

# Integrity Assessment of Pipelines and Industrial Assets by Automated Infrared Thermography (AIT)

## Fernando Lópeza, Marc-Antoine Blanchet and Luc Mauzeroll

<sup>a</sup> Corresponding author: flopez@torngats.ca

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# Outline

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- 1. Introduction
- 2. NDT by Infrared Thermography
- 3. Registration and Advanced Processing of Thermographic Data
  - a. The 2D Fourier Transform
  - b. The Phase Correlation Method
  - c. High Resolution Dynamic Thermography
- 4. Applications
- 5. Final Considerations

# Introduction

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### **Non-destructive Testing Techniques**

- 1. Visual (Visual Inspection);
- 2. Penetrating Radiation (X-Rays and Neutron Imaging);
- 3. Magnetic (Magnetic Participles, Eddy Current);
- 4. Mechanical Vibrations (Ultrasound, Acoustic Emission);
- 5. Chemical (Chemical Spot Testing);
- 6. Infrared and Thermal (Infrared Thermography);
- 7. Optical (Moiré Interferometry, Holography and Shearography);

Ch. Hellier. Handbook of Nondestructive Evaluation. McGraw-Hill, NY, 2003.

# Introduction



mechanical vibrations (Ultrasound, Acoustic 



Ch. Hellier. Handbook of Nondestructive Evalua







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Imager

Radiometric Imager



NDT in Canada 2017 Conference (June 6-8, 2017)

# Introduction

#### **Incloddccion**

### **Integrity Assessments of Pipelines and Industrial Assets**

 Infrared Thermography (IRT) stands as one of the emerging NDT techniques aimed to improve the inspections processes and maintenance procedures, specially in complex situations where classic NDT methods present limitations (e.g., high temperature, lack of accessibility, real time results).



 Most of the industrial components (pipelines, reservoirs, storage tanks, etc.) are affected by at least one heat transfer mechanism. This particularity makes IRT an attractive NDT approach, since it is based on the analysis of the thermal gradients produced by variations of the heat fluxes.

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# NDT by Infrared Thermography

### NDT by minared mennography

- IR thermal vision is the capability to detect and measure by artificial means, the IR radiation that all bodies with temperature above 0 K emit. IR vision is aided by computer sciences to process the acquired information.
- Infrared thermography corresponds to the acquisition and analysis of IR thermal data related to the MWIR and LWIR regions of the electromagnetic spectrum.



Adapted from: F. López, PhD Thesis, Federal University of Santa Catarina/Laval University, 2014

# NDT by Infrared Thermography

### NDT by minated mennography

• Active approach: an external excitation is applied to provoke a heat flux within the object under study. Internal defects alter the heat flux producing measurable surface temperature patterns or thermal contrasts.



- ✓ Thermal/optical
- ✓ Mechanical
- ✓ Electromagnetic

Requires deep knowledge of the physical phenomena during the tests, as well as parameters associated to IR equipment, surrounding and observed system.

# NDT by Infrared Thermography

### NDT by minated mennography

Passive approach: no external excitation is applied to produce a heat flows within the object of interest. There is enough thermal contrast between the background and features.



No external excitation is applied.

Carried out under normal operational conditions.

Features of interests are normally at higher or lower temperature than the background

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### registration and Advanced Processing of Thermographic bata

### Image Representation using the Fourier Transform

The Fourier transform is a representation of an image as a sum of complex exponentials of varying magnitudes, frequencies, and phases. The Fourier transform plays a critical role in a broad range of image processing applications, including enhancement, analysis, restoration, and compression.

$$F(\omega_1, \omega_2) = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} f(m, n) e^{-j\omega_1 m} e^{-j\omega_2 n}$$

The Discrete Fourier Transform (DFT): A DFT is a tran

A DFT is a transform whose input and output values are discrete samples.

$$F(p,q) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m,n) e^{-j2\pi pm/M} e^{-j2\pi qn/N} \qquad p = 0, 1, \dots, M-1$$
$$q = 0, 1, \dots, N-1$$

$$f(m,n) = \frac{1}{MN} \sum_{p=0}^{M-1} \sum_{q=0}^{N-1} F(p,q) e^{-j2\pi pm/M} e^{-j2\pi qn/N} \qquad m = 0, 1, \dots, M-1$$
$$n = 0, 1, \dots, N-1$$

### registration and Advanced Processing of Thermographic pata

### Image Representation using the Fourier Transform

$$F(p,q) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m,n) e^{-j2\pi pm/M} e^{-j2\pi qn/N} = Re + Im$$

 $A = \sqrt{Re^2 + Im^2}$ 

$$\phi = tan^{-1} \left(\frac{Im}{Re}\right)$$



### registration and Advanced Processing of Thermographic Data

### Phase (PC) Correlation Algorithm :

The PC algorithm is based upon the that the information pertaining to the displacement of two images resides in the phase of the cross power spectrum.

Let  $f_1(x, y)$  and  $f_2(x, y)$  be two image functions that differ by a displacement or translation of  $(x_o, y_o)$ :

 $f_2(x, y) = f_1(x - x_o, y - y_o)$ 

Their Fourier transform are related by:

 $F_2(u, v) = F_1(u, v) e^{-j2\pi(ux_0 + vy_0)}$  \* The Fourier magnitudes are the same, but their phase are different.

The cross-power spectrum is given by:

 $P(u,v) = \frac{F_1(u,v)F_2^*(u,v)}{|F_1(u,v)F_2^*(u,v)|} = e^{j2\pi(ux_o+vy_o)}$ \* Phase difference between the Fourier Transform of both images.

The inverse Fourier transform of the cross-power spectrum:

$$p(m,n) = \frac{1}{MN} \sum_{u,v} P(u,v) e^{j2\pi(ux_o + vy_o)} = \delta(x_o, y_o)$$

#### registration and Advanced Processing of mermographic pata

### Implementation of Phase (PC) Correlation Algorithm :



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- High Resolution Dynamic Thermography (HRDT) is an advanced processing methodology/environment developed by the R&D team of TORNGATS, which consists on the acquisition, processing and analysis of thermographic data in transient regime.
- This methodology aims to enhance the detectability of subsurface defects in cases where important heat transfer losses take places.
- The main premise used in this analysis is the fact that zones with internal anomalies will behave – thermally - different from the rest of the surface. By using advanced signal processing techniques, it is possible to increase the signal-to-noise ratio of thermal gradients produced by subsurface defects.

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### Methodology:



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### **Multivariate statistical regression – Partial Least-Squares Regression:**



- **Objective:** successive and simultaneous decomposition of X and Y into latent variables, describing maximum variance in X and maximum covariance in X in Y
- Available algorithms:
  - NIPALS (noniterative partial least squares); SIMPLS (available in MatLab)



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# **Applications: Detection of corrosion under isolation (CUI)**

#### Applications, perection of corrosion under isolation (cor)

### Inspection of a pipe with 1 <sup>3</sup>⁄<sub>4</sub> diameter with isolation:



Visible image

Single thermal image

# Applications: Detection of corrosion under isolation (CUI)

Applications, petection of corrosion underisolation (cor)



## **Applications: Characterization of the level of internal deposits**

#### Applications, characterization of the level of internal deposits

### Inspection of a pipe with 20 inches diameter without isolation:



Visible image

Single thermal image

## **Applications: Characterization of the level of internal deposits**

#### Applications, characterization of the level of internal deposits

### Inspection of a pipe with 20 inches diameter without isolation:



### **Applications: Inspection of rooftops by Aerial Infrared Thermography**

#### Applications: inspection of roottops by Aerial intrared Thermography

- Project EGP 506183 16. Aerial infrared thermography (AIT): Methodology to calculate energetic parameters of building rooftops based on direct temperature measurement.
- Financial Institution: Natural Sciences and Engineering Research Council of Canada
- Partner: Université Laval (Professor Xavier Maldague)

Hexacopter model DJI S800 EVO





5635 Rue Rideau, Ville de Québec, QC G2E 5V9

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## **Applications: Inspection of rooftops by Aerial Infrared Thermography**

#### Applications: inspection of roottops by Aerial infrared Thermography





### 1<sup>st</sup> PLST Loading



# **Final Considerations**

Find considerations

- Infrared thermography (IRT) is a promising technique for the nondestructive inspection of pipelines and industrial components. However, its accuracy and reliability greatly depend on the appropriate methodology of acquisition and post-analysis.
- High Resolution Dynamic Thermography addresses the most important drawbacks of IRT when applied on complex situations: images misalignment and highly contaminated by noise (specially reflection and convection) and the anisotropy of the structures under investigation.
- The R&D team of TORNGATS is permanently working on science-driven solutions for the most challenging situations in the industry. In this scenario, several R&D initiatives are in progress, aiming to provide to the industry unique, reliable and innovative NDT solutions.

# Acknowledgments

### Acknowledgments









# Fréd Éric Lajoie TORNGATS - Gestionnaire des opérations par UAV