ALS Sensor Development
Chances and Challenges for DTM
Generation and Administration

Norbert Pfeifer
Gottfried Mandlburger
Christian Briese

Christian Doppler Laboratory
Spatial Data from Laser Scanning
and Remote Sensing

Outline

- Sensor developments – new data streams
- Raw data processing – extraction of information/data
- Administration of enriched data – setting a standard
- Exploitation of enriched data – improving automation, reliability, precision
Development in ALS Technology

- 1996/97 – 1pt/10m² – one echo / shot – Vienna Woods, first project @ I.P.F.
- now:
  - ~250kHz PRR (for oscillating mirrors: PRR = measurement rate)
  - Recording of first and last echo and possibly intermediate echoes
  - Recording of the intensity of the backscattered echoes
  - Flying heights up to ~6km
  - Ranging precision: ±2cm (vendor specification, 1σ, best conditions, only ranging!)
  - GPS frequency: 10Hz, IMU frequency: 2kHz
  - Multiple wavelengths …
  - Multiple emitted laser shots concurrently in the air …
  - Multiple laser scanners on one platform: downwards / sideways …
  - Forward, nadir, and backward looking in one laser scanner …
  - Full waveform recording …
  - Integration with other sensors: moderate

ALS Sensor development – multiple wavelengths

- LiDAR bathymetry
  - Green: better transmission in water
  - nIR: recording of topography and water top surface

- Satellite missions
  - nIR: ranging
  - Green: cloud studies
  - UV: atmospheric studies stronger molecular and aerosol scattering

- Terrestrial developments
  - 4 color prototype (e.g.), object studies, e.g. humidity, ranging possible (Wehr et al., 2007. Optical 3D Measurement Techniques, Zurich).
ALS sensor developments

- Multiple pulse in air
- Multiple laser scanners
- Multiple directions from one scanner
  multi-faceted mirror with different inclination angles

ALS Sensor development – Full Waveform

Laser-Footprint: $\varnothing \sim 0.2 - 3m$
Capturing the entire echo with a digitization intervall of $\sim 1$ ns
ALS Sensor development – Full Waveform

- Gaussian decomposition

Detection of echoes by
Fitting of Gaussians

⇒ Information per echo:

- Amplitude (Intensity) $P$ [DN]
- Range $R$ [m]
- Echo width $s_p$ [ns]

FWF Data

Range

Amplitude

Echo width

Cross-section
Best practice processing of ALS data with commercially available high-end sensors

- Aerial data acquisition → binary, vendor specific data
- FWF analysis → echo information: XYZ, range, echo number, echo width, amplitude, angles (not FWF) + cross section
- Strip adjustment with tie and control patches → update coordinates
- Radiometric calibration → update amplitude, cross section
- Filtering / classification → class ID per point (including probability measures)
- DTM computation, building reconstruction, …

Data Administration

- Current Status
  - Coordinates (point, multipoint, line, polygon, …)
  - Coding information (geometric type and semantic)
  - Metadata (owner, creator, accuracy, compilation date, …)
  - Missing: Additional point attributes

- Extended Administration Concept for Storage of LiDAR Data:
  - Storage of additional echo attributes (range, amplitude, echo width)
  - Storage of pulse emitting time for linkage with trajectory
  - Storage of return number of each echo enabling pulse-based or echo-based administration
  - Storage of cross section (object information without assumptions on the object)
  - Storage of class identifier
Table Definition for Full Wave Form LiDAR Data

<table>
<thead>
<tr>
<th>IDOBJ</th>
<th>INTEGER</th>
<th>UNIQUE INDEX NOT NULL</th>
<th>SYSNUM IDENTIFIER</th>
<th>GEOLOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATAFORMAT</td>
<td>CHAR(16)</td>
<td>INDEX NOT NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGGREGATE</td>
<td>CHAR(64)</td>
<td>INDEX NOT NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COORDINATES</td>
<td>MULTIPOLY</td>
<td>INDEX NOT NULL</td>
<td>PERIOD(3)</td>
<td>RESOLUTION(2,2,2)</td>
</tr>
<tr>
<td>OBJECTNAME</td>
<td>CHAR(16)</td>
<td>INDEX NOT NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OBJECTTYPE</td>
<td>CHAR(16)</td>
<td>INDEX NOT NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEATURECODE</td>
<td>CHAR(32)</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STATUS</td>
<td>CHAR(16)</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROJECT</td>
<td>CHAR(32)</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MODEL</td>
<td>CHAR(32)</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>XYACCURACY</td>
<td>NUMBER(12.2)</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZACCURACY</td>
<td>NUMBER(12.2)</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CREATOR</td>
<td>CHAR(32)</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OWNER</td>
<td>CHAR(32)</td>
<td>INDEX NULL ARRAY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMPILEMODE</td>
<td>CHAR(32)</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROPERTIES</td>
<td>CHAR(32)</td>
<td>INDEX NULL ARRAY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMPILEDATE</td>
<td>DATE</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMPILETIME</td>
<td>TIME</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INSERTDATE</td>
<td>DATE</td>
<td>INDEX NOT NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INSERTTIME</td>
<td>TIME</td>
<td>INDEX NOT NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPDATEDATE</td>
<td>DATE</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPDATETIME</td>
<td>TIME</td>
<td>INDEX NULL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
Selection Examples, TopDM

a: Point cloud (all echoes)
WHERE PULSETIME > 555675.5
AND PULSETIME < 555678.0

b: Selection by GPS time
WHERE ZENITHANGLE >= -1.5
AND ZENITHANGLE <= 6.5

c: Selection by zenith angle
WHERE AMPLITUDE > 75

Data: Leithagebirge, Lower Austria

FWF ALS data: exploitation for DTM generation

Aerial image

DSM

DTM – robust interpolat.

Amplitude

Echo width

DTM, only narrow ech´s
FWF ALS data: exploitation for DTM generation

- Exclusion of points with large echo width, hard classification

- Enhancement determine a-priori weights depending on echo width
DTM derivation from FWF ALS with robust interpol.

- Individual accuracy per point, reweighted by robust interpolation
- Enhancement in DTM computation

Conclusions

- FWF ALS data administration
  - proposal of a system
  - standardization beneficial (?)
- Exploitation of FWF
  - example: DTM
  - general information content not investigated
  - usability for standard products not investigated
  - new products …
ALS Sensor development – Full Waveform

- Emitted pulse
- Height distribution of objects
- Received echoes

Convolution

Cross section requires radiometric calibration
DTM derivation from ALS with robust interpolation

- Iteratively compute weights depending on distance of averaging DTM to points

\[
\begin{bmatrix}
C(P_1P_1) & C(P_1P_2) & \cdots & C(P_1P_j) & \cdots & C(P_1P_n) & 1 \\
C(P_2P_1) & C(P_2P_2) & \cdots & C(P_2P_j) & \cdots & C(P_2P_n) & 1 \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\
C(P_iP_1) & C(P_iP_2) & \cdots & C(P_iP_j) & \cdots & C(P_iP_n) & 1 \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\
C(P_nP_1) & C(P_nP_2) & \cdots & C(P_nP_j) & \cdots & C(P_nP_n) & 1 \\
1 & 1 & \cdots & 1 & \cdots & 1 & 0 \\
\end{bmatrix}
\begin{bmatrix}
\lambda_1 \\
\lambda_2 \\
\vdots \\
\lambda_i \\
\vdots \\
\lambda_n \\
-\mu \\
1 \\
\end{bmatrix}
= \begin{bmatrix}
Z_1 \\
Z_2 \\
\vdots \\
Z_i \\
\vdots \\
Z_n \\
\end{bmatrix}
\Rightarrow K \cdot \lambda = c
\]

- Enhancement determine a-priori weights depending on echo width

LIDAR Bathymetry

Range measurements through different media

Source: http://www.optech.on.ca
Using green lasers
(Technology extension)

- near IR: reflection on water surface
- green light: penetrates into the water

Depth: 3x Secchi depth
- attenuation (–)
- scattering (~)

flying height: 200m-500m
green diameter@water: 2m
green FoV: 15m
1000Hz

Proceedings, ROPME/PERSGA/IHB Workshop on Hydrographic Activities in the ROPME Sea Area and Red Sea, October 24-27, Kuwait City.

Returning waveforms of one shot
1ns quantization
Deep/Shallow green channels for bottom detection
Infrared channel for water surface detection
Raman channel (green excited) red emission for water surface detection
Tide corrected depth: 26.04m
Level 0, 1, 2, 3 vs. TopDM

- Level $i$ … description for satellite data products
  - 0: raw sensor data stream
  - 1: geo-physical quantities
  - 2: model-based derivations of level 1
  - 3: integrated with other sources

- TopDM
  - Data imported after
    - fine georeferencing
    - echo analysis
  - … Level 1
  - augmented by
    - cross section computation with emitted pulse shape assumption
    - classification
  - … Level 2

Kriging/Linear Prediction with individual a-priori weights

\[
\begin{bmatrix}
C(P_1 P_1) & C(P_1 P_2) & \cdots & C(P_1 P_n) \\
C(P_2 P_1) & C(P_2 P_2) & \cdots & C(P_2 P_n) \\
\vdots & \vdots & \ddots & \vdots \\
C(P_n P_1) & C(P_n P_2) & \cdots & C(P_n P_n)
\end{bmatrix}
\begin{bmatrix}
\lambda_1 \\
\lambda_2 \\
\vdots \\
\lambda_n
\end{bmatrix}
= 
\begin{bmatrix}
Z_1 \\
Z_2 \\
\vdots \\
Z_n
\end{bmatrix}
\Rightarrow 
K \cdot \lambda = c
\]
Kriging/Linear Prediction with individual a-priori weights and additional slope observations

\[
\begin{pmatrix}
C_z(P_1P_1) & \cdots & C_z(P_1P_2) & C_z(P_1N_1) & \cdots & C_z(P_1N_m) & 1 \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots \\
C_z(P_nP_1) & \cdots & C_z(P_nP_2) & C_z(P_nN_1) & \cdots & C_z(P_nN_m) & 1 \\
\frac{\partial C_z(N_1P_1)}{\partial t_1} & \cdots & \frac{\partial C_z(N_1P_2)}{\partial t_1} & \frac{\partial C_z(N_1N_1)}{\partial t_1} & \cdots & \frac{\partial C_z(N_1N_m)}{\partial t_1} & 0 \\
\vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots \\
\frac{\partial C_z(N_mP_1)}{\partial t_m} & \cdots & \frac{\partial C_z(N_mP_2)}{\partial t_m} & \frac{\partial C_z(N_mN_1)}{\partial t_m} & \cdots & \frac{\partial C_z(N_mN_m)}{\partial t_m} & 0 \\
1 & \cdots & 1 & 0 & \cdots & 0 & 0
\end{pmatrix}
\begin{pmatrix}
\alpha_1 \\
\vdots \\
\alpha_m \\
1
\end{pmatrix}
\]

Robust Interpolation with a self adapting asymmetric weight function
Diskrete Echo vs. Full-Waveform ALS Systeme

Zusätzliche Kenngrößen pro detektiertem Echo

Echo Parameter:
- Distanz $R_i$
- Amplitude $A_i$
- Echo weite $EW_i$
- Cross section $\sigma_i = C_{cal} * R_i^{4/3} * A_i * EW_i$
- $\sigma_R$
- ...?
ALS Leithagebirge - Luftbild

ALS Leithagebirge – DOM (first Echo)
ALS Leithagebirge – DGM (SCOP++ (HRI))

ALS Leithagebirge – Amplitude
ALS Leithagebirge – Echoweite

ALS Leithagebirge – DOM (first Echo)
Verbesserte DGM Erstellung unter der Berücksichtigung der Echoweite

ALS Leithagebirge – DGM (SCOP++ (HRI))
Verbesserte DGM Erstellung unter der Berücksichtigung der Echoweite