USING TERRESTRIAL LASER SCANNING FOR DYNAMIC BRIDGE DEFLECTION MEASUREMENT

Linh Truong-Hong
Debra F. Laefer

Urban Modelling Group
School of Civil, Structural and Environmental Engineering
University of Dublin
**MOTIVATION**

**Strain gauge**

Vibrating wire strain gauge installation for vertical deflection measurements in the North Halawa Valley Viaduct


**LVDT**

Installation of LVDTs for vertical displacement measurements at Sap-Gyo Bridge

Fiber optical sensors: Fiber Bragg Grating, Fabry Perot Interferometer, Long Gauge Sensors, and Distributed sensors

Inside of Fiber Bragg grating (FBG) and its package

Forty FBG sensors installed on the Tsing Ma bridge to measure temperature and strain

Ref: Chan, et al. (2006). Fiber Bragg grating sensors for structural health monitoring of Tsing Ma bridge: Background and experimental observation,
MOTIVATION

GPS

PHOTOGRAMMETRY

GPS Antenna on land

GPS Measurement System

TARGET POINT

GPS Antenna on a bridge

Layout of measured suspension bridge


Albert, et al. “Pilot Studies on Photogrammetric Bridge Deformation...
MOTIVATION

Advantages:
- High accuracy and good quality of data, small size, light weight, and long term stability

Disadvantages:
- Measures at fixed locations
- Attaches sensors or targets to the structure
- Needs a network to transmit data collection (for sensor system)
- Expensive (for sensor system)

A new method for measuring dynamic deflection by using terrestrial laser scanning
OUTLINE

• Introduction
• Background and Equipment
• Proposed method
• Experimental tests
• Results and Discussion
• Conclusions
**Introduction**

- Reconstructing models
- Proposed method

**Background & Equipment**

- Experimental tests

**Results & Discussion**

- Detect damage


**Introduction**

- **Background & Equipment**
  - Laser scanner
  - Scan of duct bank
  - Cross-sectional dimensions

**Proposed Method**

- Measure structural
- Results & Discussion

**Conclusions**

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Static deflections of a bridge

- Lichti et al. (2002)
- Lovas et al. (2008)

I-SiTE TLS system
Wooden bridge
RMSE = ±9.1 mm for the bottom
= ±4.9 mm for top

Minimum vertical clearance

- Riveiro et al. (2013)

- Liu et al. (2013)

- Terrestrial laser scanners are classified as triangulation and ranging techniques.

**Experimental tests**

**Proposed method**

**Results & Discussion**

**Conclusions**

**Output:** point cloud

- x, y, z coordinates
- Intensity values
- Red, green, blue
Assumption:
- Across relatively small investigated area
- Time-lapse due to the mirror rotating to take an adjacent vertical scan line is ignored
- Scanning time for collecting each data point in the same scan line is equal
Introduction

Background & Equipment

Proposed method

Workflow of defined scan time for data points

Point-surface based method for deflection measurement

Reference data set
\[ P_r = \{p_{ri}, i \in \{1, \ldots, n_r\}\} \]
\[ p_{ri} = [x_{ri}, y_{ri}, z_{ri}] \in \mathbb{R}^3 \]

Sample data set
\[ P_s = \{p_{si}, i \in \{1, \ldots, n_s\}\} \]
\[ p_{si} = [x_{si}, y_{si}, z_{si}] \in \mathbb{R}^3 \]

Convert to a spherical coordinate system
\[ p_{si} = [\theta_{si}, \varphi_{si}, R_{si}] \]

Extract scan line order
\[ \theta = \{\theta_{si}, i = 1, \ldots, N\} \]
\[ N = \{N_{i}, i = 1, \ldots, N\} \]

Extract point order in each scan lines, \( N_i \)
\[ \varphi = \{\varphi_{ji}, j = 1, \ldots, M\} \]
\[ M = \{M_{ij}, j = 1, \ldots, M\} \]

A local surface from \( q \)
\[ S: ax+by+cz+d = 0 \]

Intersection point, \( p'_{si} \)
between \( S \) and a ray \( X(t) = p_{si} + tn \)
\[ 0 \leq t \leq \infty; \ n = [0, 0, 1] \]

A vertical displacement
\[ d(p_{si}, p'_{si}) \]

Smoothering vertical displacement

\[ \Delta d_{t_i} = \frac{1}{m} \sum_{j=t_i-\Delta t/2}^{t_i+\Delta t/2} d_{t_j} \]
Measurement bridge description:
- Loughbrickland Bridge on Highway A1
- 29 beams, 20.18m long, 36.29m wide, with a 69-degree skew
Introduction

Background & Equipment

Proposed method

Experimental tests

Terrestrial laser scanner: Leica station P20
- Selected area = 30 mm x 30 mm
- Angle spacing = 0.0045 degrees
- Offset distance ≈ 7.5 m
- Total data points/scan = 2625 points

Results & Discussion

Conclusions
Results:

Original data points

Ref. data points

Sampled data points

Filtering data points

Mapping of data

Results & Discussion

Conclusions
Results: Displacements and averaged displacements of the bridge beam from 4 consecutive scans.

Displacements smoothing displacements with a time step by 0.125s.
- TLS can determine vertical displacements without targets or scaffolding, traffic disruption, and can use for long-term monitoring.

- TLS to dynamic deflection measurement still holds many challenges:
  - appropriate sampling step unknown
  - noise filter needed
  - missing data between consecutive scans
- Preliminary study used TLS to collect real vertical bridge movements due to dynamic vehicle loads.
- Point-surface based method applied to calculate bridge deflection.
- Vertical displacement directly derived from the point-surface based method varied in ±1 mm, while smoothing based approach was ±0.5 mm.
- Appropriate sampling step and noise filtering were still needed.
THANK YOU FOR

YOUR ATTENTION!