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Article

Automated Assessment of Digital Terrain Models Derived From Airborne Laser Scanning

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Keywords: Digital Elevation Models (DEM), laser scanning, quality, estimation

Summary: This paper presents the derivation of surface-related quality indicators describing the confidence-metrics of the final geo-products derived from airborne laser scanning (ALS). We first discuss the number of factors influencing the quality of the digital terrain models (DTM) and review the rigorous derivation of quality metric per each laser target when considering all the elements of direct-georeferencing as well as the scanning geometry. As in the context of DTM creation, however, the laser measurements are rarely used as single values; we extend this approach by considering other factors as classification, sampling density and interpolation. Further, we propose a novel procedure that enables an automated generation of a DTM quality map encapsulating all these factors assuming that the following conditions are fulfilled: i) the accuracy of each ground point involved in DTM generation is known or derived; ii) the DTM is represented as a regular grid where the elevation values are calculated by projecting the grid-cell centre coordinates on the corresponding facet of the TIN-model whose nodes are the irregularly sampled laser-points reflected from the ground. The derived DTM-quality map is thus influenced by the choice of grid resolution with respect to the actual density of the laser point-cloud, as well as the accuracy of individual laser returns. Finally, we present an example that demonstrates surface-quality map computed for an ALS point-cloud where the distribution of automatically classified ground points is very disparate and contains important gaps due to dense vegetation or insufficient surface-reflectance. We conclude with suggestions on possible applications of such quality-maps that can be associated as metadata to the DTM.

Zusammenfassung: *Automatische Qualitätsbeschreibung der Höhenmodelle aus luftgestützten Lasermessungen*. Dieser Artikel behandelt die Ableitung von Indikatoren zur Qualitätsbeschreibung von Höhenmodellen, die aus ALS-Daten abgeleitet wurden. Zuerst wird über die Anzahl der Faktoren, die die Qualität der Digitalen Geländemodelle (DGM) beeinflussen, diskutiert. Zudem wird eine konsequente Ableitung von einer Qualitätsmetrik, die die in die direkte Georeferenzierung einfließenden Fehlerquellen sowie die sich verändernde Messgeometrie berücksichtigt, überprüft. Weitere Begriffe wie Klassifizierung, Punktwolkendichte und Interpolation erweitern diese Metrik, da im Rahmen der DGM-Generierung die Lasermessungen nur selten als einzelne Werte betrachtet werden. Dann wird eine neue und automatisierte Erzeugung einer DGM-Qualitätskarte, die all diese Faktoren beinhaltet, vorgestellt. Voraussetzungen für diese neue Methode sind: i) Die Genauigkeit jedes einzelnen Punktes ist bekannt oder wurde abgeleitet. ii) Das DGM besteht aus einem regelmäßigen Gitter, in dem jeder einzelne Höhenpunkt mittels einer Projektion der Zellenzentrumskoordinaten auf die entsprechende Dreiecksfacette des unregelmäßigen Dreiecksnetzes berechnet werden kann. Das Dreiecksnetz ist auf die Bodenpunktwolke bezogen. Die abgeleitete DGM-Qualitätskarte wird somit durch die Gitterweite in Bezug auf die tatsächliche Dichte der Punktwolke sowie die Genauigkeit der einzelnen Laserpunkte geprägt. Schließlich werden einige Beispiele von Qualitätskarten präsentiert, die aus Bodenpunktwolken mit sehr unterschiedlicher Punktdichte und einige Lücken wegen dichter Bodenvegetation oder mangelndem Reflexionsgrad generiert wurden. Es wird mit Vorschlägen für mögliche Anwendungen solcher Qualitätskarten, die als DGM-Metadaten betrachtet werden können, abgeschlossen.

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1 Introduction

Airborne laser scanning (ALS) has become a well established and broadly employed technology in the mapping industry. The performance of the commercially available ALS systems is increasing at an astonishing pace, going hand in hand with the reduction in acquisition time and production cost. Surprisingly, the development of the software-tools accompanying data processing and quality monitoring has not followed. As the ALS technology requires concurrent employment of LiDAR and at least two navigation technologies, the generation of the laser point-cloud coordinates is relatively complicated, (Glennie 2007) while the subsequent classification and calculation of digital elevation models (DEM) is involved even more. Hence, the rigorous estimation of uncertainties or reliability parameters of DEM that shall consider the whole chain of treatment with a number of dynamically/time-varying parameters is reaching a great complexity, reason for which it has not been so far implemented into practice. Instead, the enterprises responsible for DEM creation are performing some alternative methods for quality assurance. These may be limited to a part of the processing, i.e. internal control between overlaps (Latypov 2002), or to specific section(s) of the model where external control is available (Csanyi & Toth 2007). As for the former, although sophisticated methods are available for parametrical adjustment (Kager 2004, Friess 2006), the estimated confidence-levels related to point-cloud or surface-patches are not utilized further in the DEM generation. The users of DEM have generally no access to the raw ALS observations and therefore may either assume a uniform precision (as provided) or attempt assessing DEM accuracy through independent means (Artuso et al. 2003, Hodgson & Bresnahan 2004). The later approach is almost always limited to parts of the model (larger or smaller) where external data are available as these come at additional cost.

The general term DEM encompasses digital surface models (DSMs) as well as digital terrain models (DTMs). Both DSM and DTM are interpolated from pre-classified and unorganized laser point-clouds. There exist many different interpolation techniques (Droj 2008). However, the most frequent approach is the generation of a TIN (2.5D triangulation) followed by a linear interpolation at a predefined planar cell-size (Fig. 1).

The accuracy assessment for DEMs may follow different approaches (Habib et al. 2009, Karel et al. 2006) but is often limited in practice to the collection of independent measurements at discrete points (ground check points) gathered within the survey area. Subsequently, the reference coordinates are compared to

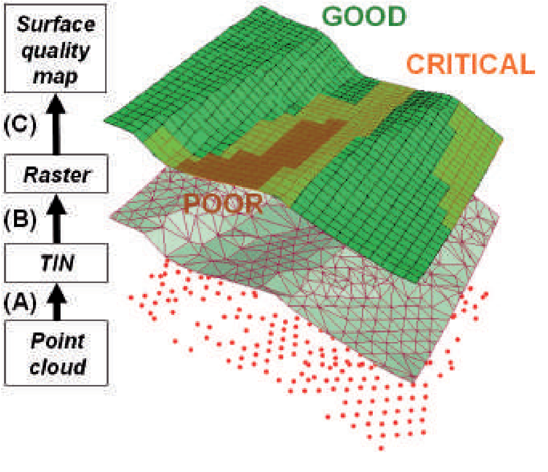

Fig. 1: Processing steps from raw point-cloud to surface quality map: (A) 2.5D triangulation, (B) Raster surface model by linear interpolation, (C) Surface quality map by point-to-surface error propagation.

the model elevations at the given location (e.g. Hodgson & Bresnahan 2004, Hyyppä et al. 2005). Such method has a major drawback in the fact that the estimated vertical accuracies cannot be generalized to the rest of the DEM. They remain highly correlated to the site conditions such as slope, undergrowth, and vegetation cover as well as the mission parameters such as employed technology, flying height, equipment, etc.. The controls utilizing independent airborne surveys, e.g. photogrammetry may be more sophisticated and robust (Höhle & Höhle 2009). Nevertheless, as good as they are, they apply only to the studied sample. Therefore, there is generally no guarantee that the estimated accuracy extends to all parts of the model.

Optimally, a DTM quality analysis should take into account the precision, absolute and relative accuracy of the initial sampling points. Hence, a quality measure should also consider the surface sampling variations (point density) and spatial distribution of the point accuracy. This study presents a novel procedure that enables the computation of height reliability indexes for each elevation of a DTM and the subsequent generation of a DTM quality map that encapsulates all important factors. The method requires that the two following conditions are met:

- Accuracy information for each ground point (represented by σ_x, σ_y, σ_z) involved in DTM generation is correctly determined and available. For a point-cloud generated by airborne laser scanning (ALS) the proposed procedure is that by (Schaer et al. 2007).
- The DTM is represented as a regular raster (Fig. 1) with the elevation values calculated by projecting the cell-center coordinates on the corresponding facet of the triangulated irregular network (TIN) whose nodes are the irregular sampled ground points as depicted (section 4).

The conditions of obtaining reliable estimate of σ_x, σ_y, σ_z for each ground control depend mainly on the reliability of trajectory estimation with GNSS/INS observation. The latter is strongly influenced by the (lack of) redundancy in satellite constellation (e.g. number of used satellite system, visible satellite vehicles and their geometry, recorded frequencies), number of base-stations and their separation as well as in inertial observation (e.g. redundant IMUs). Although such possibilities exist (Skaloud 2007), they are rarely exploited in practice and this theme is beyond the scope of this paper. Hence, depending on the actual observations and methods used for the trajectory determination, the required σ_x, σ_y, σ_z can represent either absolute or relative accuracies. In case of the latter, it is recommended to employ some of the previously mentioned methods utilizing 'ground-truth' as an external control (despite its limitation), otherwise the methodology presented in the following remains unaffected.

In the remainder of this paper, we first present a summary of factors influencing DTM accuracy (section 2). This analysis serves as a prerequisite for the subsequent layout of the presented estimation procedure that starts with the assessment of target accuracy (section 3). Afterwards, a methodology is portrayed that transforms the accuracy of individual targets within a laser point-cloud to a height reliability index of a DTM-raster (section 4). The algorithm for computing height reliability index for all raster cells for its representation as DTM quality map is listed in detail within section 5. Finally, two examples are given that explore the usage of DTM quality maps coded as metadata with the elevation-model (section 5).

2 Factors influencing DTM Accuracy

For the generation of DTMs from ALS data, the required processing steps, the associated error sources and the possibilities to estimate these errors can be summarized as follows (see Fig. 2):

- *Point-cloud creation*: The laser data and the trajectory are merged to obtain a point-cloud in a desired datum. The accuracy of the individual point can be assessed by single point error propagation (section 3), whilst the raw point density can be measured by a density map (Schaer et al. 2009)
- *Ground classification*: The density of the remaining ground points after classification has a very strong impact on the final

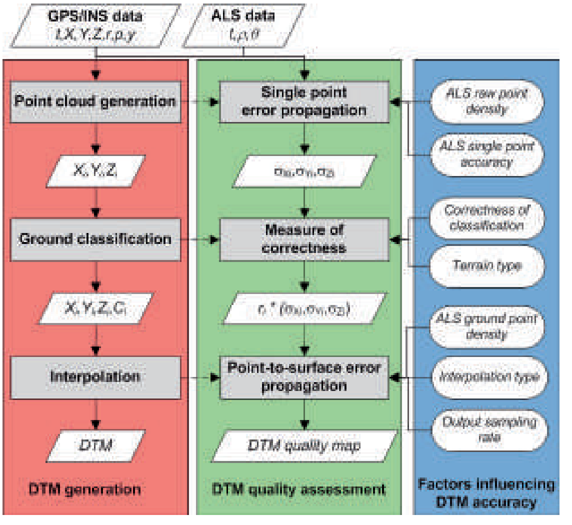

Fig. 2: General workflow for DTM production from airborne laser scanning with suggested quality indicators.

DTM quality. For example, Hyyppä et al. (2005) emphasizes the impact of vegetation on DTM accuracy, as dense canopy strongly degrades the ground penetration capacity of the laser beam. Therefore, independently of the applied classification algorithm, the density and spatial distribution of the ground points mainly depend on the topography and land cover of the scanned area. Another important factor is the correctness of the classified points. For instance, if only a single laser point situated on a tree is wrongly classified as ground point, this may influence the resulting DTM elevations over a large area. Ideally, the correctness of the classification should be measured by some sort of confidence factor r_i for each laser point. However, this remains a very challenging task, as actually no algorithm is capable of correctly classifying all points and deliver additional confidence information. Hence, the correctness of the ground classification is often controlled by visual inspection of the resulting surface.

- *Interpolation*: In the final step of DTM processing, the individual points are connected to a continuous surface function describing the elevation for each location within the perimeter. To correctly assess the influence of each laser point on the interpolated surface, the interpolation should ideally be accompanied by some point-to-surface error propagation process. This process should consider on the one side the input variance of the node points and on the other side the actual sampling density. The latter shall determine if the newly computed surface values are interpolated, i.e. the actual spatial-point density is higher than required by the model, or extrapolated, i.e. the actual spatial-point density is lower than required by DEM.

3 Assessment of Target Accuracy

In Schaer et al. (2007) we have suggested summarizing all components contributing to a single laser-return into a unique quality attribute. Such 'q-indicator' is constructed as accumulation of random errors coming from the error propagation of laser georeferencing equation and the analysis of scanning geometry. Fig. 3 depicts the workflow for this computation process.

Firstly, the error propagation is carried out using the navigation and laser-system data and their accuracy estimates. Secondly, the point-cloud is generated in an arbitrary mapping system, followed by spatial indexing. After the computation of the local normal vector and curvature for each point, the dataset is pre-filtered using local-covariance analysis, removing all points above a certain curvature threshold (Pauly et al. 2002). The next step performs the scanning geometry analysis, using the estimated local terrain normal, the laser direction and the beam divergence to compute the 3D footprint for the remaining laser points. Finally, the estimated effects of the scanning geometry (σ^2_{geom}) are combined with the previously estimated position-covariance (C_{nav}) to construct one unique quality indicator by (1) as suggested by Schaer et al. (2007). Thus, every laser point receives a separate q-indicator value that not only reflects the quality of georeferencing but also the scanning geometry.

$$q_i = \sqrt{\mathrm{trace}\left(C_{nav(xyz)_i}\right) + \sigma^2_{geom(x,y)_i} + \sigma^2_{geom(z)_i}} \quad (1)$$

As we have shown in Schaer et al. (2009), it is feasible to estimate such indicator directly in the flight when the real-time georeferencing is implemented. The subsequent classification process can also be automated as its possible imperfections have little influence on the estimated geometry of scanning. In off-line processing, however, more sophisticated as well as more computation-resources demanding classification algorithms can be applied. Their performance is mostly influenced by the terrain slope and the complexity of the scene as concluded in a comprehensive study conducted by Sithole & Vosselman (2004). Same report states that while most of the classification filters work well in gently sloped terrain with small buildings and sparse vegetation, in more complex scenes e.g. city-scapes with many discontinuities, the surface-based filters tend to provide better results. On the other hand, the correctness of vegetation classification improves substantially with the latest generation of the laser-scanners employing full wave-length processing (on-line or off-line). Nevertheless, the quality of filtering is difficult to quantify as it depends strongly on the processing experience and judicious choice of algorithms per terrain (and scanner) type. Therefore, we will assume in the sequel that the classification reliability is either homogenous, or can be expressed by a function of terrain type.

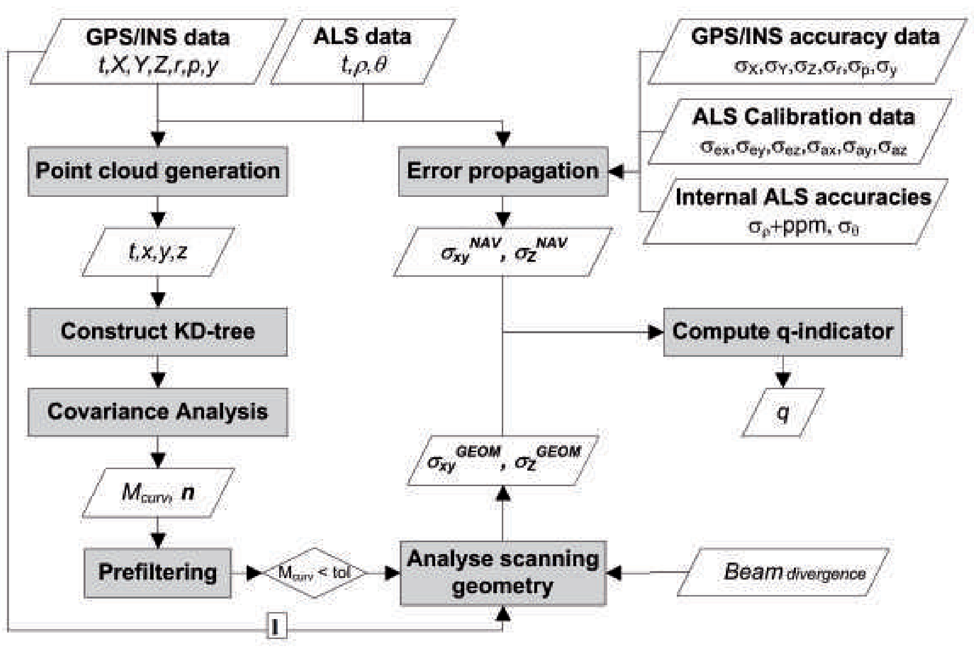

Fig. 3: General workflow for the computation of the q-indicator.

4 Computation of Height Reliability Index

This section describes in detail the procedure for the computation of DTM raster and DTM quality maps based on a point-cloud of known accuracy. We start with the linear interpolation of regular-grid (i.e. raster) elevations based on the triangulated surface (TIN), whose existence is the pre-requisite for the proposed methodology (section 1). An overview of techniques for constructing TIN from the individual points can be found, for instance, in El-Sheimy et al. (2005).

4.1 *Interpolation of Height*

Let us consider the plane equation (described by coefficients a, b, c, d) for a facet with nodes a, b, c of a TIN (Fig. 4):

$$ax + by + cz - d = 0, \text{where } \mathbf{n} = \begin{pmatrix} \mathrm{a} \\ \mathrm{b} \\ \mathrm{c} \end{pmatrix} = \begin{pmatrix} \mathrm{n_x} \\ \mathrm{n_y} \\ \mathrm{n_z} \end{pmatrix} \quad (2)$$

is the normal vector of the facet that can be computed from the node coordinates, coordinates $\mathbf{a}$ (x_a, y_a, z_a), $\mathbf{b}$ (x_b, y_b, z_b) and $\mathbf{c}$ (x_c, y_c, z_c) as:

$$\mathbf{n} = (\mathbf{c} - \mathbf{a}) \times (\mathbf{b} - \mathbf{a})$$

$$\begin{pmatrix} n_x \\ n_y \\ n_z \end{pmatrix} = \begin{pmatrix} (y_c - y_a)(z_b - z_a) - (z_c - z_a)(y_b - y_a) \\ (z_c - z_a)(x_b - x_a) - (x_c - x_a)(z_b - z_a) \\ (x_c - x_a)(y_b - y_a) - (y_c - y_a)(x_b - x_a) \end{pmatrix} \quad (3)$$

Using (2) first for evaluating d at the node $\mathbf{a}$ (i.e. $d = n_x x_a + n_y y_a + n_z z_a$), the height value z_i for a given 2D coordinates (x_i, y_i) can be again computed from (2) as:

$$z_i = \left(d - n_x x_i - n_y y_i\right) / \mathrm{n}_z \quad (4)$$

4.2 *Error Propagation*

Applying the law of error propagation to (4), the direct estimate of the elevation accuracy of z_i can be formulated such as:

$$\sigma_{z_i}^2 = \mathbf{f}_i \mathbf{C}_{ll} \mathbf{f}_i^T \quad (5)$$

where the vector $\mathbf{f}_\mathrm{i}$ can be constructed as the partial derivatives of (4) and the node coordinates:

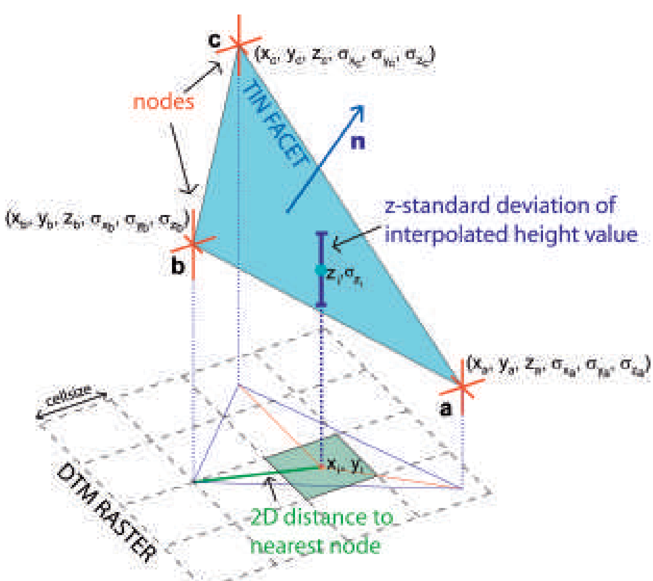

Fig. 4: Propagation of individual point errors to DTM height by TIN interpolation.

$$\mathbf{f}_i = \left[\frac{\partial z_i}{\partial x_a} \; \frac{\partial z_i}{\partial y_a} \; \frac{\partial z_i}{\partial z_a} \; \frac{\partial z_i}{\partial x_b} \; \frac{\partial z_i}{\partial y_b} \; \frac{\partial z_i}{\partial z_b} \; \frac{\partial z_i}{\partial x_c} \; \frac{\partial z_i}{\partial y_c} \; \frac{\partial z_i}{\partial z_c} \right] \quad (6)$$

The stochastic model $\mathbf{Q}_{ll}$ is constructed using the variance information for each node:

$$\underset{9\times 9}{\mathbf{Q}_{ll}} = diag\left[\sigma^2_{x_a} \; \sigma^2_{y_a} \; \sigma^2_{z_a} \; \sigma^2_{x_b} \; \sigma^2_{y_b} \; \sigma^2_{z_b} \; \sigma^2_{x_c} \; \sigma^2_{y_c} \; \sigma^2_{z_c} \right] \quad (7)$$

4.3 *Variance scaling*

Depending on the raster-cell size ($cell_{sz}$ in (9)), it can be determined whether the newly computed elevation value is based on interpolation or extrapolation. The Nyquist-Shannon sampling theorem states that if a function contains no frequencies higher than *f*, it can be completely reconstructed by points spaced ½ *f* apart. Adopting this theorem to DTM generation, it can be deduced that an original sampling of half cell-size is needed to correctly describe the terrain features of the given output frequency (in our case $cell_{sz}$). Accordingly, if a pixel centre coordinate is closer than $cell_{sz}/2$ to the initial node, the new value can be assumed as correctly interpolated. Hence, the terrain features at the output sampling rate are correctly represented. If the distance is larger than $cell_{sz}/2$, the height is supposed to be extrapolated. To incorporate this interpolation-extrapolation process into the DTM quality analysis, the 2D distance (d_{min}) of the pixel centre coordinates (X_i, Y_i) to the nearest node (see Fig. 4) is computed:

$$d_{min} = min\left\langle \Delta\mathbf{a}_{2D}, \Delta\mathbf{b}_{2D}, \Delta\mathbf{c}_{2D} \right\rangle$$

where

$$\begin{aligned} \Delta\mathbf{a}_{2D} &= \left\| x_i - x_a, y_i - y_a \right\| \\ \Delta\mathbf{b}_{2D} &= \left\| x_i - x_b, y_i - y_b \right\| \\ \Delta\mathbf{c}_{2D} &= \left\| x_i - x_c, y_i - y_c \right\| \end{aligned} \quad (8)$$

The d_{min} parameter is applied to scale the computed height accuracies by the factor *s* to produce a height reliability index r_z:

$$r_z = \sqrt{s\,\sigma^2_{z_i}} \begin{cases} s = \dfrac{d_{min}}{c} + 0.5, & \text{if} \quad d_{min} \le \dfrac{cell_{sz}}{2} \\ s = 2\dfrac{d_{min}}{c}, & \text{if} \quad d_{min} > \dfrac{cell_{sz}}{2} \end{cases} \quad (9)$$

Tab. 1: Computation algorithm for DTM quality map.

DTMQUAL

Require: *TIN* with n facets, list *FACET* (3 x *n*) with indexes of node points
Require: List *NODE* (6 x *m*) with m node points with coordinates (x_i, y_i, z_i) and standard deviation (σ_{xi}, σ_{yi}, σ_{zi})
Require: *DTM* and *DTMQUAL* with raster origin (X_{UL}, Y_{UL}), cell-size ($cell_{sz}$), and grid dimension (x_{dim}, y_{dim})
for *row* = *1* : x_{dim} **do**
  for *col* = *1* : y_{dim} **do**
    [X_i, Y_i] = *GetMapCoordinates*(*row, col,* X_{UL}, Y_{UL}, *c*) {Compute map coordinates corresponding to centre of raster cell *row, col*}
    n_i = *FindCorrespondingFacet*(*TIN,* X_i, Y_i) {find *TIN* facet that includes coordinates of cell centre}
    I = *FACET*[n_i] {extract indexes of node points **a**, **b**, **c**}
    for *k* = *1* : *3* **do**
      NodeCoordinates[*k*, :] = *NODE*[*I*[*k*], 1 : 3] {extract node coordinates [*x, y, z*]}
      NodeSTD[*k*, :] = *NODE*[*I*[*k*], 4 : 6] {extract node standard deviations [σ_x, σ_y, σ_z]}
    end for
    DTM[*row, col*] = *InterpolateHeight*(*NodeCoordinates*, X_i, Y_i) {apply eq. 4 to compute height value}
    DTMQUAL[*row, col*] = *ComputeHeightReliabilityIndex(NodeSTD,* X_i, Y_i, $cell_{sz}$*)* {apply eq. 5 to eq. 9 to compute height reliability index}
  end for
end for

5 Computation of DTM Quality Map

The process of computing the DTM quality map by extending the computation of height-reliability index to all cells is outlined by the pseudo-code listed in Tab 1.

Both, DTM interpolation and height reliability index computation are carried out in the same process for most optimal computation performance. The height reliability index r_z is computed for every grid cell of the DTM and is stored to a separate georeferenced raster called DTMQUAL in the pseudo-code.

6 Use of DTM Quality Maps

6.1 *Metadata Generation*

Fig. 5d shows such a quality map computed for an ALS point-cloud where the distribution of automatically classified ground points (see Fig. 5a) is very disparate and contains important data gaps, i.e. due to dense vegetation and water cover. The triangulation process is closing these data gaps (see Fig. 5b). In these areas, the derived DTM values (Fig. 5c) are distant from the initial node points. They cannot be considered as trustful as they are the result of an extrapolation process. Due to the scaling of the height variance ($\sigma_{z_i}^2$) yielding the height reliability index r_z (see (9)), the final quality map reflects (Fig. 5d) the reliability deterioration for such areas. The insufficient sampling density may be caused by flying parameters, e.g. large height or speed above the surface versus LiDAR pulse-repetition rate, or by poor surface reflectance. Obviously, there is a less of problem if the pulse absorption is caused by a water surface as this part of surface is essentially flat, see upper part of DTM, as compared to other material where height varies e.g. glacier, crops, and man-made surfaces. Such differences are visually apparent and their distinction can also be automated. Nevertheless, the water-surfaces were intentionally left in this example to highlight the influence of spatial sampling on the determination of the height-reliability index.

The visual inspection of the hill-shaded DTM (Fig. 5c) allows identifying several wrongly classified points that can be seen as single peaks in pyramidal form (marked yellow in figure). As the slope of these incorrect TIN facets is normally much steeper than the slope of their neighbours, the resulting height variance using (5) is much larger. This enables highlighting such areas of incorrectly classified points, as they appear as zones with decreased height accuracy (dark red). Accordingly, such quality maps can be employed as quality metadata associated to the DTM. Such metadata indicate areas where the DTM values are reliable and areas where they should be considered with precaution.

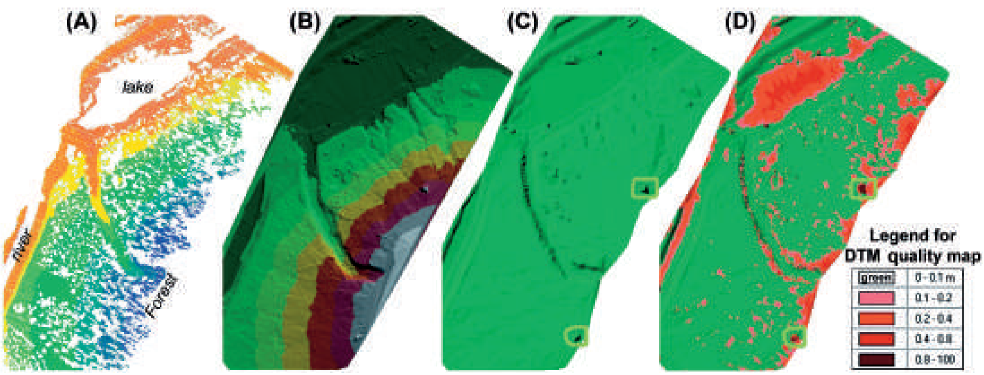

Fig. 5: (A) Automatically classified ground points colour-coded by elevation, (B) DTM-TIN, (C) DTM raster interpolated from TIN, (D) DTM quality map superposed on DTM colour-coded by index r_z (cells with $r_z < 0.1$ are transparent, i.e. correspond to the green-shaded surface).

6.2 *DTM Data Fusion*

The availability of a DTM quality map allows constructing weighting schemes for DTMs generated by merging data of different sources and accuracies e.g. Warnier & Mandlburger (2005). Merging two DTMs (DTM_1 and DTM_2) can be expressed as follows:

$$DTM_{12}[x,y] = \frac{w_1 \cdot DTM_1[x,y] + w_2 \cdot DTM_2[x,y]}{w_1 + w_2} \tag{10}$$

As shown in Fig. 6, the respective weights w_1 and w_2 for each position x,y are computed as the inverse of the squared DTM reliability index r_z (computed by (9)) values of the respective DTM quality maps ($QDTM_1$ and $QDTM_2$):

$$w_1[x,y] = \frac{1}{QDTM_1[x,y]^2}, \quad w_2[x,y] = \frac{1}{QDTM_2[x,y]^2} \tag{11}$$

Additionally, applying the laws of error propagation, the height accuracies of the merged rasters can be estimated. The values of the merged DTM quality map ($QDTM_{12}$) for a given location x, y follows from (10) and (11) by the law or error propagation and therefore can be computed via the following formula:

$$QDTM_{12}[x,y] = \sqrt{\left(\frac{1}{QDTM_1[x,y]^2} + \frac{1}{QDTM_2[x,y]^2}\right)^{-1}} \tag{12}$$

7 Conclusions

Despite the complexity of the airborne laser scanning, we are convinced of the feasibility of considering all the stochastic processes of the underlying technologies and estimating a reliability of the reconstructed DTM from the data itself. In this paper we have extended the previous research in assessing the accuracy of individual targets within a laser point-cloud. Applying the laws of error propagation we have combined these accuracies together with spatial distribution and presented a concept of a quality map that can be associated as metadata to the DTM. These quality maps indicate areas where the height values are reliable and areas where they should be considered with a precaution. These maps reflect the dynamic nature of the acquisition process and can be a valuable asset when estimating the accuracy of DTM derived quantities, i.e. slope, aspects. Moreover, the availability of such cellwise quality indicators allows constructing weighting schemes also for DTMs generated

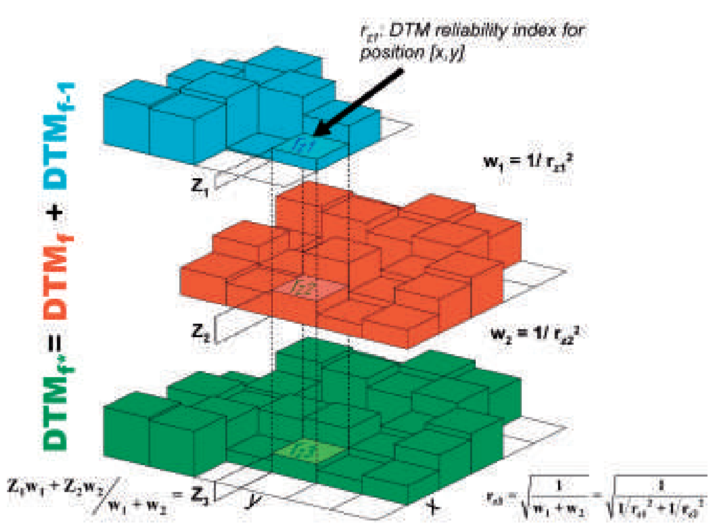

Fig. 6: Example for DTM grid merge weighted by DTM reliability index.

by merging data from different sources and estimating the accuracies of the results.

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