HOW TO EVALUATE THE QUALITY OF AIRBORNE LASER SCANNING DATA

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ABSTRACT:

The discussion on the quality of digital elevation models form airborne laser scanner was dominated by the proof of vertical and horizontal accuracy. If the accuracy criteria were verified by ground control points, the evidence of high quality was produced. Based on experiences in projects for the Swiss Federal Office of Topography and according to the lidar requirements formulated by the US American Federal Emergency and Mapping Agency (FEMA) the interpretation of quality must change. Six different quality indicators are described as starting point for enhanced specification of laser data sets. Indicators are worthless if they do not contain a level of acceptance; for each indicator a proposal is discussed. With the help of the more precise requirements and specifications the quality evaluation is simplified. A common understanding of the quality between contractual partners is mandatory for efficient and effective lidar projects.

KURZFASSUNG:

Bei der Diskussion um Qualität von Digitalen Terrainmodellen aus flugzeuggestütztem Laserscanning wurde bis anhin der Fokus praktisch ausschliesslich auf die vertikale und horizontale Genauigkeit gelegt. Mit Erfüllen der Genauigkeitsforderungen galt ein DTM als ein Produkt von guter Qualität. Ausgehend von Erfahrungen in verschiedenen Projekten für das Schweizerische Bundesamt für Landestopographie und angelehnt an die Anforderungen der amerikanischen Federal Emergency and Mapping Agency (FEMA) wird der Qualitätsbegriff erweitert. Es werden sechs Qualitätsindikatoren beschrieben, welche die Basis für die Spezifikationen von Laserscanning-Daten bilden. Weiter wird für jeden Indikator ein mögliches Akzeptanzniveau beschrieben. Mit dieser präziseren Beschreibung von Anforderungen wird das Beurteilen der Qualität transparent gemacht und es wird sichergestellt, dass beide Vertragspartner die Laserscanning-Daten bei der Qualitätskontrolle gleich interpretieren.

1. INTRODUCTION

Laser scanning technology has been widely used to acquire date over large areas since about ten years. Main goal of most projects was deriving digital elevation and digital surface model (DEM and DSM). The technology offers short data acquisition time, highly detailed detection of the earth surface and the accuracy fits the needs of many applications.

Yet airborne laser scanning is considered as a new technique and many research activities are ongoing. While several researchers put their focus on improving the base techniques and on maturing the technology, the discussion about *quality* of the data is often reduced to accuracy. From an end user perspective, this cannot be the only criteria to test if the data fulfill the needs and expectations. This paper focuses on the topic quality evaluation (better quality management) in a more general context than in previous published papers (see chapter 2.2). The reason for this holistic approach lays in the missing precision of current project definitions in Europe (or the requests for proposal) which leads to misinterpretation, delays and high costs (for both customer and clients). The author proposes to adopt broader founded ideas from the US American Federal Emergency and Management Agency (FEMA) which are amended by ideas from the experience of producing several thousand square kilometers DEM and DSM for the Swiss Federal Office of Topography.

2. QUALITY MANAGEMENT

2.1 Common understanding

Before talking about quality, quality criteria, quality assistance or quality management (QM) we should have a look at the definition of the term quality. In ISO9000 (ISO, 2000) quality is defined as “degree to which a set of inherent characteristics fulfils requirements” or later stated more precise as “Customers require products with characteristics that satisfy their needs and expectations. These needs and expectations are expressed in product specifications and collectively referred to as customer requirements.” Kamiske and Brauer, 2003 mention eight dimensions of product quality we should keep in mind for further discussions: Fitness for use, configuration, reliability, conformance with standards, durability, customer, esthetics and quality image. eindeutig

To fulfill the demand of their clients, many companies built up a quality management system (QMS) according to ISO9000. While the standard describes general requirements, it is in the responsibility of the company to define the internal processes to meet the standard. The ISO9000 certificate gives therefore a kind of guarantee that the company established proven processes. Support processes and procedures to assure quality are also integral part of the QMS. When ISO9000 has been elaborated in the mid-eighties, the focus was put on the product quality (i.e. compare final product with the specification). But the practical experience showed that the best guarantee for error

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free products are well-proven and stable processes. One of the new ideas of the updated ISO9000 (since the edition from 1994) is thinking and acting process oriented. Part of this philosophy is the continuous improvement process, which means that every process does not follow a linear flow but must contain also a feedback loop. This loop goes back on the Deming's idea of *Plan-Do-Check-Act* (Deming, W.E., 1986). Note: the initiative to develop enhanced specifications is the result of an improvement process when working on large projects.

2.2 The geodetic perception

In geodesy, the term quality is mostly used synonymous to accuracy. Representative for other geodetic disciplines we refer to discussions in laser scanning. Various papers have been published with focus on quality of laser scanning data e.g. Ahokas et al., 2003; Maas, 2002 or Pereira and Wicherson, 1999. They all share the common understanding that the proof of quality is given when the criteria accuracy is fulfilled.

At least Kraus and Pfeifer, 1998 and Pereiera and Wicherson, 1999 mention the problem of inaccurate filtering of DEM (in forested areas) which results in low accuracy and therefore impacts the quality.

Evidence of accuracy is typically produced by either ground control points or by analyzing the overlap of flight strips as described by Filin 2003. Figure 1 shows the current understanding of the term quality. The hexagon symbolizes the entire product quality and the hatched area remains undefined/uncontrolled quality when using only accuracy.

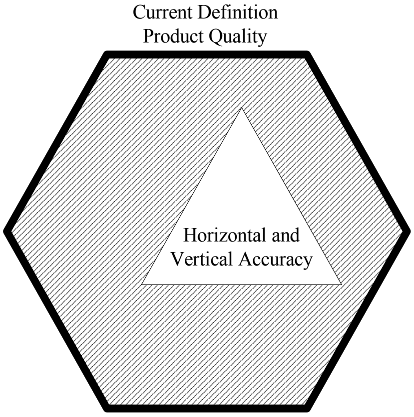

Figure 1. The current definition of quality

Surveying engineers have a high reputation if it comes to accurate and precise work. Typically this is achieved by redundant and independent measures. But the costs for aircraft, pilots and airborne laser scanners (or ‘lidar’) are extremely high that it is necessary to open the view and search for new approaches. From earlier mentioned dimensions of product quality we should have a closer look to these four points: fitness for use, configuration, reliability and conformance with norms. Durability, customer service, esthetics and quality image are of less importance in lidar data acquisition projects.

3. DEFINITION OF QUALITY OF LASER SCANNING DATA

3.1 Influences on the quality of laser data

After this general discussion on the term *quality* but before we start to discuss in detail specifications, it is worth to have a look on how the quality is influenced in a typical laser scanning project.

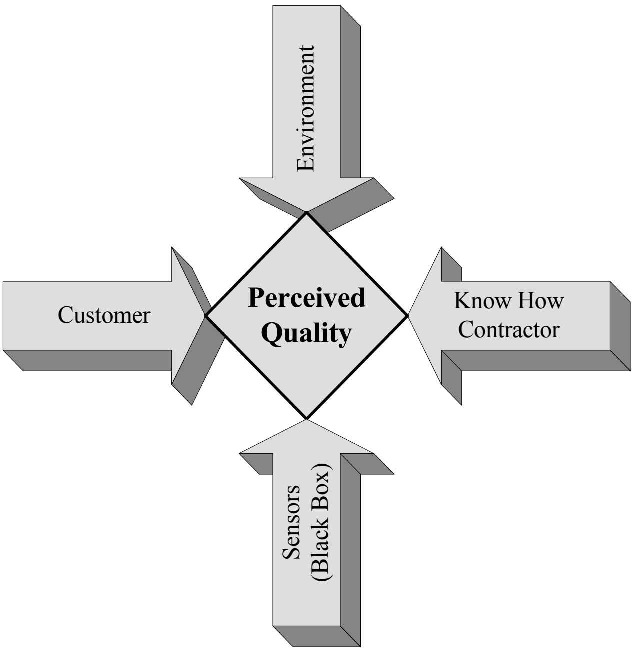

Figure 2. Main influence on the quality

The quality perceived from the client (or its users) is influenced by four domains: The client’s expectation should be reflected by requirements and specifications which are part of the project definition (the common visible part of the project definitions are the request for proposal–RFP). The purchaser has therefore a direct impact on the results: the more precise the specifications are written, the clearer is its expectation for the contractor and the easier is the verification of the data. The supplier on his side has the know-how about the processes for the production. Other influences come from the actual used technique (which are in this case the sensors of the lidar ‘black box’) and also from the environment conditions (e.g. topography, weather) which are out of the customer’s control.

Unfortunately, there is not yet a common understanding of lidar specification in geo-standards. Current definitions of ISO19113 (ISO, 2002) and ISO19114 (ISO, 2003a) do not cover lidar related issues. Due to this lack, most RFP’s - at least in the German speaking part of Europe – contain no other specifications than vertical and horizontal accuracy, average point density and the allowed time window for data acquisition (typically leaf off conditions or depending on water levels). Another reason for this minimal amount of specification is most likely caused by the difficulty of defining and controlling quality indicators for other criteria. While point density and accuracy can be easily verified by statistical methods, other criteria may only be proven by image *interpretation*. But this methodology does not coincide with the surveyor’s tradition of formulas and standard deviation.

3.2 Developing requirements and specifications

The process of specification-development starts with a detailed analysis of the needs and demands for the data set (see also Mikulski, 2001). Involved in this process are all the stakeholders of the project to make sure that the resulting functional requirements cover all requests from the applications which should be served by the new data. From the dimensions of product quality, this process should end in compliance with *fitness for use* and, in future, also *conformance with standards*. It ensures as well an optimum balance between amount of requirements and spectrum of applications. More requirements tend to increase the costs but more stakeholders to share them. It is recommended to have a lidar specialist to review the requirements.

In the next step, the functional requirements are refined to precise technical specifications. During this process, inconsistencies between requirements may be detected and resolved or eliminated (like flying in mountainous area under leaf off and snow free conditions). The review of the specifications through the stakeholders should also confirm that all the requirements are covered. It is recommended to make not only the specifications but also the requirements available to the supplier for a better understanding of the ideas behind the project.

The specifications can not only define product characteristics but also supporting processes, flight planning and flight, quality control, quality documents and deliverables.

As mentioned earlier, FEMA developed one of the most detailed standards for lidar data sets for the use in the Flood Mapping program. The documentations focus on this requirement and therefore do not cover any issues related with DSM. From Appendix A (FEMA, 2003a; FEMA, 2003b) are extracted the requirements exceeding current European philosophy. This list is amended based on the author's practical experience:

- *Flight planning*: An analysis of the project area, project requirements, topography, proximity to restricted air space, and other factors will determine the flight path configuration. The mission should include parallel flight lines and, for quality control purposes, at least one cross flight line.
- *GPS*: Maximum distance between rover and base station and the PDOP have a significant influence on the positioning accuracy and can be defined in the specification.
- *System calibration* includes repetitive flights over a calibration area under project conditions (i.e. flying height, lidar settings) and processing of the data to derive calibration parameters. The procedure should at least be performed once per project, for some projects this may happen on a daily base.
- *Data voids* are areas with no points, where multiple returns should have been measured, according to the requirements. Data voids can be caused by malfunction of the system or non-reflective surface (e.g. water, dark soil)
- *Artifacts* are regions of anomalous elevations or oscillations and ripples within the DEM data resulting from systematic errors, environmental conditions, or incomplete post-processing.
- *Completeness:* Besides the data voids it may be very important to have a certainty which objects can be detected by laser scanning. Small footprints may lead to incomplete detection of objects like tree tops (see Wack et al., 2003), power line or obstacles.
- *Steps* are areas with an abrupt change of height. Steps are typically seen between adjacent flight lines and are therefore caused by navigational data or poor calibration.
- *Product definition*: Depending on the functionality of the date, the products must be described as accurate as possible: e.g. point densities, accuracies, including or excluding breaklines, bridges for digital orthophoto (DOP) production (as required in RFP's in North Rhine-Westphalia).

The well defined specifications are a good base for the development of distinct quality indicators. Poorly described requirements tend to increase the risk in the project for both contractual partners: the clients will not get what they wanted, the supplier have to make assumptions which increase the internal costs for the project, if they not comply with the customers intention.

3.3 Quality planning

How can the supplier take advantage of clearer specifications? Once the extended version of specification is reflected by the work flows and the process description according to ISO 9000, the actual specification can be used to define the processes which are necessary for this project and which parameters must be considered in each process. For larger project it is recommended to compile a quality plan of QMS documentation which may be published on an intranet site. When gathering all relevant project information, the project leader has also to consider the potential risks and to prepare some work around for critical steps. This ensures that everyone involved in the project knows all the detail about it and is aware of difficulties whereby the risk of failures and errors decrease.

4. PROPOSAL FOR ENHANCED GUIDELINES

4.1 Functional Requirements

Analyzing some current RFP's, it seems like most of the projects focus on DEM and neglect the potential of the DSM data set. Taking into account the huge potential of DSM application, it is evident that the group of stakeholders shall be extended.

4.2 Technical Specifications

The points from technical specifications as listed in chapter 3.2 must be stated more precisely so that they contain wherever possible measurable indicators. For each criterion or combination of criteria the level of acceptance must be defined too. For the moment, the points *Flight Planning*, *GPS* and *calibration* are ignored not to narrow the supplier's standard processes unnecessarily. Insufficient care in these processes end in reduced accuracy which can easily be verified and demonstrated.

Product definition

Every application may have its specific requirement regarding content of a product. This should lead to generate one data set with different point classes. Depending on the actual application, one class or combinations of classes are extracted for further use. Here, a proposal of definitions is hinted:

- The class ground (DEM) contains all measures from bare earth. Constructions like sidewalks or tracks less than 50 cm higher than surrounding terrain can be considered as bare earth. Underpasses and access to subterranean garages may impact the water flow and must be stored in an own class. Whereas open pit mines and deposits have not to be processed (expect if these areas are the main topic of the survey).
- The DSM contains all permanent objects. Due to difficulties to distinguish certain permanent objects from non permanent and also due to potential high costs for a complete clean out of DSM there should be added some exceptions:
  Temporary objects like vehicle (esp. in urban areas), trains standing in stations, installations for fairs or markets, tents on campground and installations on construction sites may be part of the DSM.
  Conservatories, hot houses and similar construction on farms have to be eliminated from the DSM.
  Transmission lines or aerial passenger lines towers, flood light pylons or (radio-) antennas must be separated in an own DSM class.
  Aerial lines must be removed from DSM.
  Bridges are gathered in a separate class to facilitate, in combination with the DEM, data the production of digital orthophotos.
  Buildings and vegetation may be differentiated in two classes depending on the applications and financial resources.

Data voids

Talking about data voids, the product must be always part of the definition: In DEM, data voids may occur in forested areas due to dense canopy. The DSM may be accurate at this location. The situation is reversed in urban areas: building with none reflecting or mirroring roofs often cause data voids in the DSM, whereas the DEM quality is not influenced. The specification must be amended in following form:

- In the DEM, data voids may occur in areas with dense canopy (typically in conifer or rain forest), above water and on roads (this description can be found as well in Bavarian RFP's). If the area of one single void exceeds 5'000 m^2, terrestrial survey may be required.
- Data voids in the DSM point class may be accepted if not more than 2 % of the buildings of a town are missing. If the number is higher the supplier must inform the customer and other solutions may be agreed.
- Data voids must be documented and proved by the contractor with overlay from DOP or pixel maps.

Artifacts and Outliers

Artifacts in flat or slightly inclined areas (slope < 15 degrees) as single points or group of points < 5 m^2 are accepted, if the height difference to adjacent points is less than three times the required standard deviation.

In areas with slopes > 15 degrees, artifacts of single points or point groups < 15 m^2 are accepted, as long as the height different to adjacent points is less than six times the standard deviation and no other artifacts are within 50 m.

Completeness

99.5 % of the objects with a ground surface of more than four potential laser hits have to be detected and must be part of the DSM (per example: if the required point density is 2 pts/m^2 resp. 0.7 m point spacing the minimum demanded object size is 1.4 m*1.4 m = 2 m^2). The minimum height of these objects is defined by the required vertical accuracy.

Steps

The acceptable level of tolerance for steps depends on the required vertical accuracy. In flat areas (slope < 1 degree) even small steps impact the flood modeling. The height difference between the point levels therefore shall not exceed half of the standard deviation.

Summary

Even though this proposal covers only part of the actual user requirements, it describes quality indicators much more precise than before. These specifications contain also for each group measurable quantities to evaluate the quality of a data set. Now the definition of lidar quality has changed from original one attribute to a group of six (see Figure 3). All the postulated dimensions of product quality (also the conformance with standards as far as they have been developed) are now covered.

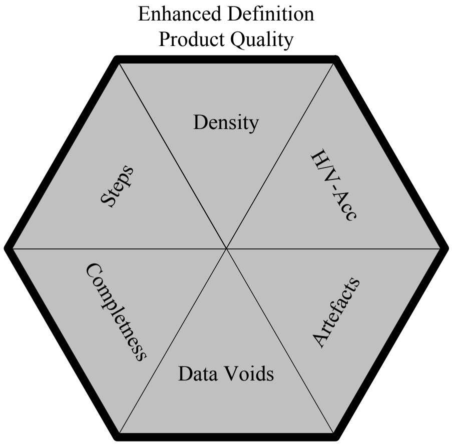

Figure 3. Six characteristics defining the lidar quality

4.3 Quality assurance und control

The quality assurance refines the quality plan with regard to when and where the data must be evaluated against the quality indicators. Some of the quality procedures are not new but well tested like checking PDOP values before taking off. Because the hitherto existing specifications have been much simpler, new quality controls must be introduced to make sure that the delivered and perceived quality is the same as the requested quality. Due to the high cost of airborne data acquisition, all sensors must be monitored in flight to react immediately in case of problems. Navigational sensors can now delivery indicators on reliability of the solution real time if set up as a centralized integrated solution (see also Jekeli, 2001). For the lidar points one could imagine that the measures are also compiled real time to a hillshaded image which helps the operator to detect e.g. malfunction of the system, data voids or the degree of penetration in forested areas.

For strip calibration and controlling of horizontal and vertical accuracies various tools or algorithms (e.g. Filin, 2003, (Latypov and Zosse, 2002) already exist.
To control the classification of the points, it is important to extend the automated checks (e.g. point density, GCP accuracy) with a set of visual representation (hillshaded DEM and DSM, slopes, density grids, difference grids). The more complex requirements are demanded, the more important is a set of current reference data like pixelmap, cadastral data or even capturing still images synchronous to the lidar points.
Because the exterior orientation is already given by the navigational solution, the imagery can be easily compiled to a DOP which offers up-to-date information of the situation and topography.

5. OUTLOOK

Most of the ideas presented in this paper are based on experience in various "real" projects and on the study of lidar related literature. As next step it is planned to discuss this proposal with various agencies or companies which already purchased lidar data. Also lidar suppliers and system manufacturer shall be interviewed.
Once the single parts of the specifications are discussed, amended and agreed a Software tool for lidar processing and checking should be developed. Part of the tool will also be the automated generation of Meta data according to the standard ISO 19115 (ISO, 2003b).

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