UNIVERSITY OF CALGARY

Monitoring dynamic concrete beam deformation with range cameras

Xiaojuan Qi and Derek Lichti
Department of Geomatics Engineering
University of Calgary, Canada

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Outline

- Introduction
- Dynamic deformation measurement principle
- Results of the concrete beam deformation measurement
- Conclusions

Introduction (1/3)

Motivation

- Monitoring the bridge deformation in situ
- Monitoring the concrete beam fatigue test in real time

Introduction (2/3)

Point-wise devices

- Dial gauge

Image source: http://www.gagewebsite.com/2011/04/08/dial-gauge-2/

- Linear-variable differential transformer displacement transducer

Image source: http://www.rdpe.com/us/ssd.htm

- Laser displacement sensor (LDS)

Image source: http://www.acuitylaser.com/laser_displacement_sensor.html

Photogrammetric devices

- Terrestrial laser scanning

Image source: http://www.leica-geosystems.com/hds/en/lgs_62189.htm

- Traditional photogrammetry

Image source: http://www.canon.ca/inetCA/products?m=gp&pid=905

- 3D range camera (RC)

Image source: Image source: http://www.csem.ch

Introduction (3/3)

The objective of current research

The objective of the current research is to monitor the deformation of a concrete beam subjected to periodic loads using range cameras in a laboratory

Dynamic deformation measurement principle (1/4)

Range imaging measurement principle

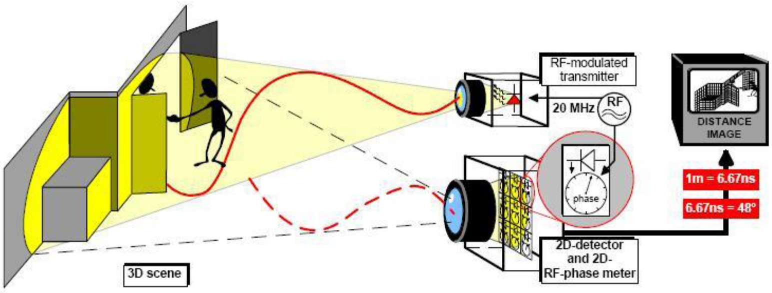

Image source: Lange, R. and Seitz, P., 2001. Solid-state time-of-flight range camera. *IEEE Journal of Quantum Electronics,* 37 (3), pp. 390-397

Range imaging measurement principle

$$C_i = \frac{A}{2}\cos(\varphi + \frac{\pi i}{2}) + K$$

$$\varphi = \tan^{-1}\left(\frac{C_3 - C_1}{C_0 - C_2}\right)$$

$$\rho = \frac{\phi c}{4\pi f_m}$$

C_i - discrete measurements of amplitude (i = 0, 1,2,3)

A - emitted signal amplitude

K - offset added the model background illumination

c - light speed

f_m - modulation frequency

3D co-ordinates from range measurement

$$\begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} = \frac{\rho_i}{\sqrt{(x_i)^2 + (y_i)^2 + (p_d)^2}} \begin{bmatrix} x_i \\ y_i \\ -p_d \end{bmatrix}$$

p_d - principal distance of the range camera
x_i, y_i - target image co-ordinates reduced to the principal point and corrected for systematic errors
ρ_i - range measurement corrected range errors
X_i, Y_i, Z_i - object co-ordinates in range camera sensor co-ordinate system

Dynamic deformation measurement principle (4/4)

Effect of the target motion

$$\hat{C}_i = \frac{A}{2}\cos\left(\varphi + \frac{\pi i}{2} + \Delta\varphi_i\right) + K$$

$$\hat{\varphi} = \tan^{-1}\left(\frac{\hat{C}_3 - \hat{C}_1}{\hat{C}_0 - \hat{C}_2}\right)$$

$$\hat{\rho} = \frac{\hat{\phi}c}{4\pi f_m}$$

$\Delta\varphi_i$ - phase shift

$\hat{C}_i$ - biased discrete measurements of amplitude

$\hat{\varphi}$ - biased phase difference

$\hat{\rho}$ - biased range measurement

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Experiment description (1/6)

Range camera - SR4000

SR4000 parameters

Pixel array size	176 ×144
Field of view	69° x 56°
Pixel pitch	40 µm
Non-ambiguity range	5 m
Calibrated range	0.8 m - 5 m
Maximum frame rate	54 fps

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Experiment description (2/6)

The measurement system of the dynamic concrete beam deformation

Range camera

Hydraulic actuator

Spreader beam

Concrete beam

Thin plates

Laser displacement sensors

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Experiment description (3/6)

Loading procedure and data capture

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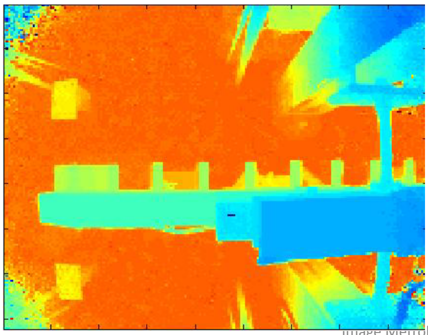
Experiment description (4/6)

Loading procedure and data capture

- The 3D range cameras have to be warmed up for one hour
- Different modulation frequencies (29 MHz and 31 MHz)
- Range sampling frequency is 10Hz

Range image of the experiment scene-top view



Amplitude image of the experiment scene-top view

Experiment description (5/6)

Data processing

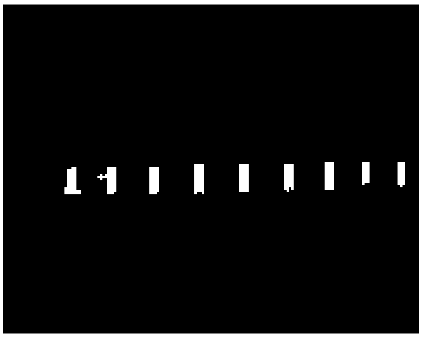
The results with depth-based classification

Binary image from the amplitude

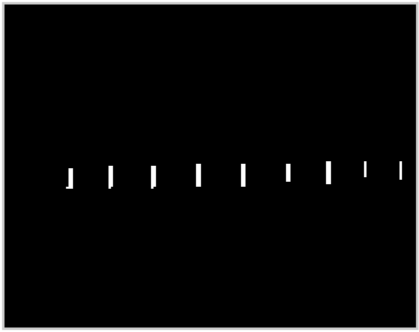
Experiment description (6/6)

Data processing

The results with eccentricity classification the thin plates



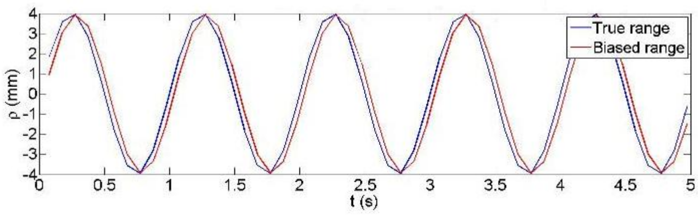
The final results with image erosion



Results (1/4)

Analysis of the target motion effect

The true and biased periodic ranges to the moving target

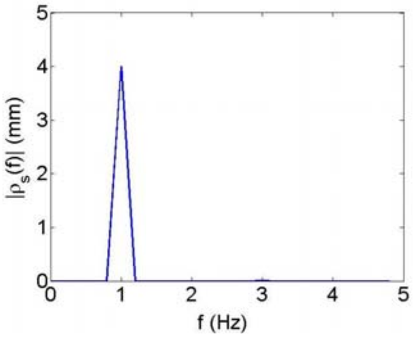


Phase difference is -13.2°

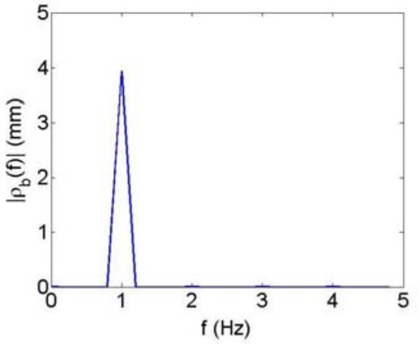
Results (2/4)

Analysis of the target motion effect

The magnitude spectrum of the true signal



The magnitude spectrum of the biased signal

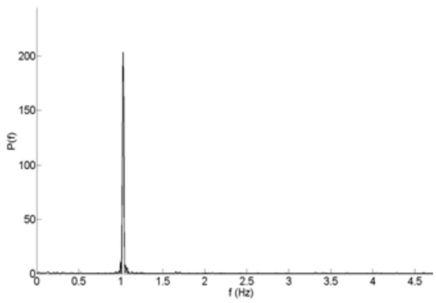


Amplitude difference is only -0.061 mm which is 1.5% of the ideal amplitude 4 mm

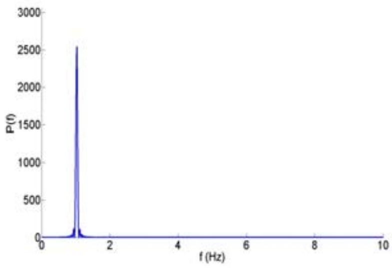
Results (3/4)

Trajectory analysis of the thin plate and the deformation of the concrete beam

f_0 =1.0286 Hz from RC



f_0 =1.0296 Hz from LDS

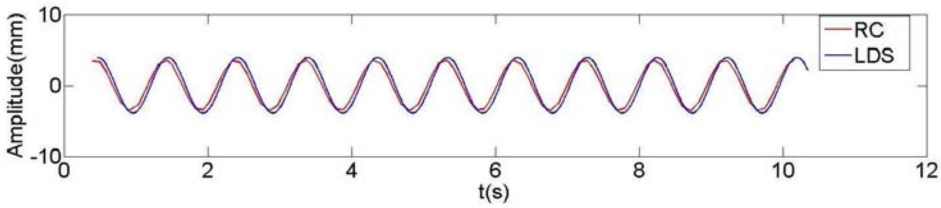


Estimated frequency difference is -0.001 Hz

Results (4/4)

Trajectory and deformation analysis of the thin plate located at mid-span concrete beam

The trajectories of the chosen thin plates estimated from the RC and LDS data



$$h(t) = A \cos 2\pi f_0 t + B \sin 2\pi f_0 t$$

The estimated maximum deformation are 3.6 mm and 3.9 mm from the RC and LDS respectively

Conclusions

- The deformation measurement of a concrete beam subjected to the periodic loading has been made using a range camera
- The target motion do not adversely affect the deformation measurement accuracy when the periodic sinusoidal motion has 4 mm amplitude and 1 Hz frequency
- The results from real data have indicated that periodic deformation can be recovered with sub-millimetre accuracy validated by LDS when the 1 Hz target motion is sampled at 10 Hz

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Thanks !

Questions?

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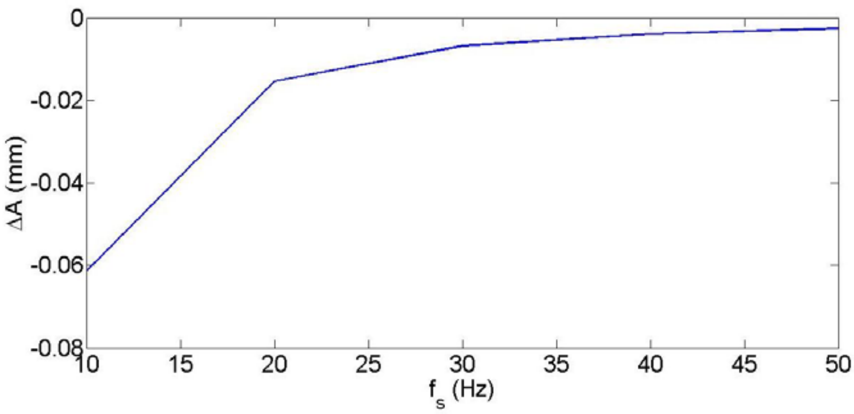
Analysis of the target motion affect



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