Characterizing Braided River Morphology and Kinematics with Terrestrial Laser Scanning

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River Feshie, Cairngorm Mountains

- Scottish Highlands
- Wandering, weakly braided gravel-bed river
- Armoured gravel-cobble sized bed
- Since 1998 …
- Repeat topographic survey and hydrometric monitoring
- Patterns/controls on morphodynamics
- Methods for sediment budgeting
- Model parameterization and validation
Transient flow simulation through a 1m resolution DEM of a complex braided river represented as a series of steady state solutions
Topographic Survey

- Digital Elevation Model (mesh) interpolated from ground survey observations

29,000 survey observations
Acquired using RTK GPS
A ‘Decade’ of Technological Progress

Before 1995
10-100 pts
Cross-sections

From 1995
1,000-100,000 pts
Manually-sampled Distributed Survey

Since 2000
+ 1,000,000 Distributed Survey
Terrestrial Laser Scanning

- New generation of tripod-mounted, ruggedized laser scanners
- Pulse-based, time-of-flight laser distance ranging
- 6-12 sec angular resolution
- 4-40 KHz Sampling rate
- 250-350 m range
- Generate 3d xyz point cloud data
- 1000,000,000 pts

LEICA GEOSYSTEMS SCANSTATION
Opportunities

- High sampling rate
  - Rapid survey acquisition times

- Dense spatial sampling
  - Previously unachievable sampling density over scalable over large areas

- Precise individual measurements
  - ~total station quality (2-4 mm)

- Non-invasive
  - Observation and recording without interference

- Fully 3D datasets
  - cf single perspective airborne lidar
Examples of TLS Applications & Models

- **Novel Characterization**
  - Deterministic grain-scale/patch scale surface models
  - Flow resistance in the fluvial systems

- **Change Detection**
  - Monitoring the evolution of fluvial and estuarine morphologies

- **Flood Modelling**
  - Refined boundary models and visualization
Scale-Free Models

- Sampling rate enables landform recording at scales from the grain up to the reach in one single, integrated dataset.

- Morphological models constructed at the scale of the primary building blocks of the fluvial system.
Challenges

• **Managing & modelling large datasets**
  – Efficient computational engines to explore and characterize point clouds

• **Managing scan artefacts**
  – Automatic identification & removal

• **Vegetation removal or modelling**
  – Identification of ground points

• **Subaqueous survey**
  – Laser not water penetrating

• **Representing 3D landforms**
  – 3D cf 2.5D models
  – Automated complex meshing from sparse point cloud data
Feshie 2006-2007

- Target reach ~ 1 x 0.3 km
- 90% exposed at low-flow

**Aims:**
- Methodological sensitivity of DEM differencing
  - Scale, density, interpolator
- Sub-bar scale morphology and evolution
  - Organization of particle clusters, chute development
- Retrieval of 3d surface roughness and facies mapping
  - Flow resistance and grain sorting patterns
Field Data Acquisition

- Scanner deployed at 18 sites
  - Mean separation 80 m
- Sampling resolution 15 mm at 30 m
- 37 targets; GPS-positioned
- Scan times ~ 1-1.5 hours

Also
- Standard GPS survey
- Ground-level oblique and low-altitude blimp photography
- Roughness profiles and grain-counts
Scan Registration

Scans registered to a geodetic coordinate system using a combination of:

Least-squares bundle adjustment based on 37 targets
Cloud-Cloud fitting
Feshie 2007

> 250,000,000 xyz
Photorendered point cloud

Density (median) =
~1400 pts/m²

> 250 coincident tie-points

**RMSE:**
Control = 7 mm
Check = 8 mm
Surface Modelling

- High data volumes ~ 9 Gb uncompressed ASCII
  - Intelligent decimation before interpolation
  - Sub-grid data recovery and representation

- Filtering toolbox: extract statistical representation of the point cloud at multiple spatial scales

- Grid (2d) or volexate (3d) point cloud
- Zmin, Zmax, Zrange, \( n \)
- StDev (\( \sigma \)), Detrended StDev (\( \sigma_d \))
DSMs and DEMs

Zmax ~ Elevation of surface objects (vegetation)
Zmin ~ local bed level
2.5d models
DEMs of Difference

A

Gross Distribution: 2007-2006

Total Area of Erosion: 65791.0 m²
Total Area of Deposition: 45214.0 m²

Elevation Change (m)

Area (m²)

B

Total Volume of Erosion: 15317.1 m³
Total Volume of Deposition: 8196.9 m³
Net Volume: 7126.2 m³

Elevation Change (m)

Volume (m³)

DoD

High : 1.5
Low : -1.5
0 25 50 100 Metres
Budget Sensitivity

- **2007-2006**

- **GPS**
  - 11,130 m$^3$ Erosion
  - 8,668 m$^3$ Deposition
  - Balance = -2,262 m$^3$

- **TLS**
  - 15,317 m$^3$ Erosion
  - 8,191 m$^3$ Deposition
  - Balance = -7,126 m$^3$

- **315% bias**
Retrieval of Surface Roughness and Facies Maps

Local topographic shows first order correlation with vegetation cover
‘Roughness’ Retrieval

- $\sigma_d$ topographic metric describing bed roughness and flow resistance
- Extracted from profiles or patch scale models
- TLS provides reach-scale mapping which correlates well with profile based assessment and maps to $D_{50}$ and $D_{84}$
Reach-Scale Facies Maps

AP 2007

2007

2006

AGU 2007
Conclusions

- Enormous potential offered by TLS and new modelling methodologies

- As *geomorphologists* we now have a tool that enables the creation of …

  ‘virtual facsimilies’ of earth’s surface

- The challenge now is to turn …

  *Floods of data into Oceans of information*