Real-time Change detection using Laser Scanning and GNSS
Real-time Networks
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Project Team Members

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  - Matthew Mabey (ODOT Research Coordinator)
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Civil Engineering (geomatics and geotechnical) and Computer Science
Geomatics at OSU

- Growing graduate program (3MS, 1 MENG, 4 PhD)
- Recent strategic partnership with Leica Geosystems and David Evans and Associates
- Students in UG program eligible to sit for FS and FE exams.
- GPS is used in just about every geomatics course!

- New Courses
  - Digital Terrain Modeling
  - 3D laser scanning
  - BIM
Research Overview

• Change detection is a topic of intense interest in many fields

• Current workflows for TLS require post-processing

• Monitoring infrastructure is critical to public safety and economic operation.
Research Objectives

1. Obtain time-series data from multiple sites
2. Develop an in field change detection algorithm
3. Increase understanding of geologic processes
4. Improve efficiency and quality of 3D surveying
5. Improve ODOT’s allocation of resources
6. Expand ODOT capacity for 3D technologies
Anticipated Usage

1. Rapid feedback for remediation and mitigation measures effectiveness.

2. Better prediction of infrastructure impact zones by improving the means to detect landslide movement prior to failure.

3. Greatly increase spatial information available to policy makers.
Terrestrial Laser Scanner Components

- Camera
- GNSS Receiver
- USB Data Storage
- 3D Laser Scanner
- GNSS Controller
- Power Supply
- Tripod
Field Setup Mobile
Traditional Methodology

1. Laser scan and control data (GPS, total station, etc.) are collected in the field

2. Data processing is performed in the office
   • Time intensive process (hours, days, weeks)
   • Labor and equipment intensive
   • Must process all data collected

3. Analysis of the data is performed in the office
   • Analyses delayed until after data are processed
   • Delays discovery and usefulness of “interest” areas
New Methodology

1. Laser scan and GPS data are collected in the field

2. Data processing is split between office and field
   • Introduce automation of some features
     • Geo-referencing (GPS, inclination, digital compass)
     • Visual quality control of new scans (e.g. GPS & alignments)

3. Change analysis possible immediately in the field
   • Surface comparison for change detection
   • Evaluate coarse scan and rapid GPS -> re-scan specific areas as needed

4. More efficient use of data for post-processing
   • Collect detailed, higher resolution scans where needed
   • Reduces redundant data collection
   • Data already geo-referenced
**Lichen (LiDAR Change Engine)**

**Lichen Workflow**

**Baseline Creation Process**
- Field Scanning
  - Goe-reference & align scans
    - Edit, clean, & filter data
    - 3D Triangulation
    - Q/C Check

**Real Time Analysis**
- Coarse resolution scan
  - Geo-reference & azimuth correction
  - Change detection algorithm
  - Q/C Check
    - Significant change
      - Determine re-scan extents
  - No Change
    - Move to next setup
    - High resolution scan

*V1.0  8.24.11*
**Lichen - Features**

1. Simple – Intuitive GUI

2. Fast – Less than a minute for file conversion, geo-referencing, and change analysis of a scan

3. Portable – Implementable from a netbook

4. Flexible - May be used with GPS or control points (monitoring projects)

5. Modular – Setup so that a controller can be integrated from any manufacturer (pending manufacturer SDK availability)

6. Small and lightweight – (<30MB for all components)
Drive VZ400 GUI and Output
Geo-referencing

6 DOF

- GPS coordinate (from ORGN) at each scan location (trans X,Y,Z)
- Dual Axis Tilt/Level Compensator (rotation X,Y)
- Digital compass reading or back-sight (~ rotation Z)
- Software alignment to correct for backsight error (rotation Z)
Correct GPS data for unlevel setup

\[
\begin{bmatrix}
\Delta X \\
\Delta Y \\
\Delta Z
\end{bmatrix} = R \begin{bmatrix} 0 \\
0 \\
-(H + h) \end{bmatrix}
\]

\[
R(\alpha, \beta, \gamma) = \begin{bmatrix}
\cos \beta \cos \gamma & \cos \alpha \sin \gamma + \sin \alpha \sin \beta \cos \gamma & \sin \alpha \sin \gamma - \cos \alpha \sin \beta \cos \gamma \\
-\cos \beta \sin \gamma & \cos \alpha \cos \gamma - \sin \alpha \sin \beta \sin \gamma & \sin \alpha \cos \gamma + \cos \alpha \sin \beta \sin \gamma \\
\sin \beta & -\sin \alpha \cos \beta & \cos \alpha \cos \beta
\end{bmatrix}
\]

H = antenna height to ARP
h = phase offset
Aligned only using estimated backsight

- Seawall Misaligned
- Building Misaligned
- Stairwell Misaligned

Blurry Appearance
Least squares solution

Formulation:

\[
\begin{pmatrix}
  v_{x1} & v_{y1} \\
  v_{x2} & v_{y2} \\
  \vdots & \vdots \\
  v_{xn} & v_{yn}
\end{pmatrix} = \begin{pmatrix}
  x_{B1} - X_{B0} & y_{B1} - Y_{B0} \\
  x_{B2} - X_{B0} & y_{B2} - Y_{B0} \\
  \vdots & \vdots \\
  x_{Bn} - X_{B0} & y_{Bn} - Y_{B0}
\end{pmatrix} \begin{pmatrix}
  \cos \alpha_B & \sin \alpha_B \\
  -\sin \alpha_B & \cos \alpha_B
\end{pmatrix} + \begin{pmatrix}
  X_{B0} & Y_{B0} \\
  X_{B0} & Y_{B0} \\
  \vdots & \vdots \\
  X_{B0} & Y_{B0}
\end{pmatrix} - \begin{pmatrix}
  x_{A1} & y_{A1} \\
  x_{A2} & y_{A2} \\
  \vdots & \vdots \\
  x_{An} & y_{An}
\end{pmatrix}
\]

Sum of the squares of the errors:

\[
V_{SS}^2 = v_{x1}^2 + v_{y1}^2 + v_{x2}^2 + v_{y2}^2 + \cdots + v_{xn}^2 + v_{yn}^2
\]

Minimizing the sum of the squares of the errors:

\[
\frac{\partial V_{SS}^2}{\partial \alpha_B} = \frac{\partial v_{x1}^2}{\partial \alpha_B} + \frac{\partial v_{y1}^2}{\partial \alpha_B} + \frac{\partial v_{x2}^2}{\partial \alpha_B} + \frac{\partial v_{y2}^2}{\partial \alpha_B} + \cdots + \frac{\partial v_{xn}^2}{\partial \alpha_B} + \frac{\partial v_{yn}^2}{\partial \alpha_B} = 0
\]

Solution:

\[
\alpha_B = -\tan^{-1}\left( \frac{\Delta y}{\Delta x} \right) = -\text{atan2}(\Delta x, \Delta y)
\]

\[
\Delta y = \sum_{i=1}^{n} x_{Ai} y_{Bi} - \sum_{i=1}^{n} y_{Ai} x_{Bi} + y_{B0}(\sum_{i=1}^{n} x_{Bi} - \sum_{i=1}^{n} x_{Ai}) + x_{B0}(\sum_{i=1}^{n} y_{Ai} - \sum_{i=1}^{n} y_{Bi})
\]

\[
\Delta x = \sum_{i=1}^{n} x_{Ai} x_{Bi} + \sum_{i=1}^{n} y_{Ai} y_{Bi} - y_{B0}(\sum_{i=1}^{n} y_{Ai} + \sum_{i=1}^{n} y_{Bi})
\]

\[
x_{BO}(\sum_{i=1}^{n} x_{Ai} + \sum_{i=1}^{n} x_{Bi}) + n(y_{BO}^2 + x_{BO}^2)
\]
Aligned only using estimated backsight

- Building Misaligned
- Seawall Misaligned
- Stairwell Misaligned

Blurry Appearance
Aligned by PointReg
Unconstrained Software Alignment

Origin Displacement Error (m)

-8
-7
-6
-5
-4
-3
-2
-1
0
100
200
300
400
500
600
700
Distance from center scan (m)

- Easting (X) Error
- Northing (Y) Error
- Elevation (Z) Error
- Total Error
**Change Detection Algorithm**

1. Create hash table for baseline cloud (on load)  
   -> assign points to cube grid based on XYZ location
2. Import subset of new scan
3. Find distance to closest points from new scan to base scan  
   i. Search in cube  
   ii. If not found, search next cube
4. Color code based on distance (min, max thresholds)
5. Display colored results to user
Research Sites

1. Geomatics Lab (OSU)
2. Geotechnical testing Berm (OSU)
3. Beverly Beach/Johnson Creek Landslide
4. Pioneer Mountain Eddyville (US-20)
5. MSE Wall
Research Sites – Pile Testing Berm (OSU)
High resolution (0.030 degree) baseline scan taken the day of testing. For monitoring projects, post-processing may be skipped (not optimal). Total pile displacement was 10 inches.
Pile Testing Berm – Monitoring Test

- Disturbance from people walking on slope
- Pile Displacement
- Soil failure
Pile Testing Berm – Monitoring Test
Research Sites – Beverly Beach/Johnson Creek Landslide

Point Cloud to 3D mesh for a section of Beverly Beach
Research Sites – Johnson Creek Landslide

Examples of point clouds and their respective 3D triangulated meshes.
Geo-referencing and aligning a new scan to the baseline model in *Lichen*.
Site Test – Johnson Creek Landslide

Change detection in the field of the new scan (August 2011 compared to baseline model (December 2010).
Change analysis between LiDAR surveys showing advance and retreat of the cliff face at the North Section (Northing 4,954,580 m to 4,954,650 m).
Conclusions

1. Developed software that provides immediate, visual results to field crews and researchers.

2. Enabled real-time change detection for TLS systems
   a) Non-fixed position (e.g. GPS)
   b) Fixed position monitoring (e.g. control points)

3. Improved field data collection
   a) Reduced redundant data collection & processing
   b) Minimal impact to field times implementing methodology

4. Provided users with in-field quality control over new data
Importance of GPS real-time network technology

1. Need fast, accurate positioning information

2. Each overview scan is approximately 2 minutes

3. Sites can change substantially (e.g. Johnson Creek landslide) so survey control is unstable

4. Limited low-tide window on coast

5. Helps keep each survey independent

6. Limited field crew, resources, and survey control
Foreseeable Applications

1. Landslide hazard analysis

2. Coastal region monitoring projects

3. On-site monitoring of construction progress

4. Quality Control
   a) As-built
   b) 3D design to manufactured comparison

5. Disaster & Hazard Monitoring
   a) Collapsed buildings/Rescue scenarios
   b) Remediation & cleanup
Current and Next Steps

1. Report Feedback & Modification

2. Improve *Lichen*
   a) Modify monitor file sizes
   b) Direct link to GPS data
   c) Improve customization options
   d) Increase functionality of distance & color scaling
   e) Compare additional change algorithms\evaluation. Potentially include open source versions

3. Incorporate user feedback & requests where possible

4. Disseminate findings and software
Special Thanks