Measuring the potential impact of offshore mining on coastal instability through integrated time-series laser scanning and photography

by Roberto Vargas, 3D Laser Mapping
SINCE 1999
OVERVIEW

• SLOPE STABILITY MONITORING

• WHITBY COASTAL MONITORING – A CASE STUDY

• CONCLUSIONS
SLOPE STABILITY MONITORING
WHAT IS SITEMONITOR4D?

- Integrated platform for automated capture and analysis of 3D laser data of unstable slopes
- Traditionally supported terrestrial laser scanners but moving towards mobile laser scanner support
WHAT IS SITEMONITOR4D?

- **Capture repeated Laser Measurements through time to measure rates of movement**
- **Identify areas that have moved – take action**

Capture point cloud 1

Time interval

Capture point cloud 2

Change detection map

Subtract point cloud 1 from point cloud 2
SITEMONITOR4D

- **System Architecture**
SITEMONITOR4D

- **TYPICAL INSTALLATION**
SITEMONITOR4D

- **Analysis Results – Landslide 1 Metre Movement Year**
SITEMONITOR4D

- ANALYSIS RESULTS – WEDGE FAILURE 4 METRE MOVEMENT IN 9 MONTHS
WHITBY COASTAL MONITORING

IN COLLABORATION WITH DURHAM UNIVERSITY
WHITBY COASTAL MONITORING

- **Multi-year project looking at coastal slope instability in North East England**

- **Research led project exploring capabilities of LiDAR technology for slope stability assessment**

- **Developing new systems and techniques for automated slope monitoring**

- **Capturing data over a range of spatial and temporal scales**

- **Integrating both terrestrial and mobile laser scanning with imagery**
WHITBY COASTAL MONITORING

- **Location** – Whitby England
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BUT THERE IS A PROBLEM.................
WHITBY COASTAL MONITORING
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• IN GRAVE PERIL: HUMAN BONES RAIN DOWN ON HOMES AFTER LANDSLIDE AT ‘DRACULA’ CHURCHYARD – THE DAILY MIRROR JAN 2013.
WHITBY COASTAL MONITORING

• **Monitoring is an absolute priority to develop coastal management strategy.**

• **Unique opportunity to capture multi-temporal, multi-resolution 3D datasets over several years.**

• **We are capturing terrestrial and airborne datasets.**
TERRESTRIAL MONITORING
TERRESTRIAL MONITORING

• **OBJECTIVE IS TO MONITOR STABILITY OF SLOPE UNDER HISTORIC ABBEY**

• **CAPTURE DATA EVERY 20-30 MINUTES**

• **GAIN UNDERSTANDING OF SLOPE BEHAVIOUR AND IMPACT OF CLIMATE**

• **BIGGEST CHALLENGE WAS FINDING A PERMANENT LOCATION FOR THE SCANNER**

• **NEEDED TO BE PROTECTED FROM THE ELEMENTS BUT SECURE – NOT EASY AT A BUSY COASTAL TOURIST RESORT**
TERRESTRIAL MONITORING

• **The Solution –** Put the scanner in a lighthouse
TERRESTRIAL MONITORING
TERRESTRIAL MONITORING

• Capture data every 30 minutes 24 hours a day with 10 cm resolution – a truly unique dataset
TERRESTRIAL MONITORING

• Perfect solution – most of the time
TERRESTRIAL MONITORING
TERRESTRIAL MONITORING
TERRESTRIAL MONITORING

• **What are we learning from the data?**

• **Rockfalls are interesting — Sitemonitor can detect these automatically**
TERRESTRIAL MONITORING

- What are we learning from the data?
  - We can calculate rockfall frequency and volume over time
TERRESTRIAL MONITORING

- What are we learning from the data?
  - Rockfall frequency and magnitude correlated with environmental events
  - Rockfall frequency increases before large scale failure

![Graph showing rockfall frequency and magnitude over time](image-url)
TERRESTRIAL MONITORING

- **What are we learning from the data?**

- **Seepage and rockfalls are linked — we can use laser reflectance to see changes in seepage which are then linked to rockfall distribution**
TERRESTRIAL MONITORING

• What are we learning from the data?
  • Rockfalls are not all they seem.
TERRESTRIAL MONITORING

• What are we learning from the data?
  • Rockfall protection is often over-engineered.
TERRESTRIAL MONITORING

- **Still more work to do in understanding underlying slope dynamics but:**

- **We are seeing significant precursory behaviour prior to large scale events that can be used to change slope alert status – increase in rockfall frequency increases alert status**

- **We can see changes in seepage that are indicators of changes in slope structural integrity – added value in Lidar dataset**

- **Predicting point of failure is still a challenge**
WHY AIRBORNE LIDAR MONITORING?

- COVER LARGE AREAS QUICKLY

- MONITOR INACCESSIBLE TERRAIN

- LOWER SPATIAL AND TEMPORAL RESOLUTION THAN TERRESTRIAL DATA BUT MUCH LARGER AREA COVERED.
24km of coastline from Whitby to Skinningrove
Flying speed 40 knots
Height above ground 120m
Average point density 40 pts/sq m
Average pixel size 4 cm
Capture time 2 hrs
AREAS OF CHANGE SHOWN IN RED: 12 MONTH INTERVAL
Project area with data tile **boundaries**

Red zones = areas of change (on near vertical faces)
Project area with data tile boundaries

Red zones = areas of change (on near vertical faces)
First scan = coloured points

Second scan = white/red points
WHITBY BAY 2015-2016

AREAS OF CHANGE SHOWN IN YELLOW TO RED: 12 MONTH INTERVAL
MOBILE MONITORING

• **Automated event detection enables analysis of large areas of coastline**

• **Lower resolution than terrestrial data but of huge value in informing where more detailed analysis is required**
MULTI-SENSOR INTEGRATION:

AUTOMATED LANDSLIDE SURFACE VELOCITY ESTIMATION
MULTI SENSOR INTEGRATION

- **The Problem** – tracking 3D surface displacements in high-resolution but on small scales
- **Multiple Small Landslides Occur** – knowing the magnitude and direction of these significantly improves interpretation of slope stability

- **The Solution** - Integrate online-waveform laser data and imagery to track surface displacement velocity
  - **Images** – high resolution but vegetation can limit the capability to automatically track surface displacement
  - **Laser Data** – lower resolution but can be used to classify terrain surface into vegetated and non-vegetated (bare earth) areas
## Multi Sensor Integration

- **Data Characteristics**

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MULTI SENSOR INTEGRATION
MULTI SENSOR INTEGRATION
MULTI SENSOR INTEGRATION
DATA PROCESSING – ONLINE-WAVEFORM DATA

- ONLINE-WAVEFORM LASER DATA

- ABLE TO DETECT MULTIPLE TARGETS FOR EACH INDIVIDUAL LASER PULSE
DATA PROCESSING – SURFACE CLASSIFICATION

- **Laser Pulses** with multiple returns were assumed to be representative of vegetated terrain where backscatter is observed from more than one object.
- **Pulses** with only a single return were classified as bare-earth.
DATA PROCESSING – KEY POINT DETECTION

• **Use SIFT (scale invariant feature transform) algorithm to automatically detect and track features between reference and comparison images**
  
  • **Many features fall within vegetated areas and are thus not suitable for velocity estimation**
  
  • **Apply laser-derived vegetation mask to exclude these areas**
DATA PROCESSING – DISPLACEMENT RATES

• Match features (using masked SIFT keypoints) between reference and comparison survey
DATA PROCESSING – DISPLACEMENT RATES

- **Track 2D surface features to estimate 3D displacement rates**
  - Project 2D displacement vectors onto 3D pointcloud data
  - Estimated displacement rates up to \( \approx 2.5 \text{ m/yr}^{-1} \)
CONCLUSIONS

• We are learning a lot about slope dynamics and rockfalls from unique datasets

• New techniques are being developed that use laser data as the primary input

• Determining point of failure of a slope is still elusive

• Next step is to integrate all datasets to begin to determine slope behavior models
Thank you!