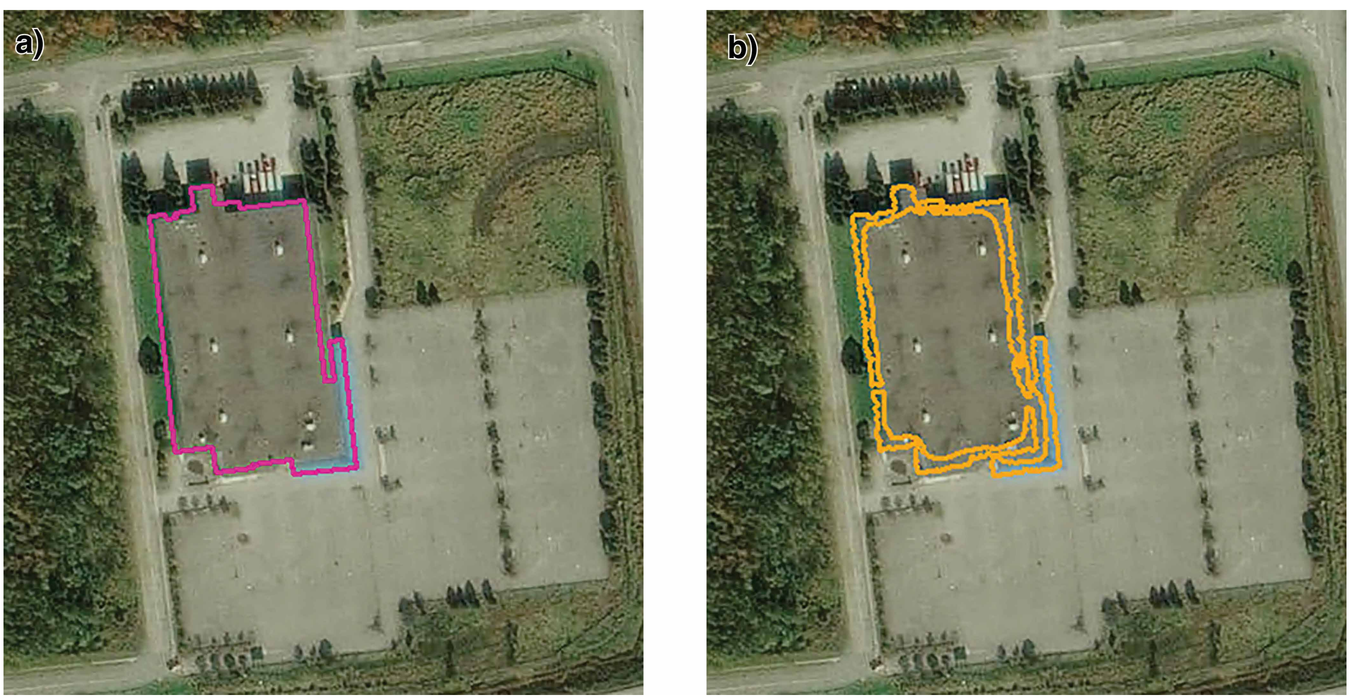

Figure 1. Detection of large-area, flat-roofed buildings with simple construction. **a)** Example 1. **b)** Example 2.

- Management of the minimum-area criterion can sometimes interfere with the detection of small objects such as sheds. It is therefore necessary to decide what the needs are with respect to the detection of these small objects.

Observations

In general, and with various degrees of accuracy, all tested software applications come equipped with the capacity to detect buildings. The testing that was performed did bring some issues to light, but in general, compared to traditional (manual) digitization methods, the software performed well. After testing using the default settings, the following points were noted:

- some applications stand out from the rest because of how easily they generate vectors of buildings (polygons) that accurately represent reality, and because of a feature that lets users generate right angles;
- the classification of ground elements seems to frequently cause errors and lead to the inclusion of vertical structures such as flat-roofed buildings. In order to maximize the quality of results, it is essential to take this into consideration and to apply the necessary corrections to problem areas;
- overpasses pose a problem. There is a need to decide the purpose for the representation of these structures. Whether to keep overpasses in the 'ground' class or to create a separate class is therefore up to the user. Whichever approach is used, it is possible to achieve correct classification of ground elements by adjusting the necessary settings in all of the software that was tested. Considering the unique nature of each system, however, it would hardly be feasible to transpose the settings from one software system to another for the classification of ground elements;
- with all software systems, manual editing is necessary to produce accurate, error-free maps;
- some software systems require an additional step, involving the use of another type of software, in order to obtain polygons;
- the intensity of the lidar data is not considered by any of the software that was tested, except by eCognition, which offers the possibility of integrating the intensity parameter into images to carry out the work;
- some software systems confuse objects such as pools with buildings;
- the development of algorithms designed to improve the accuracy of building footprints would make it possible to generate property maps. In addition, interference from vegetation during building extraction remains an issue that would justify the improvement of many algorithms.

HYDROGRAPHIC-NETWORK EXTRACTION

The section on the extraction of the hydrographic network is subdivided into two parts: extraction of the linear hydrographic network, and extraction of the surface hydrographic network.

Review of methods: linear hydrographic network

Excellent potential

Commercial / open-source solutions available

Promising but variable results

Relatively significant development efforts required

Whitebox GAT

GRASS

ArcGIS

Following the review of literature on the extraction of linear watercourses, it is evident that this theme has been studied more than surface-data extraction, as indicated by the great number of experiments and applications that have been developed. Moreover, this theme appears promising and is likely to have a significant impact, including a greater cost-benefit ratio for large-scale applications. The literature is abundant, and numerous algorithms have been developed and tested across a multitude of different conditions. Furthermore, easy-to-use commercial solutions exist. However, many obstacles still stand in the way of achieving a fully automated large-scale update of the hydrographic network. One major obstacle is the establishment of a threshold for the 'flow accumulation' function[3], which will dictate the density of the final hydrographic network. This threshold varies from one place to another, and it is not possible to assume identical drainage densities across all locations.

[3]Based on flow-direction information, the 'flow accumulation' function calculates the number of cells that contribute to the flow in each cell (accumulated flow). In general, cells with a high value represent watercourses, whereas cells with a low value represent highlands.

Development efforts required to operationalize the extraction of the hydrographic network remain relatively significant, but the potential of this application is excellent.

The algorithms designed to create a hydrologic surface (as opposed to a topographic surface) can be divided into two groups for preprocessing:

- Hydrologic conditioning method (hydro-conditioned): procedure that enables water to flow continuously through a territory in the DTM or the TIN (triangulated irregular network). This procedure includes the elimination of sinks that trap the water and prevent it from flowing.
- Hydrologic enforcement method (hydro-enforced): procedure that favours hydrologic and hydraulic modelling by enabling water to flow under structures such as bridges, culverts, and roads, instead of blocking it. The use of 3D breaklines makes it possible to slope rivers in a downstream direction, whereas lakes and reservoirs will have a flat surface.

Many experiments have been carried out using these two methods. The experiments carried out to extract hydrographic networks using hydrologic-conditioning preprocessing have in general met with problems requiring a large number of manual corrections. However, it is not easy to discern whether one method is better than the other. Methods also exist for 1) mapping a hydrographic network in its entirety and 2) updating an existing network. The 'water-droplet' method is often mentioned for performing updates.

AECOM presented a method to produce a hydro-enforced DTM from aerial photographs and airborne lidar data to update the United States' National Hydrography Dataset (NHD) in order to add watercourses larger than 6 acres to high-resolution representations (AECOM, 2012, "Guidelines for the Delineation of National Hydrography Dataset Features for the Indiana Local Resolution NHD Project", unpub. report of the Indiana Geographic Information Council, 14 p.). The automated method does not give accurate-enough results, so watercourses were digitized manually at a scale of 1:1200 and 1:2400. Within cities, underground lines and pipelines are also digitized to connect with visible watercourses.

Lindsay and Dhun (2015) presented an innovative method for producing hydro-enforced DTMs automatically with an acceptable result (87%), where the parts of a channel located upstream and downstream from bridges and culverts were successfully connected in the study area, whereas the majority of researchers performed this operation manually.

Poppenga et al. (2009) experimented with automatic watercourse extraction over an area of 2108 km^2. They compared two methods of extraction from hydro-conditioned DTMs: the accumulation-layer and the 'water-droplet' methods. The first method aims to create a uniform drainage network with a few upstream watercourses. However, the drainage network obtained is far from uniform in the majority of situations. The second method tends to create a hydrographic network similar to the one input as the base condition. The analyses note a good correspondence with the existing network. However, errors appear if bridges are not eliminated. Often, the course deviates as it approaches an obstacle but will connect up with itself correctly further downstream.

Stanislawski et al. (2015) present a method for analyzing the similarity between two sets of linear data in order to effect an automatic update of the hydrographic network. The methodology uses the national elevation data at a spatial resolution of 10 m, but it is noted that it was developed to be applied to lidar data. The method combines the hydro-conditioned DTM with flow data and base groundwater-flow data to vary the drainage conditions. The model shows errors in low-slope areas and areas with man-made features.

Extraction tools: linear hydrographic network

All of the software that was tested used substantially the same methodology for generating a linear hydrographic network. The major steps in production are summarized as follows:

1. a digital terrain model is used as base input;
2. an elevation layer in matrix form is prepared, based on the DTM;
3. the flow is analyzed, taking into account the slope present in the elevation layer. The result is an image in matrix format with an indication, for each pixel, of the quantity of water that flows through that location;
4. all pixels with a higher flow than the flow value setting predefined by the user are classified. Once all of these steps are completed, a vectorization in linear format of the hydrographic network is performed.

Overall, the results obtained are satisfactory. Figure 2 shows an example of a result obtained by extraction of lidar data in comparison with the hydrographic network obtained from CanVec. The comparison of these two results helps identify certain issues that require careful assessment, since the data sources used to generate the results are different; one comes from satellite images and the other from lidar data.

The management of elements such as bridges is the main challenge in using the models presented. Few software systems have specific features that let the user factor in this aspect and produce a coherent hydrological network.

Figure 3 shows how some software systems react when a road network conflicts with the drainage network. In example 1 (Fig. 3a), the algorithm ignores the bridge and the watercourse follows the road. In examples 2 (Fig. 3b) and 3

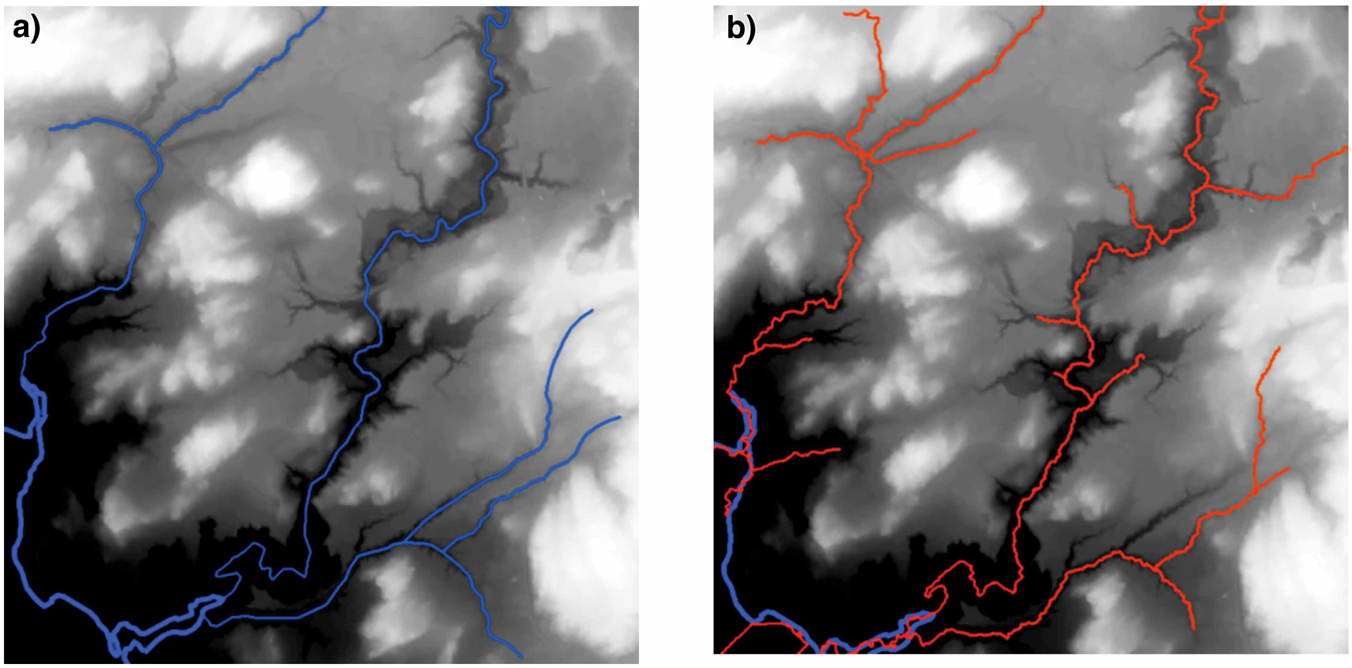

Figure 2. Linear hydrographic network from CanVec vs. one created using GRASS software. **a)** Hydrographic network from CanVec. **b)** Linear hydrographic network created using extraction tools.

(Fig. 3c), the algorithm reacts correctly to the presence of the bridge, and the hydrographic network obtained is coherent due to a specific feature that makes it possible to take this element into account.

It should be noted that during this study, no point of the source data was classified as 'bridge'; these points were classified as 'ground'. Ideally, bridges should be classified in a separate class from 'ground', which would help eliminate this problem.

Observations

The features of various tools that enable users to generate the linear hydrographic network were tested. The following observations were made:

- a few software systems provide good results in the production of the linear hydrographic network. Perfection is difficult to obtain, and the results depend on the lidar base data used by the models to generate the hydrographic network;
- some software systems produce very good base results but do not take into account obstacles such as bridges;
- the inclusion of a specific feature that takes into account structures such as bridges provides for better plotting of the linear hydrographic network;
- all of the software systems tested produce vectors whose general appearance resembles the pixelated look of the base DTM. The vectors that are generated can be softened in order to obtain a smoother line corresponding better to reality.

For linear hydrographic network extraction, further research into making automatic breaklines in artificial structures should be conducted. Automation of the determination of the flow-accumulation threshold could be achieved using hydrological modelling that uses meteorological data and soil data as well as land-use data.

Review of methods – Surface hydrographic network

Moderate potential

No commercial / open-source solutions

Interesting results

Significant development efforts required

Trimble eCognition

ENVI

ArcGIS

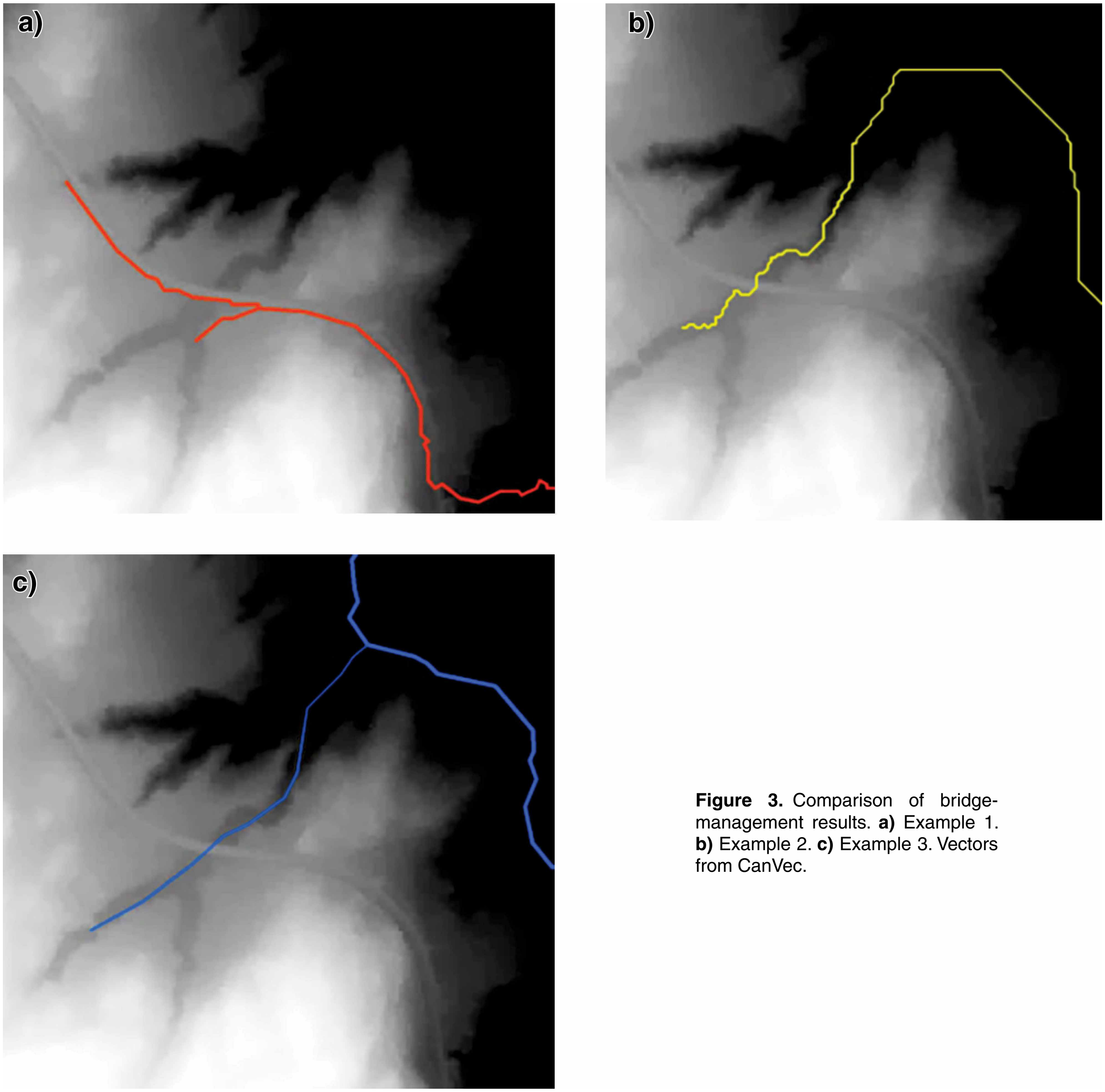

Figure 3. Comparison of bridge-management results. **a)** Example 1. **b)** Example 2. **c)** Example 3. Vectors from CanVec.

The researchers who studied the detection of the surface hydrographic network using lidar data obtained very satisfactory results. However, few researchers seem to have applied this methodology to large areas. This application has not seen frequent use operationally, since other traditional sources of data such as optical or radar imagery can be used to perform this task with a high level of success. In this sense, this theme seems less promising and holds less potential. Moreover, no automated tools for extraction of surface water bodies from lidar data using fully automated methods were identified during this study. In addition, few publications have been produced on the mapping of surface watercourses using lidar data. However, some approaches are worthy of mention, and it seems important to note recent developments in order to appreciate the state of current research. One of these methods is DTM flattening.

DTM flattening is an aesthetic modification designed to eliminate triangulation artifacts generated during the creation of the TIN. It is used to give water bodies the same appearance that they have in a traditional DTM developed by photogrammetry. Breaklines are used to produce flattening of water bodies so that they are at a uniform level.

The flattening of DTMs is generally used to deliver products intended for the general public, and it could benefit from further automation. However, little research seems to have been conducted in this area. In addition, as Heidemann (2014) points out, a large number of rules and exceptions exist that make this automation more complex. The researchers who detected water bodies automatically, with a view to generating breaklines, generally have not focused on the problem of surface watercourses that must be modelled on a slope using a 3D line.

Heidemann (2014) presented all of the specifications for the elevation products of the 3D Elevation Program produced by lidar data and managed by the United States Geological Survey (USGS). During the flattening process, no geometric change must be produced in the base lidar data. Points on the edges of breaklines must be ignored during interpolation in order to avoid artifacts. Breaklines must be used in support of point classification. For the collection of breaklines, a long list of criteria must be met to ensure conformity with the USGS standard. These criteria are classified into five categories, each of which is comprised of several criteria (only one is shown here as an example):

- ponds and lakes: water bodies 2 acres or more in area must be flattened,
- streams and rivers: rivers and streams 30 m or more in width must be flattened,
- nontidal boundary waters: only the shore belonging to the country must be represented (and not the opposite shore),
- tidal waters: all bodies of water (affected by tidal variations) must be flat and at the same level,
- islands: permanent islands 1 acre or more in area must be delineated within water bodies.

Smeeckaert et al. (2013) present a methodology for classifying water bodies directly from the lidar point cloud. The authors mention that their methodology could be applicable for large areas of land, and it has been tested on eight different sites, for a total area of nearly 800 km^2. The use of a Support Vector Machine (SVM) classification technique was developed using lidar data. Another input into the algorithm is a rough (low-accuracy) classification of water bodies, which is used to create a training data set for the algorithm. The method uses three families of predictors extracted from lidar data: point elevation, point density, and the 3D shape of neighbouring points. The results of classification are excellent on all eight sites, and accuracy is greater than 85% in all cases[4]. For some of the sites, which cover larger areas, the model obtains approximately 97% accuracy.

Extraction tools – Surface hydrographic network

As mentioned previously, surface hydrographic network extraction has not been used frequently in an operational manner because of the availability of traditional data, such as satellite imagery, which enable users to perform this task with a high level of success. No automatic extraction tool for surface water bodies from lidar data was found during the study.

Some tests have been conducted, however, using tools that already exist for the extraction of the linear hydrographic network. The different models create lines arbitrarily, and these results demonstrate that the surface hydrographic network needs to be obtained using other extraction methods. Several researchers have obtained satisfactory results, however, and their algorithms could now be implemented in commercial or open-source software.

With regard to DTM flattening, greater automation would be desirable, provided that it does not adversely affect users who use lidar data in riparian areas and along the coasts.

TRANSPORTATION-INFRASTRUCTURE EXTRACTION

This section deals with land transportation infrastructure only. Lidar has been applied in the transportation field in a large number of studies designed primarily to extract the road network. This section is divided into three subsections: road-network extraction in urban and suburban areas, road-network extraction in a forest environment, and extraction of other transportation infrastructure.

Review of methods – Urban and suburban road network

Mixed potential

No commercial / open-source solutions

Results generally good on limited areas

Very significant development efforts required

No automatic software, requires specific development

The potential of application using lidar data is mixed since several technologies already exist to map and update the road network, making lidar technology less attractive. In addition, the development efforts needed to operationalize road-network extraction remain very significant.

[4]Accuracy is equivalent to the sum of true positives and true negatives divided by the total population: (TP + TN) / P.

In the area of transportation infrastructure, extraction of the urban road network is the area that has the most articles written about it and that has drawn the most attention and effort. However, there are relatively few studies, and while a few algorithms have been developed by researchers, our review did not turn up any operational applications. In addition, the software does not come equipped with automated tools to extract road networks or infrastructure. The researchers have implemented solutions that they themselves have designed and developed using a range of software and programming languages. Nonetheless, they have met with success and very often have managed to obtain a detection rate above 80%[5]. Still, it should be noted that the study areas were very limited in size and a number of different problems arose in several of the studies, including some linked to the following:

- elevated highway connectors and overpasses;
- parking lots, sidewalks, and driveways;
- roads with steeply sloping sides;
- trees above the road producing a discontinuous network in some cases.

In the majority of studies, the persistence of similar problems is noted, i.e. confusion in certain areas such as complex highway interchanges, parking lots, driveways, and roads overhung by trees. Road-network extraction has not been applied in projects operationally.

Boyko and Funkhouser (2011) present a method to extract the road network in an urban area directly from the raw point cloud. This algorithm is applied using the road network in a line file. The authors note that their model is able to deal with multilevel intersections, bridges, and tunnels. Validation, from manually digitized vectors, gives an accuracy of 86%. However, the authors mention weaknesses in their approach, such that errors in the initial vector layer will be reflected in the model.

Review of methods – Forest-road network

Interesting potential

No commercial / open-source solutions

Promising results

Some development efforts to consider

No software with a specific automatic feature

A large community of researchers has taken an interest in the detection of roads under more or less dense forest cover. Given its ability to penetrate the forest canopy and reach the ground, lidar stands out from aerial photography and satellite imagery in this respect.

It has been demonstrated that lidar improved the mapping of the road network under forest cover. White et al. (2010) have shown that lidar was able to detect 100% of the road network, whereas aerial photography detected only 15%. We have not found any 'turnkey' automated algorithms capable of performing such detection, but some researchers have been quite successful using the methods they have developed (Sherba et al., 2014; Ferraz et al., 2016).

For forest applications, the question of point density becomes crucial. The researchers who worked in the Pacific coastal regions of the United States used lidar data with a very high point density (between 6 and 12 points/m^2). Sherba et al. (2014) demonstrated a rapid drop in road detection when point density was changed. They mapped former logging routes in order to highlight lidar's ability to detect linear corridors in a forest environment. Their fully automated algorithm obtained 86% accuracy[6]. The authors attempted to degrade DTM quality by eliminating points that reached the ground in order to observe the impact this would have on the level of road-network detection. Initially, spacing between the points on the ground was on average 0.91 m. They decreased the number of points by 50 cm increments up to a spacing of 5.66 m. The drop in accuracy is illustrated as follows: 86%, 78%, 67%, 65%, 48%, and 46%.

In Sonoma County, California, airborne lidar was used in order to improve road-centreline delineation in the forest environment (Watershed Sciences Inc., 2014, unpub. report cited above). To do this, it was visually shown that a road located under forest cover is much more visible on the hillshade layer produced by lidar than on orthophotos. The authors state that they have recorrected the entire network of roads under forest cover in Sonoma County using airborne lidar.

It is important to point out that a cross-Canada airborne lidar survey with a density of 2 to 4 points/m^2 could present some limitations in the detection of roads under forest cover in environments similar to those of the forest ecozone of the Pacific coastal region. However, this ecozone covers a relatively small area in Canada compared to the boreal forest and the mixed-forest plains, which offer great potential for the application of this method.

[5]See footnote 1.
[6]See footnote 4.

Review of methods – Other transportation infrastructure

With respect to other transport infrastructure, the rail network, overpasses, and bridges have been addressed. These elements can be mapped with a high level of confidence. Bridges offer some potential since they are used in other applications (DTM flattening). They are often classified in the large national data sets so as not to affect hydrology applications.

Sithole and Vosselman (2006) tested an automated method for detection of bridges. It is important to identify the bridges directly in the point cloud since some applications require that they be kept in, and others, that they be removed. The authors indicate that their algorithm is innovative since it is independent of bridge shape and can therefore adapt to different bridge designs. On all six study sites, the bridges were fully detected. However, the locations where the bridges begin and end as well as the access ramps were less well detected.

For rail-network mapping, Beger et al. (2011) used an approach combining aerial photography and very high-density lidar collected by helicopter to reconstitute a rail-network centreline of nearly 70 km. To do this, they used an object-oriented method of classification developed in the eCognition software. The classification results showed detection rates of 94% and 97% for the two study sites[7]. The approach encountered greater difficulty, however, on the edges of stations and platforms where several rail junctions are present and in places where rail cars are parked.

With respect to overpasses, Wang and Hu (2015) present a method for locating these in urban areas, directly in the lidar point cloud. At the outset, a region-growing algorithm was developed from initial points that spread to neighbouring points according to certain rules. A set of topological rules was developed to help locate overpasses. The main rules are as follows: 1) the points belonging to the overpass are above the ground but also have a connection with the ground, 2) the curves of the overpass are gradual and continuous, 3) the surfaces are smooth, and 4) the slopes are less than 9% (according to the standards for overpass construction in China).

Transport-infrastructure extraction tools

With respect to road transport-network extraction, there is currently no algorithm for automatic detection in residential or forest environments. This component is worthy of further research and development.

POWER-LINE EXTRACTION

Review of methods

Moderate potential

Commercial solutions available

Mixed results

Development efforts or further experimentation needed

Global Mapper

A significant number of flyovers have been done for the purpose of monitoring power lines. The literature is moderately abundant, and commercial software applications that incorporate features developed for power lines are available.

However, the extraction of power lines from lidar data in a general mapping context has not been carried out in a large number of studies. The flyovers presented in the studies focused only on the line right-of-way and the surrounding area. These flyovers do not cover as wide a variety of land-use classes as would a comprehensive flyover. In addition, a large number of studies have been carried out using very high-density point clouds obtained from helicopter flyovers.

It is possible that the complete operational application may encounter more problems than those described in the studies surveyed. It can therefore be assumed that the development efforts that will have to be invested in operationalizing power-line extraction are still significant. The potential of this application is certain, however.

When mapping power lines using lidar data, algorithms are able to obtain classification results above 90%. The catenary curve is frequently used to model the lines from towers. Some studies mention that small power lines in forest environments could also be mapped.

In Canada and the United States, major lidar flyovers along line corridors have been carried out to monitor thousands of kilometres of power lines. These flyovers are designed predominantly to model vegetation in the right-of-way, as well as hazardous trees.

Kim and Sohn (2011) obtained a classification result of 93% on two study sites. However, the towers of one of the sites were less successfully classified because they were the steel-lattice type.

[7]See footnote 1.

The study by Sohn et al. (2012) presents an approach for classifying power lines, towers, and buildings in the right-of-way surrounding a line. High-voltage lines were correctly classified 96% of the time and towers were correctly classified 100% of the time.

In their attempt to reconstitute a topographic sheet, Zhu and Toutin (2013) tested the mapping of individual electrical wires on towers. Some confusion persisted between forest objects and the lines. The classification result for power lines is 50%, which is the highest margin of error of all the classes investigated.

It is important to mention that in the studies by Kim and Sohn (2011) and by Sohn et al. (2012), the lidar point density was 30 and 15 points per m^2, respectively, and the flyover focused on a specific line corridor. The study by Zhu and Toutin (2013) mentions the use of data at a resolution of 1 m, which suggests a density of 1 to 4 points/m^2. In addition to the different methodologies, point density seems to be a crucial factor in the successful automated extraction of power lines.

Power-line extraction tools

Only one software system was tested for the generation of power-line images. It lets users extract power lines once the points are classified. The automatic land-classification feature was used. This method identifies the ground accurately and makes it possible to detect power-transmission lines. The tests carried out have helped raise certain issues, such as the strong presence of noise in the results and the existence of sections of truncated lines.

The tests carried out did not allow for the successful elimination of the multiple points located in the forest that were classified as power lines. In general, power lines are well identified, but holes are present in several places even though points classified as power lines are present. It should also be noted that the power lines are interrupted where there are towers.

Observations

Few software systems offer a feature that can be used to identify and vectorize power lines. Some solutions can be developed by programming, but these were not the subject of this study. The following conclusions may be drawn:

- the results require post-processing manual editing in order to obtain a satisfactory product;
- tall power lines are better detected that smaller ones. Depending on identification needs, the height of the object to be vectorized can be used to screen out undesirable objects;
- from initial startup, the software issued a notice that a very high point density must be used in order to generate a satisfactory result. Fragmentation in the lines can therefore be explained by the fact that the data set used had an average of 8.8 points/m^2.

Efforts could be invested in order to further automate the process, improve the algorithm, and enable the use of a lower point density. The majority of lidar applications designed to map power lines are developed for specific needs, typically in high-density areas, which is not the case for surveys carried out for less targeted purposes.

REFERENCES

Beger, R., Gedrange, C., Hecht, R., and Neubert, M., 2011. Data fusion of extremely high resolution aerial imagery and LiDAR data for automated railroad centre line reconstruction; ISPRS Journal of Photogrammetry and Remote Sensing, v. 66, no. 6, Suppl., p. S40–S51. https://doi.org/10.1016/j.isprsjprs.2011.09.012

Boyko, A. and Funkhouser, T., 2011. Extracting roads from dense point clouds in large scale urban environment; ISPRS Journal of Photogrammetry and Remote Sensing, v. 66, no. 6, Suppl., p. S2–S12. https://doi.org/10.1016/j.isprsjprs.2011.09.009

Ferraz, A., Mallet, C., and Chehata, N., 2016. Large-scale road detection in forested mountainous areas using airborne topographic lidar data; ISPRS Journal of Photogrammetry and Remote Sensing, v. 112, p. 23–36. https://doi.org/10.1016/j.isprsjprs.2015.12.002

Heidemann, H.K., 2014. Lidar base specification (ver. 1.2); U.S. Geological Survey Techniques and Methods, Book 11, Chapter B4, 67 p.

Kim, H.B. and Sohn, G., 2011. Random forests based multiple classifier system for power-line scene classification; The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, v. XXXVIII-5/W12, p. 253–258. https://doi.org/10.5194/isprsarchives-XXXVIII-5-W12-253-2011

Lindsay, J.B. and Dhun, K., 2015. Modelling surface drainage patterns in altered landscapes using LiDAR; International Journal of Geographical Information Science, v. 29, no. 3, p. 397–411. https://doi.org/10.1080/13658816.2014.975715

Poppenga, S.K., Worstell, B.B., Stoker, J.M., and Greenlee, S.K., 2009. Comparison of surface flow features from lidar-derived digital elevation models with historical elevation and hydrography data for Minnehaha County, South Dakota; USGS Scientific Investigations Report 2009–5065, 34 p.

Rottensteiner, F., Trinder, J., Clode, S., and Kubik, K., 2007. Building detection by fusion of airborne laser scanner data and multi-spectral images: Performance evaluation and sensitivity analysis; ISPRS Journal of Photogrammetry and Remote Sensing, v. 62, no. 2, p. 135–149. https://doi.org/10.1016/j.isprsjprs.2007.03.001

Sherba, J., Blesius, L., and Davis, J., 2014. Object-based classification of abandoned logging roads under heavy canopy using LiDAR; Remote Sensing, v. 6, no. 5, p. 4043–4060. https://doi.org/10.3390/rs6054043

Sithole, G. and Vosselman, G., 2006. Bridge detection in airborne laser scanner data; ISPRS Journal of Photogrammetry and Remote Sensing, v. 61, no. 1, p. 33–46. https://doi.org/10.1016/j.isprsjprs.2006.07.004

Smeeckaert, J., Mallet, C., David, N., Chehata, N., and Ferraz, A., 2013. Large-scale classification of water areas using airborne topographic LiDAR data; Remote Sensing of Environment, v. 138, p. 134–148. https://doi.org/10.1016/j.rse.2013.07.004

Sohn, G., Jwa, Y., and Kim, H.B., 2012. Automatic powerline scene classification and reconstruction using airborne LiDAR data; ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, v. I-3, p. 167–172.

Stanislawski, L.V., Buttenfield, B.P., and Doumbouya, A., 2015. A rapid approach for automated comparison of independently derived stream networks; Cartography and Geographic Information Science, v. 42, p. 435–448. https://doi.org/10.1080/15230406.2015.1060869

Tomljenovic, I., Höfle, B., Tiede, D., and Blaschke, T., 2015. Building extraction from airborne laser scanning data: An analysis of the state of the art; Remote Sensing, v. 7, no. 4, p. 3826–3862. https://doi.org/10.3390/rs70403826

Wang, Y. and Hu, X., 2015. Automatic extraction and topology reconstruction of urban viaducts from LiDAR data; The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, v. XL-3/W3, p. 131–135. https://doi.org/10.5194/isprsarchives-XL-3-W3-131-2015

White, R.A., Dietterick, B.C., Mastin, T., and Strohman, R., 2010. Forest roads mapped using LiDAR in steep forested terrain; Remote Sensing, v. 2, no. 4, p. 1120–1141. https://doi.org/10.3390/rs2041120

Zhu, X. and Toutin, T., 2013. Land cover classification using airborne LiDAR products in Beauport, Québec, Canada; International Journal of Image and Data Fusion, v. 4, no. 3, p. 252–271. https://doi.org/10.1080/19479832.2012.734339

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