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Automated inspection of offshore wind turbine foundation using complementary NDT and defect detection techniques

Authors

Sulochana Subramaniam

Guojin Feng

Alvin Chong,

Jamil Kanfoud,

Tat Hean

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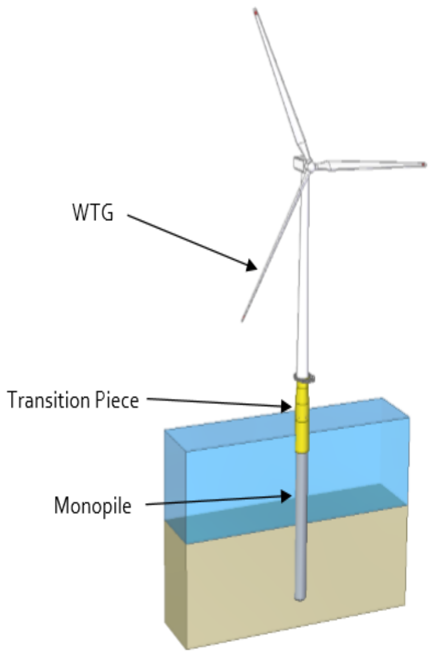
The project iFROG combines enabling capabilities in electronics/sensors/photonics and robotics to deliver innovative marinised autonomous robot for inspection and predictive maintenance of offshore wind turbine foundations both above and below the water line.

Overview of the Presentation

- Introduction
- Inspection scheme of the Monopile
- Hybrid NDT techniques
- NDT signal and image processing
- Interactive GUI for defect detection
- Conclusion and future scope

Introduction

- The wind turbine generator interfaces with the monopile through a transition piece.
  - Grouted connection
  - Bolted connection
- The main platforms of the Monopile,
  - ***The bottom portion close to the connection between the transition piece and Monopile.***
  - ***The above portion airtight platform for sealing the foundation.***
- Designers have assumed that by sealing the Monopile internal from seawater and air, oxygen will be consumed, and corrosion will be suppressed.
  - It is very difficult to completely seal the platforms.
  - The result is corrosion - seawater ingress.
- Human inspection is no longer possible for inside of older Monopile foundations due to presence of partially filled water.



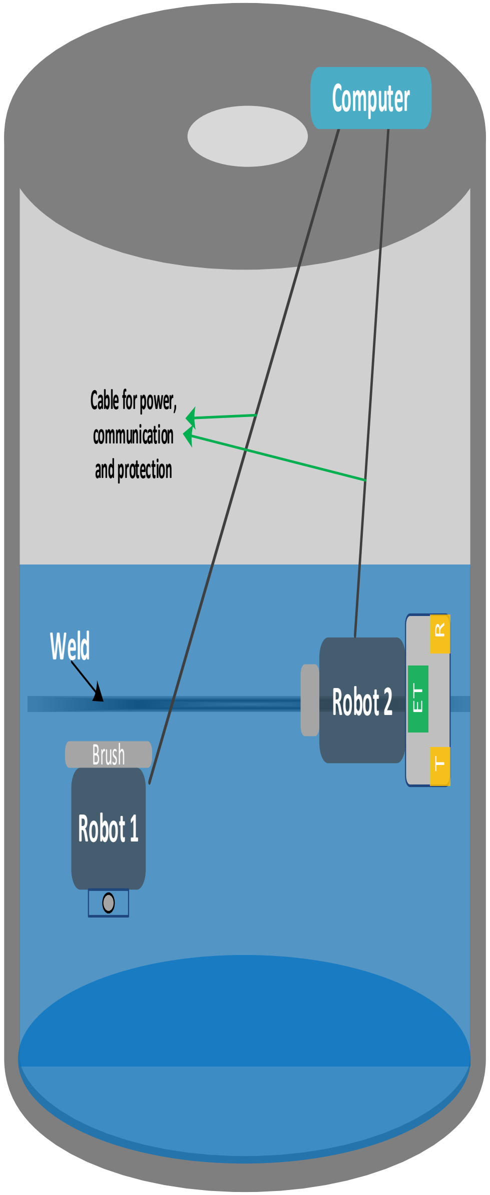
Need for This Project

- **Remote inspection and monitoring**

- Diver or ROV (remotely operated vehicle)
  - Visually inspect for cracks
  - Challenging due to potential issues with visibility and marine growth.

- Sonar or acoustic emission non-destructive testing
  - Indication of defect existence
  - Lack the ability to size the defects.

- A scheme for the automated inspection of wind turbine monopiles has been developed by combining,
  I. **Two autonomous robots**
  II. **Three complementary non-destructive testing (NDT) techniques**
  III. **NDT software for automatic defect detection**



Inspection Scheme of the Monopile

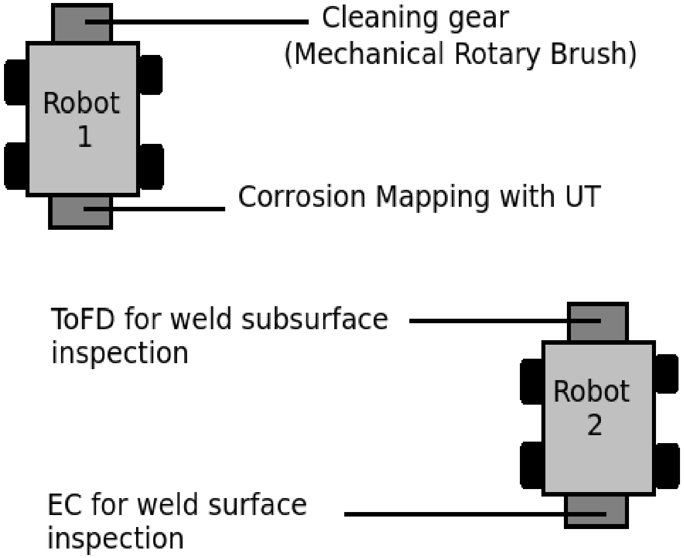
- Welds occur as circumferential lines at approximately 2-meter intervals along the length of the Monopile as well as vertical welds on each section.

- Amphibious robotic platform capable of climbing and navigating on the wind turbine foundations in air and underwater.

- The two robots are physically connected with tether distributed around the Monopile foundation to prevent falling and moving.

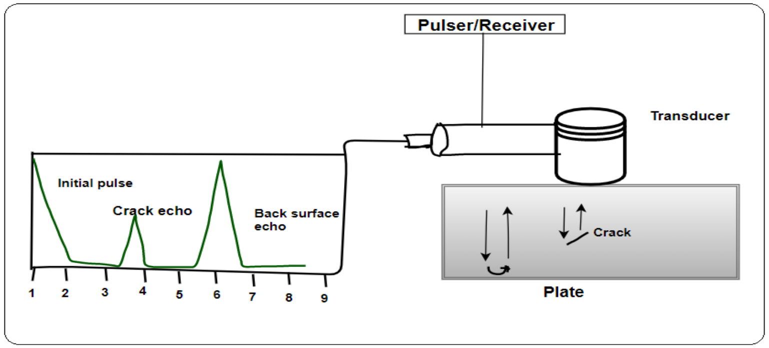
- Cleaning (Robot 1)

- NDT inspection (Robot 2).

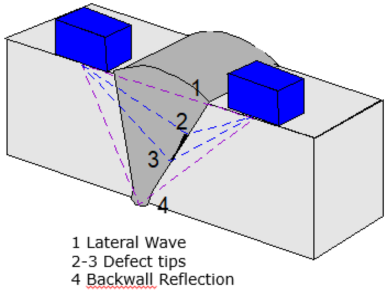


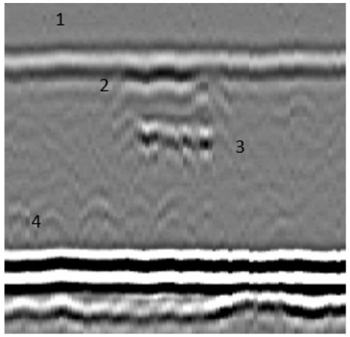
NDT techniques

- Ultrasonic technique(UT)
  - Corrosion mapping

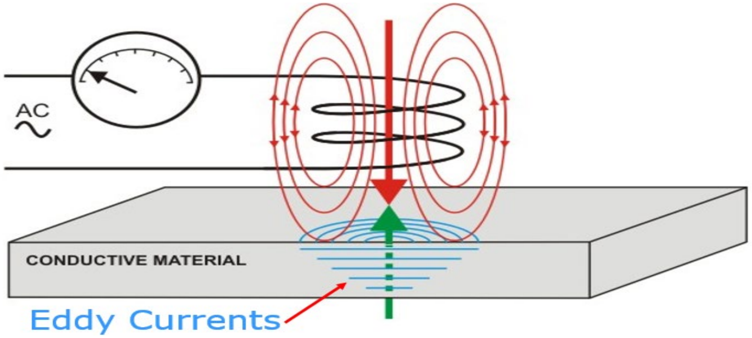


- Time of flight diffraction technique(TOFD)
  - Sub-surface mapping





- Eddy current testing(ECT)
  - Surface mapping



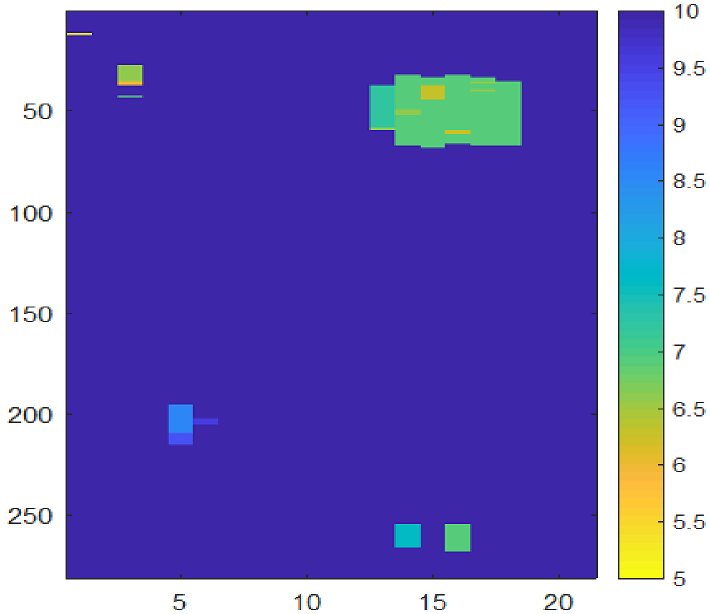
UT Data Analysis

❖ Find the distance from starting to first peak of the A-Scan signal and multiply by ultrasound resolution to calculate thickness in each point.

❖ Using the thickness measurement, the corrosion map is plotted.

❖ The defects or corrosion in the reference plate is simulated by the human operator.

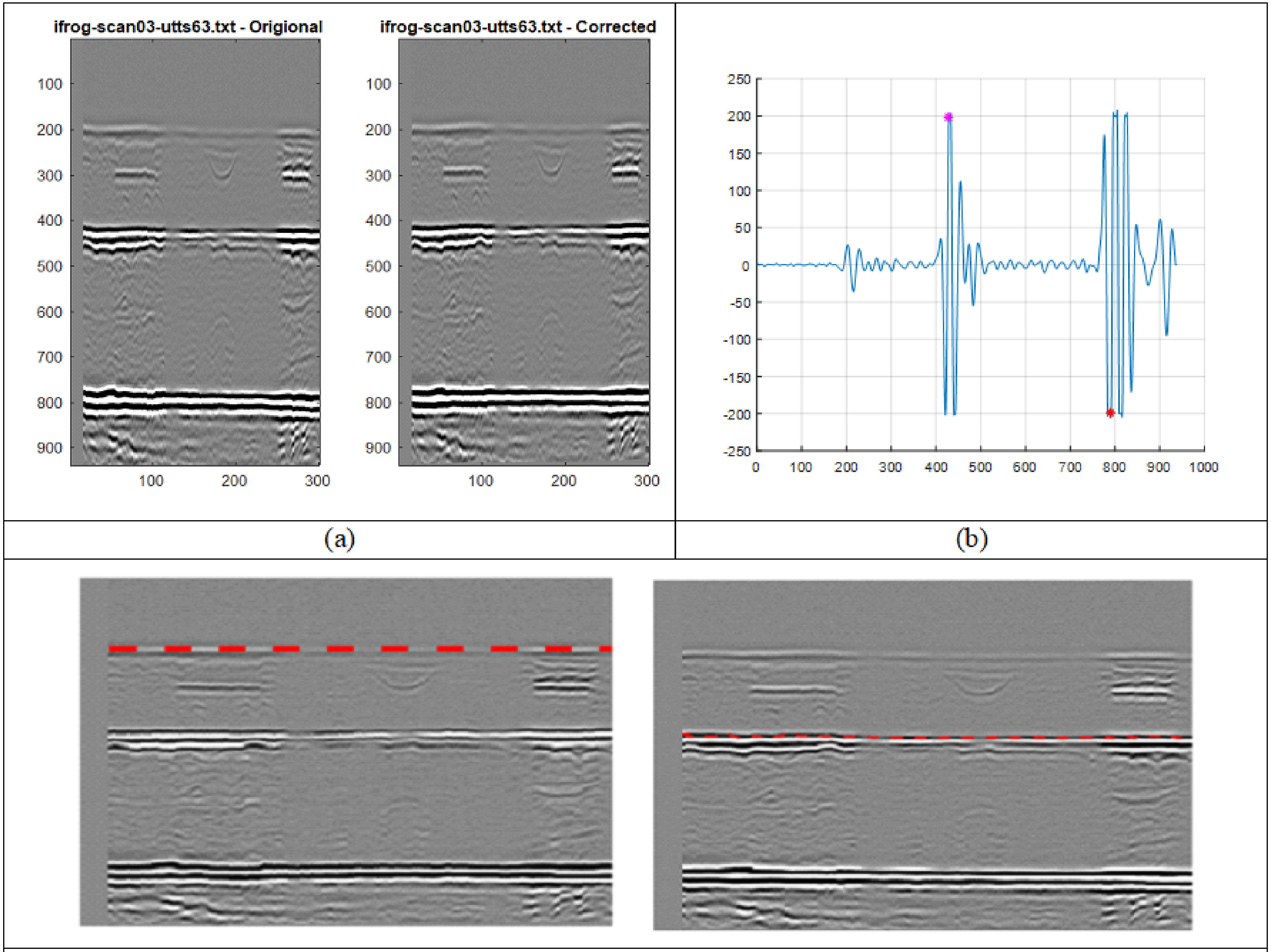
❖ The plotted corrosion map indicates the correct identification of corrosion thickness and the same verified with the actual corrosion map.



TOFD Data Analysis

- The wavelet based denoising is used to enhance the signal to noise ratio of the signal.
- Scan alignment is carried out by subsampling each scan and cross correlating each scan with reference scan.
- First positive maximum of the signal is identified using some threshold and marked as a lateral wave.
- Then autocorrelation function used to find the backwall eco and the region between lateral and backwall eco marked as an area of interest(ROI).
- ROI is segmented using thresholds (T) can be represented by the following expression $T = \mu + z.\sigma$
- where $\mu -$ mean gray level of the entire image pixels. $\sigma -$standard deviation of the mean gray levels in the defective image (original). z$-$ could be selected by trial and error to determine strictness of the defect-detection test.
- Automated sizing has been done using some predetermined calibration parameters and signal processing algorithms.

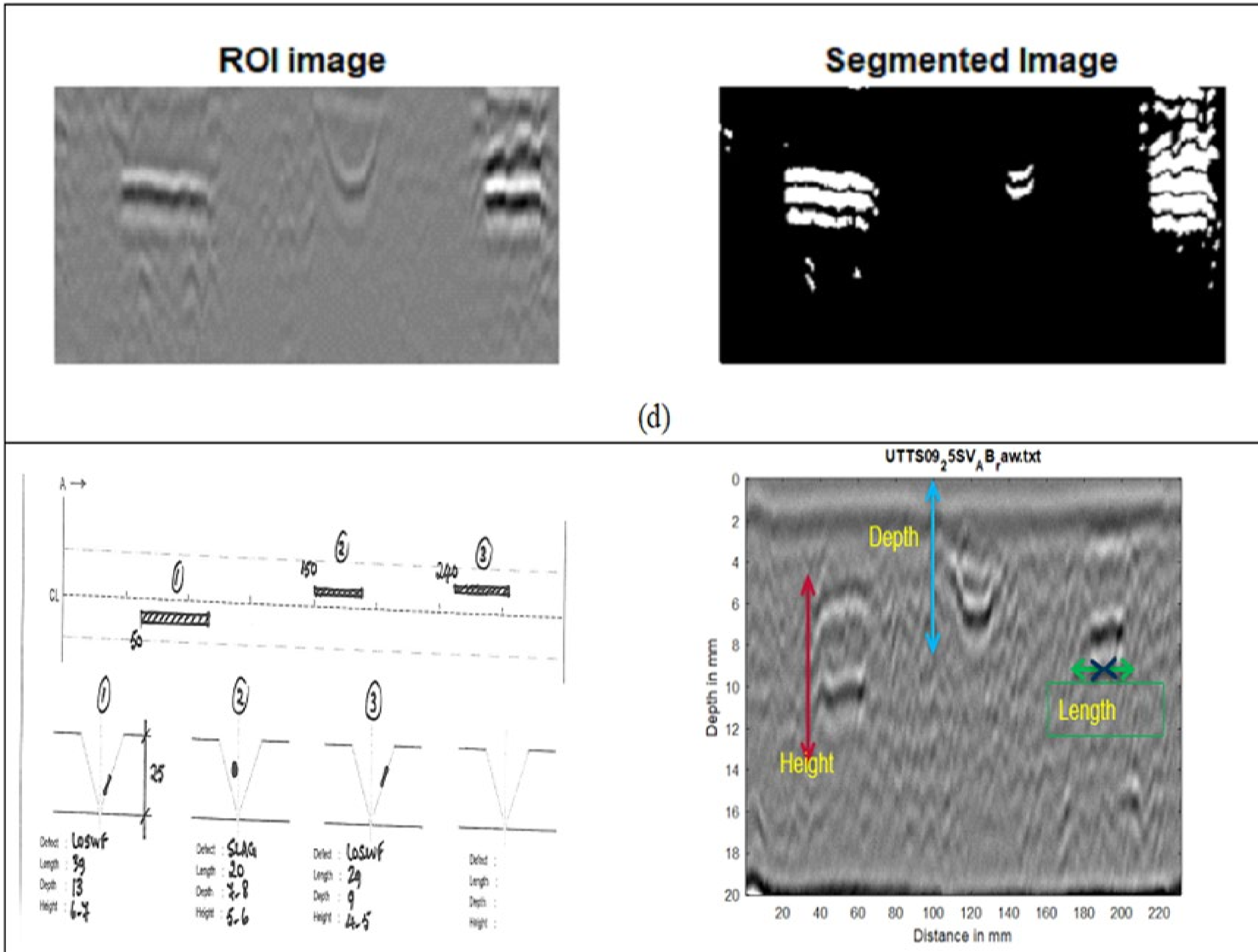
TOFD Data Analysis



(a) (b)

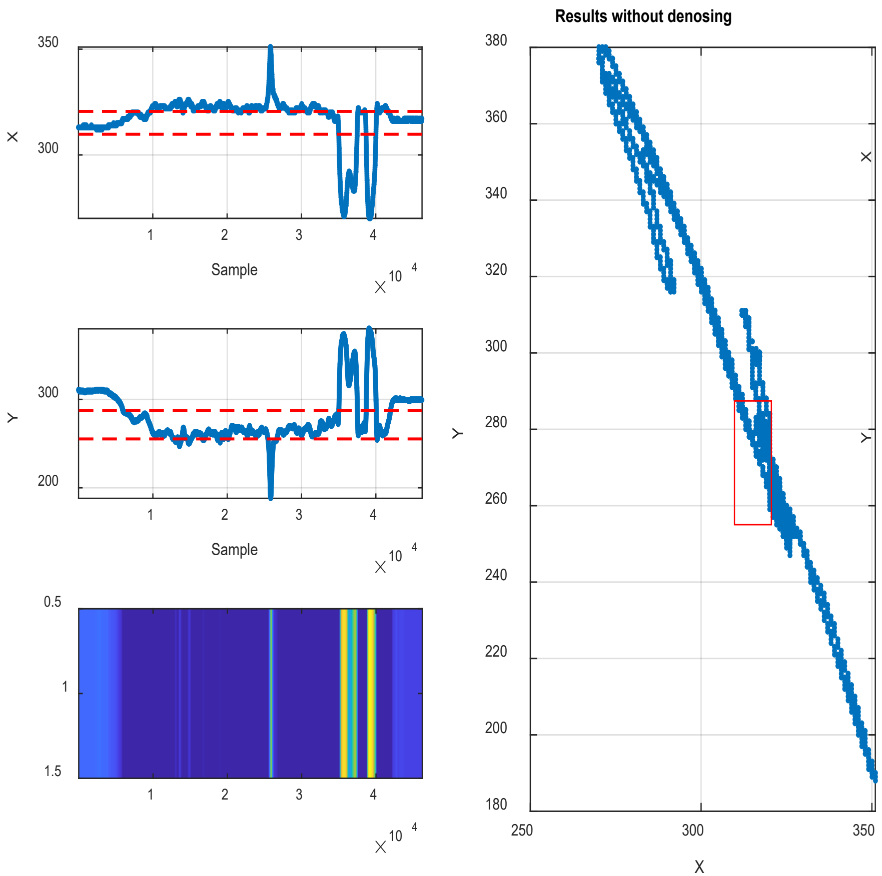
(c)

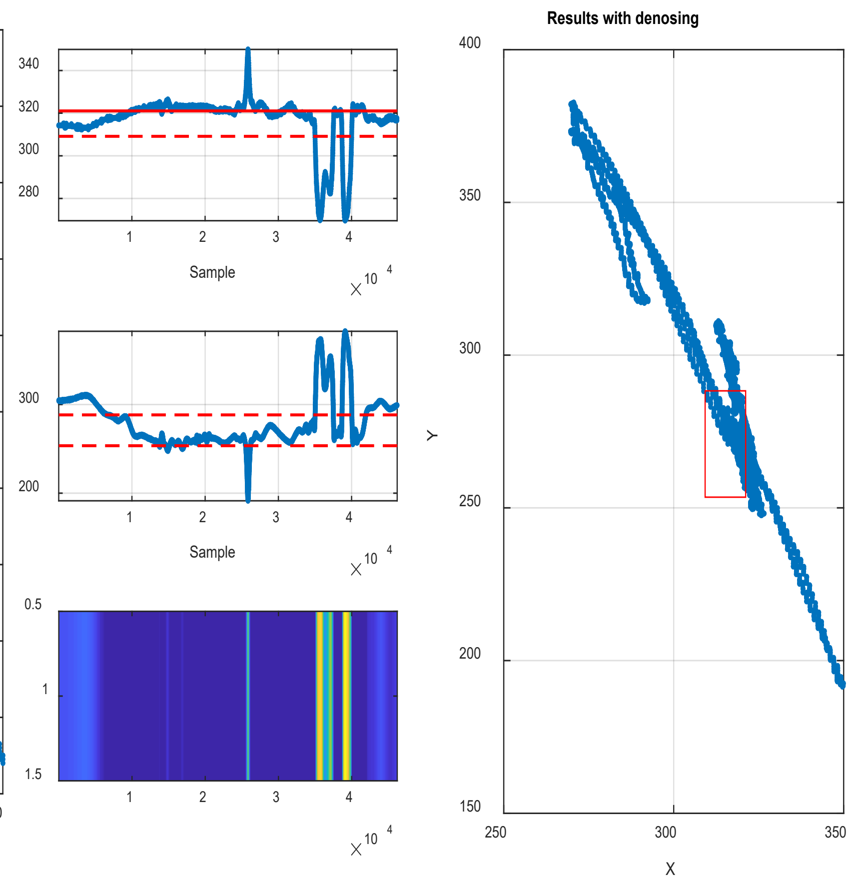
TOFD Data Analysis



Eddy Current Data Analysis

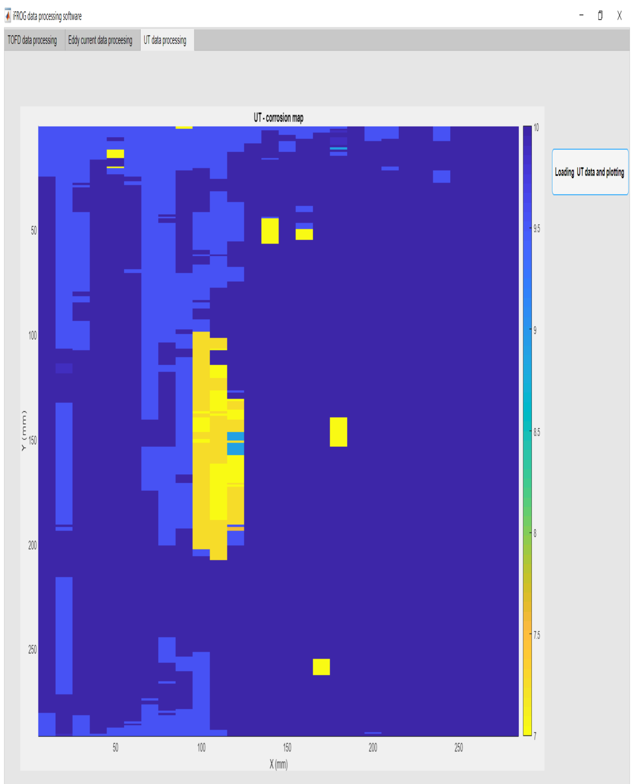
- The signal is denoised with Wavelet transform+ Donoho and Johnstone's universal threshold denoising
- Rectangle is plotted over the reference signal and based on this rectangle the points lies outside the rectangle of the other signals are marked as a defect.

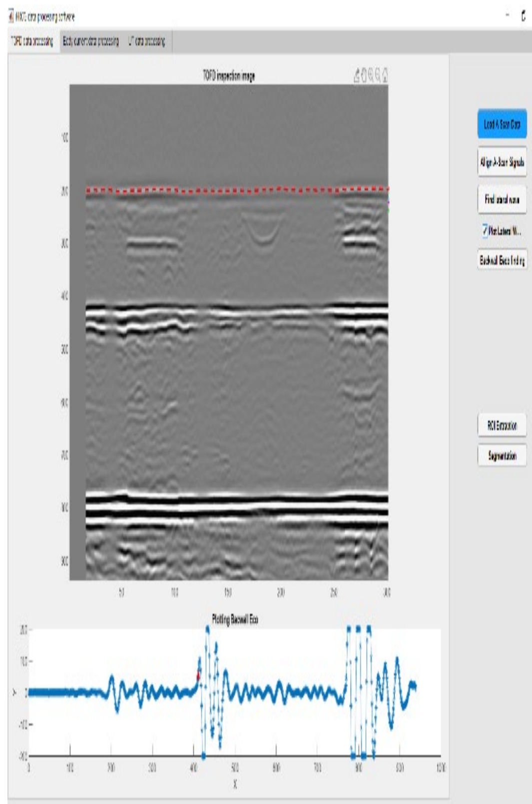


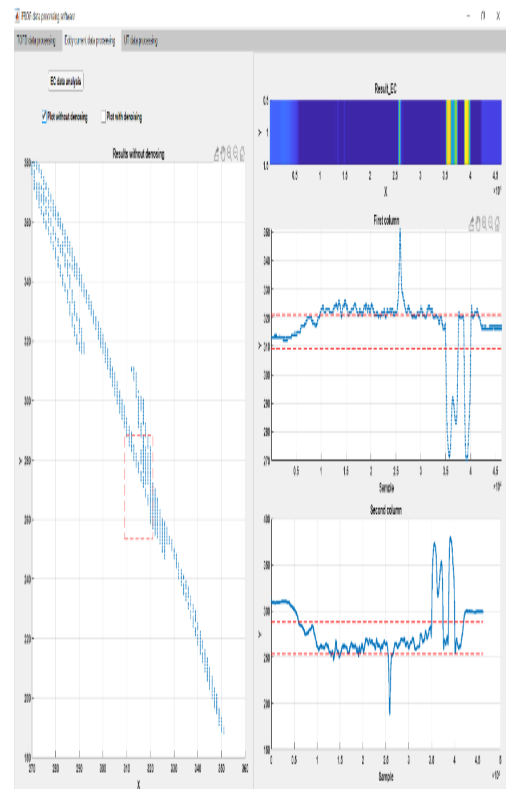


NDT Software

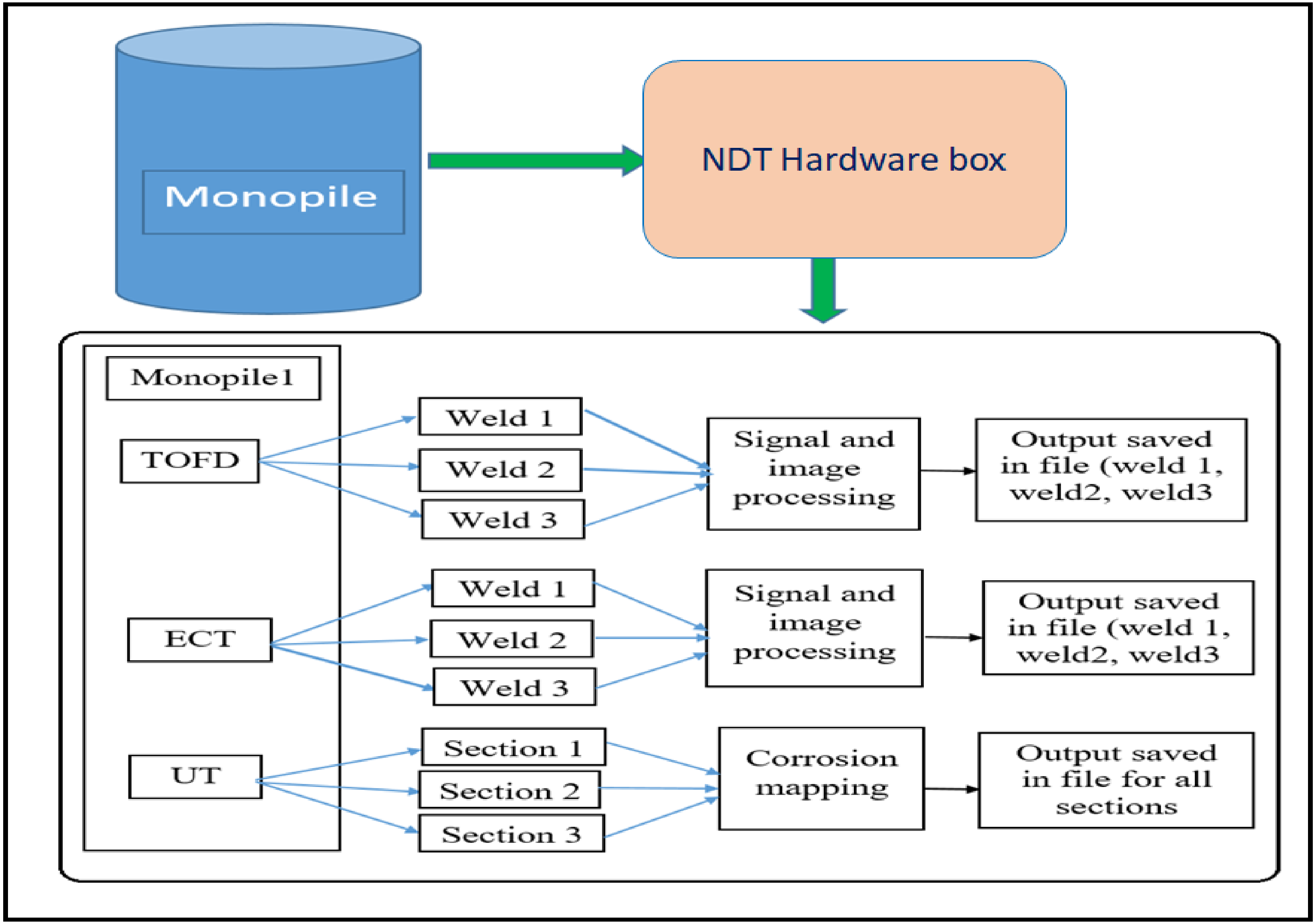
- The developed TOFD, ECT and UT signal processing algorithms are incorporated into one GUI,
- GUI provides an interface to end user, allowing them to view the acquired signals, apply developed signal and image processing algorithms to process signals and view the detected defects.







Output Structure



Conclusion and Future Scope

- The NDT equipped robots can move across the monopile efficiently and reliably.
- The addressed signal and image processing approaches for all three NDT techniques have been extremely promising in the context of automatic defect detection.
- The outcome of this project reduces the overall maintenance costs and provide a safe strategy; rather than human assisted methods.
- This is a unique intelligent procedure for inspecting offshore windfarm monopiles especially in the underwater and deep-sea environments.
- Overall, the automatic defect detection lead to several actionable insights over the next coming years.
- There will be a potential to use artificial intelligence techniques in automatic defect detection.

Acknowledgement

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❖ The iFROG project is a collaboration between the following organisations:

- Innovative Technology & science limited (InnoTecUK)
- Brunel Innovation Centre, Brunel University London
- TWI Limited**,**
- ORE Catapult Development Services Limited.

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