University of Strathclyde Engineering

Unmanned Aerial Vehicle for Autonomous Non-Destructive Testing Inspections

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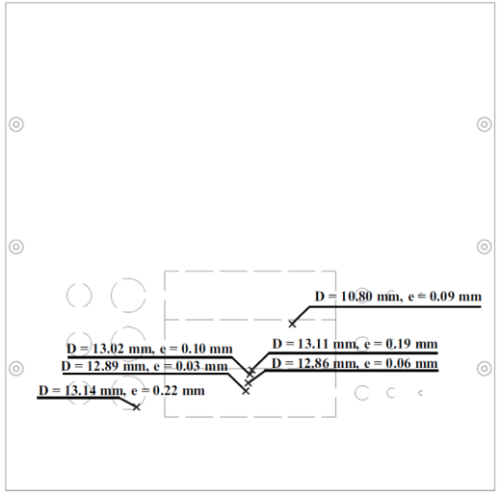
PPS EDF AFRC ADVANCED FORMING RESEARCH CENTRE UNIVERSITY OF STRATHCLYDE CUE

Introduction

- Unmanned aerial vehicle (UAV) provides flexibilities to undertake many challenging access problems.
- Close-range and contact-based inspections grant more detailed and accurate evaluations whilst demanding an advanced UAV flight control system.

Introduction

- We developed an autonomous UAV system to conduct:
  - Close-range photogrammetric inspections
  - Contact-based ultrasonic thickness measurements



Introduction

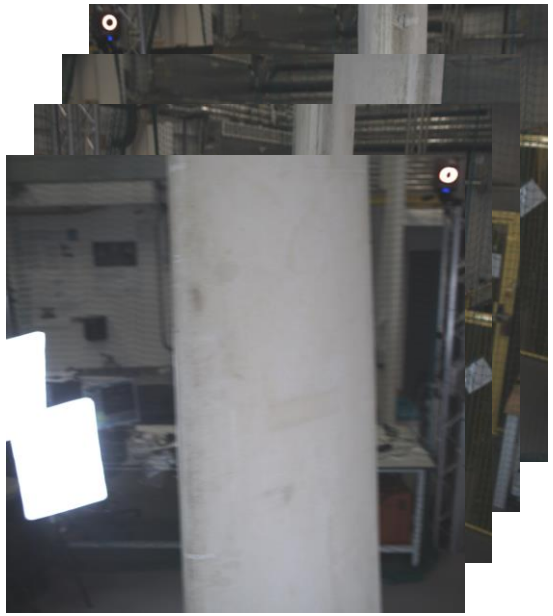
- Manually deploying such inspections requires a highly developed skillset and intense concentration for a pilot.

Manual Controller

Auto Controller

Photogrammetric Inspection

- Conventional UAV scan provides pictures and cannot provide overview of the surface.



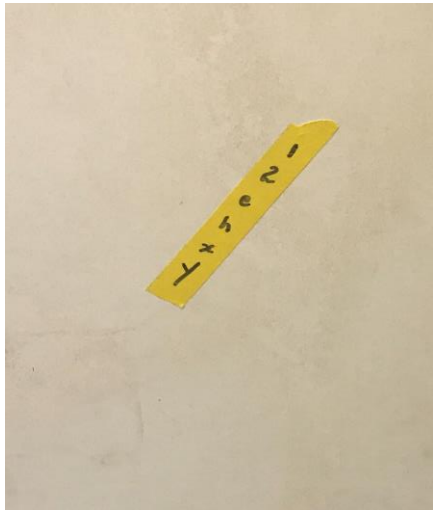
Pictures

3D Model

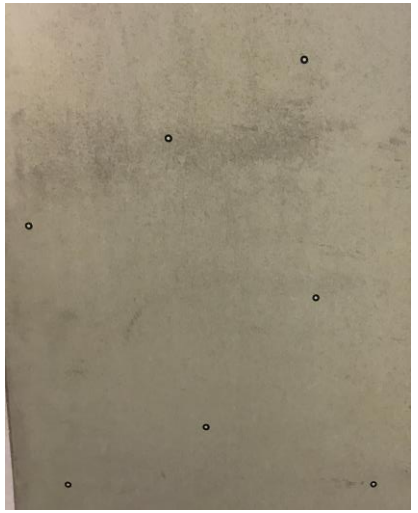
Photogrammetric Inspection

Wind Turbine Blade

- 3.1m height
- 386mm wide (top); 619mm wide (bottom)
- Prior-prepared Surface



Texture



Dots

Photogrammetric Inspection

AscTec Firefly UAV

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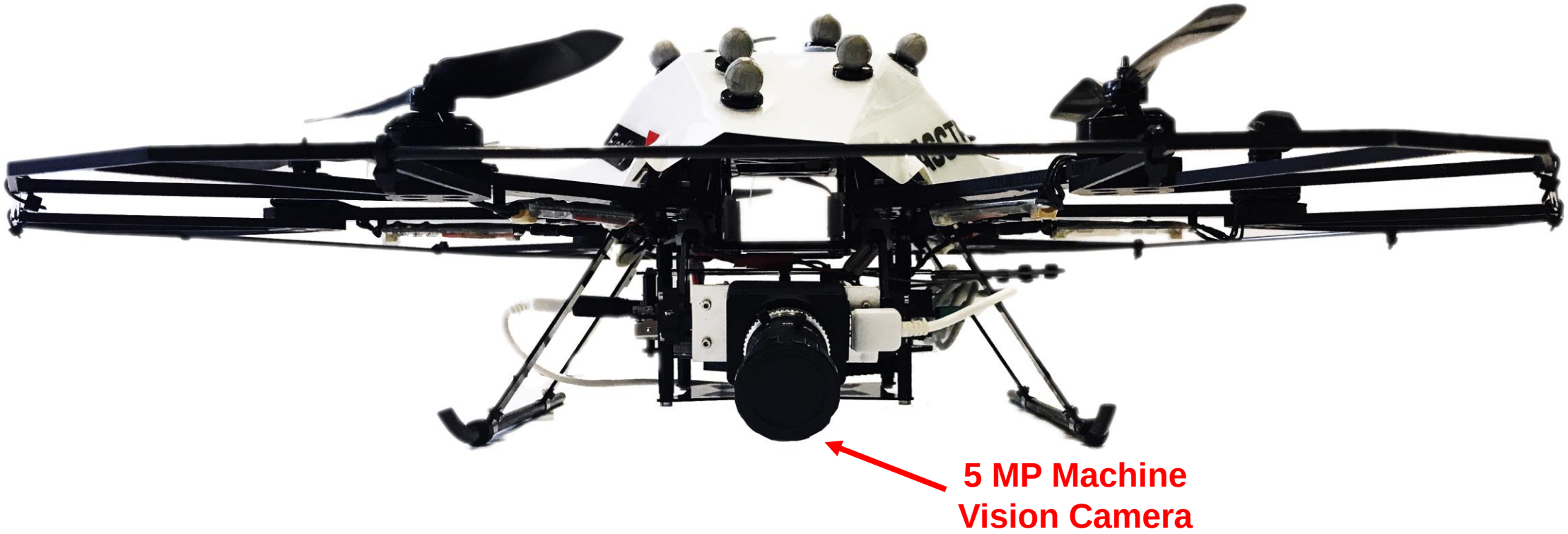


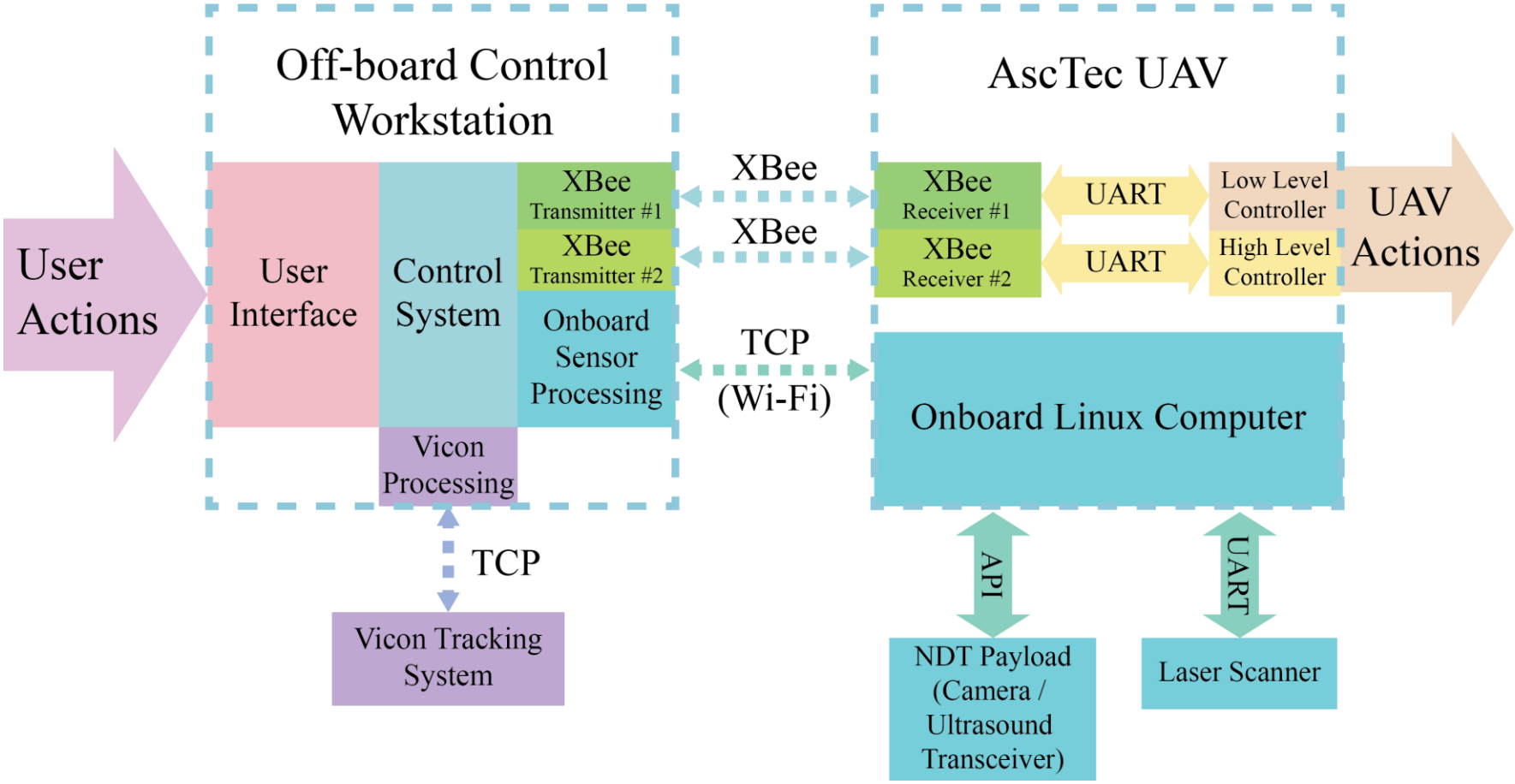
Photogrammetric Inspection

Measurement Sensor - Vicon Tracking System

- 12 Vicon cameras mounted on the frame
- Vicon Tracking System provides position and orientation of the UAV (similar to GPS and accelerometer)

Photogrammetric Inspection

System Diagram



Photogrammetric Inspection

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Photogrammetric Inspection

Photogrammetric Inspection

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Results – 3D Reconstruction

Image Comparison

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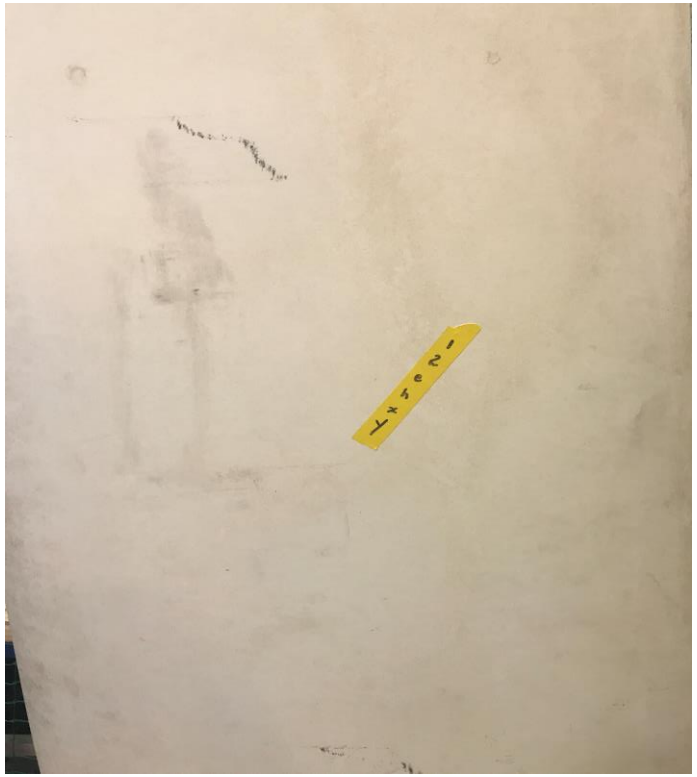
Reconstructed Model

Reference Image



Results – 3D Reconstruction

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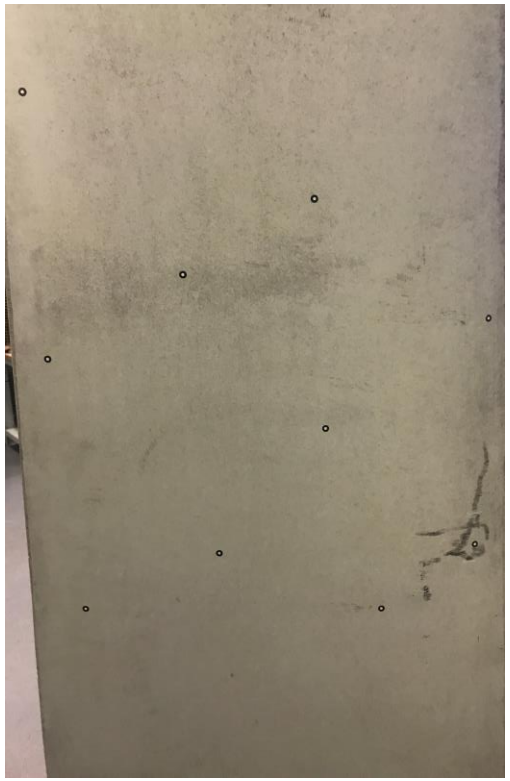
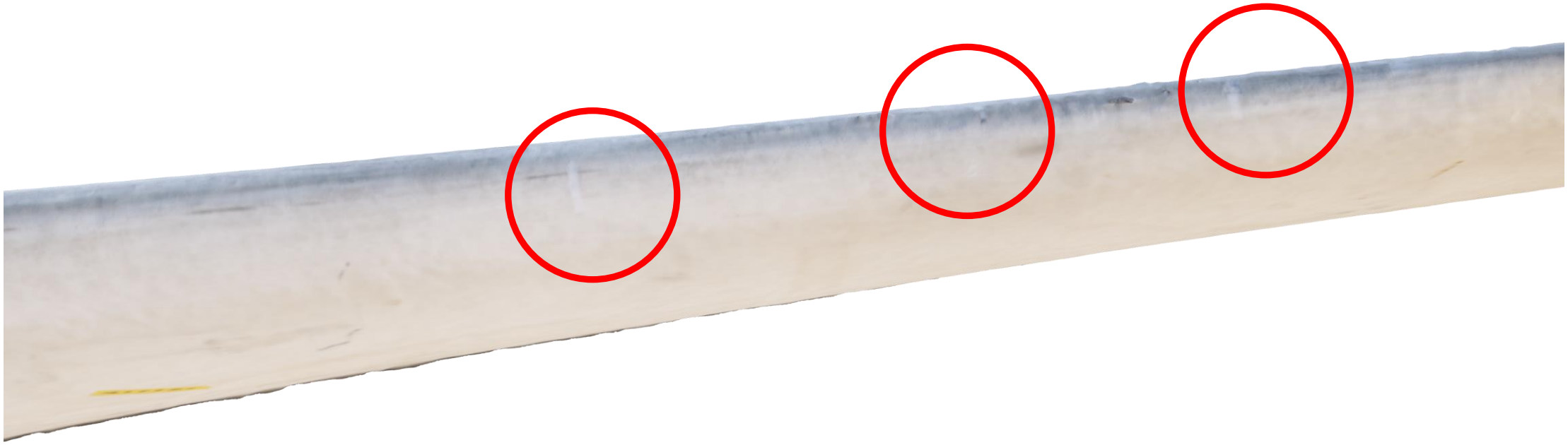
Reconstructed Model

Reference Image



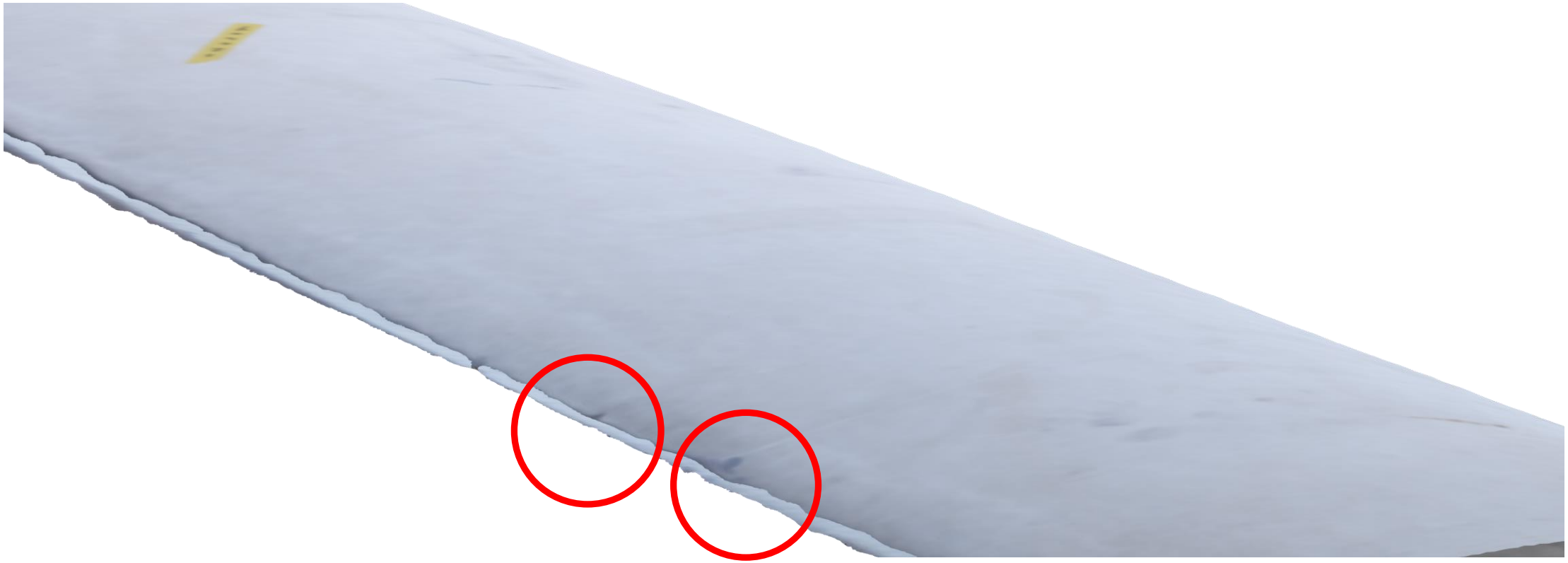
Results – 3D Reconstruction

Defects on Leading Edge



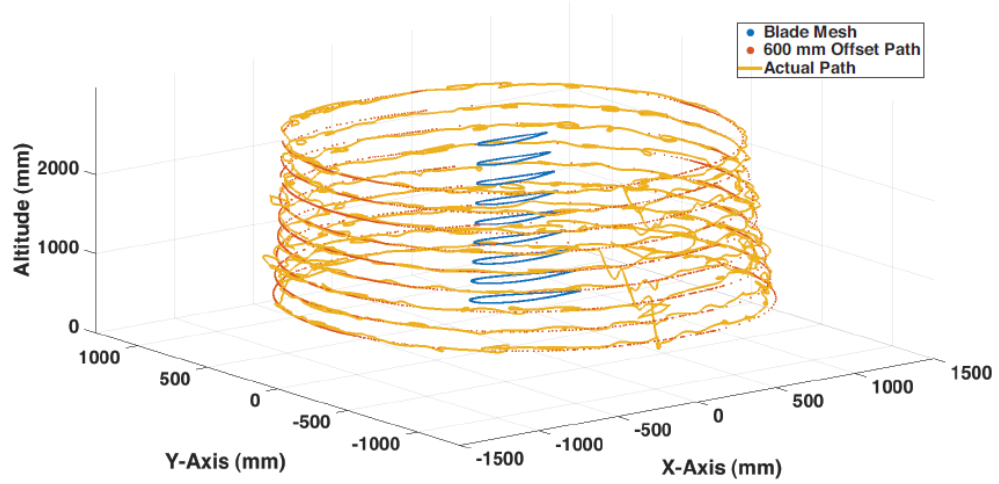
Results – 3D Reconstruction

Defects on Trailing Edge



Photogrammetric Inspection

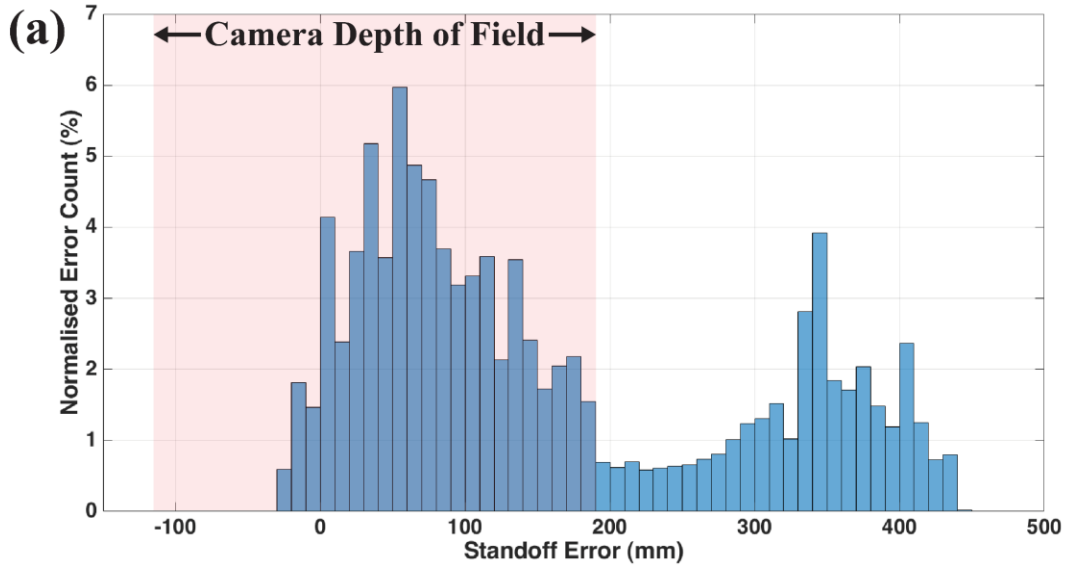
Laser Maintained Standoff



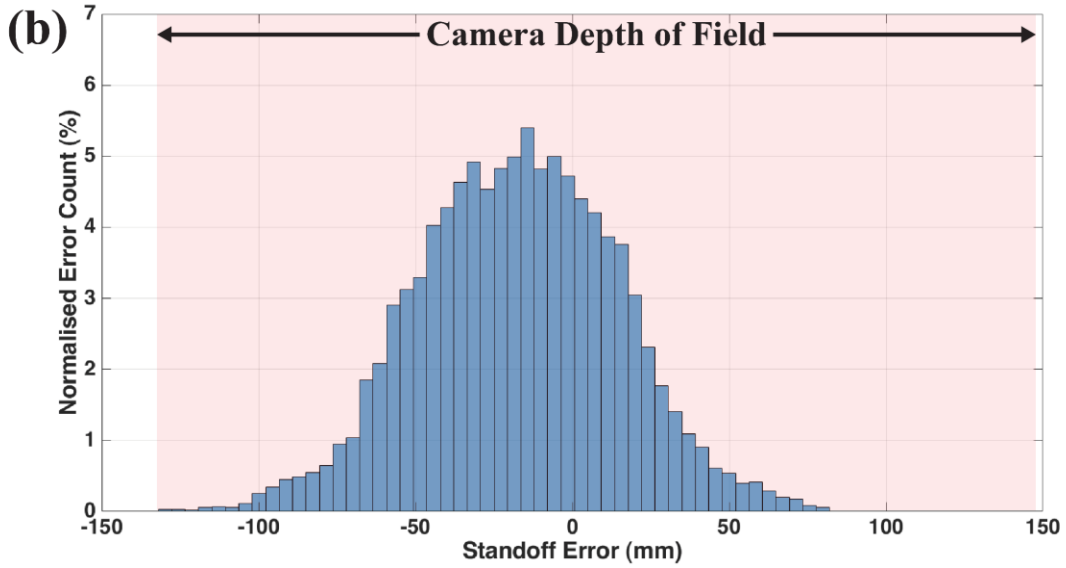
- During the close-range inspections, camera depth of field is typically narrow (319.7 mm). Varying standoff can introduce focal blur and influence inspection accuracy.
- Hokuyo URG04-LX scanner on top of the UAV is utilised to map surroundings, maintain constant standoff during inspections.

Photogrammetric Inspection

Laser Maintained Standoff



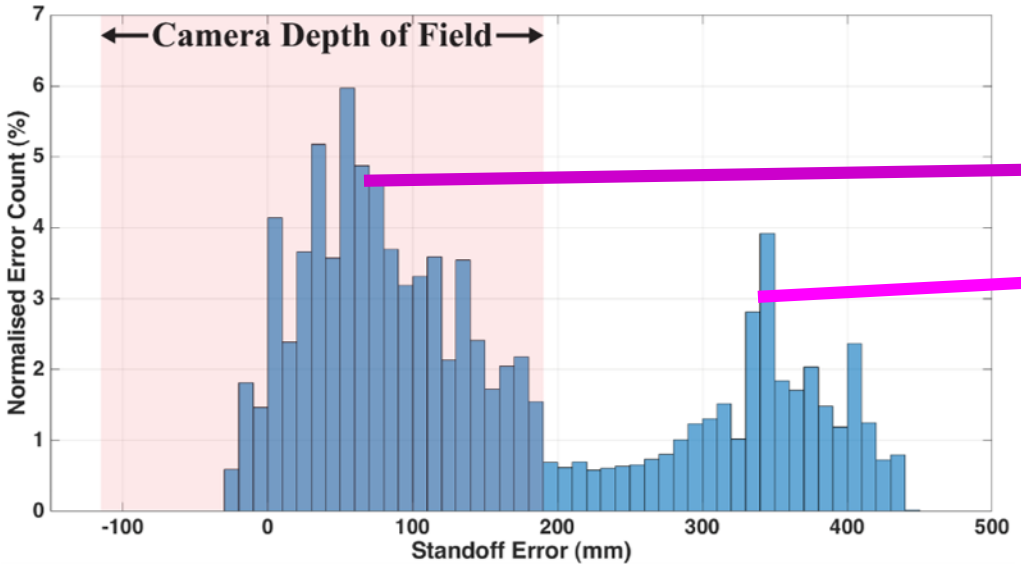
Without Laser

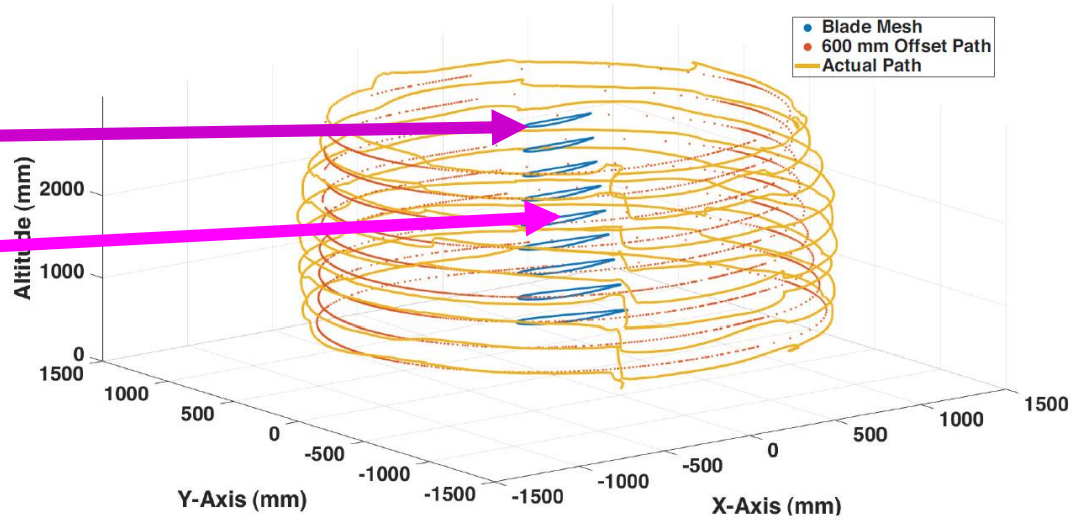


With Laser

Photogrammetric Inspection

Laser Maintained Standoff

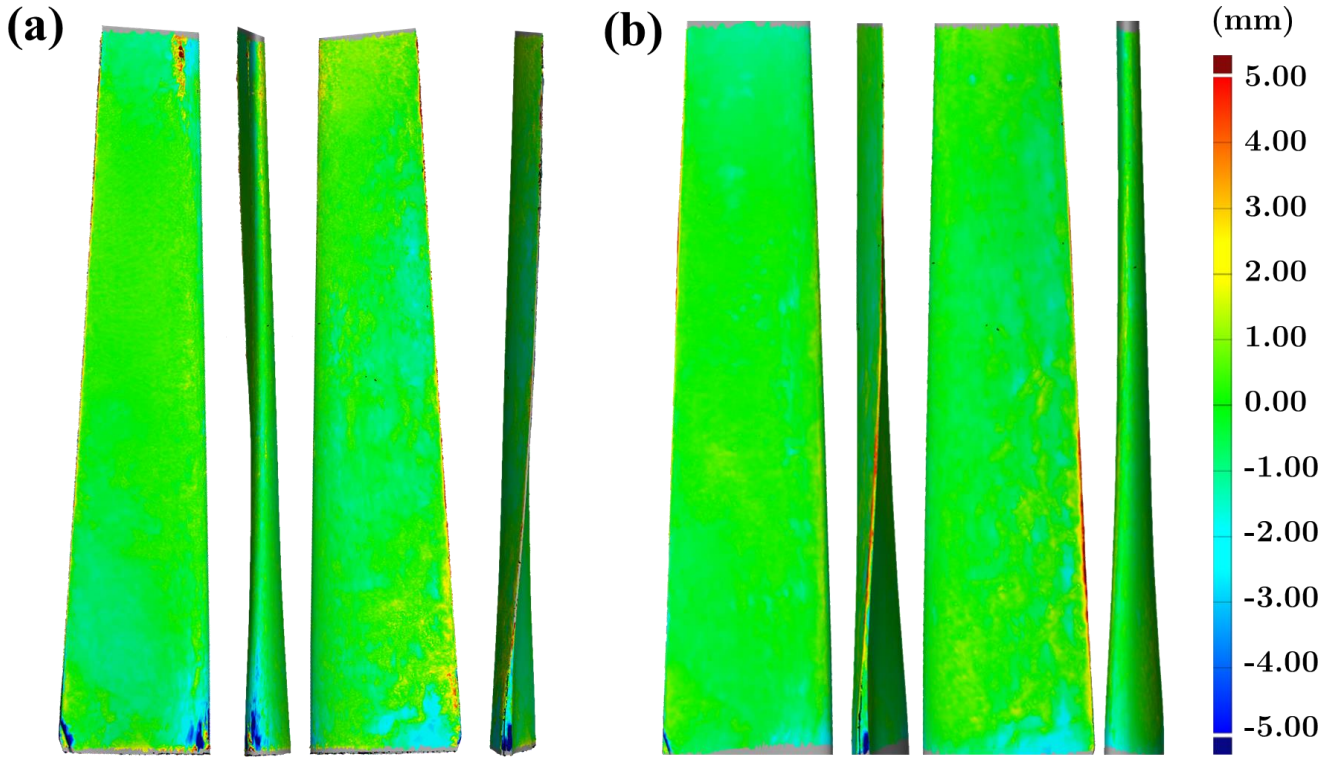




Without Laser

Photogrammetric Inspection

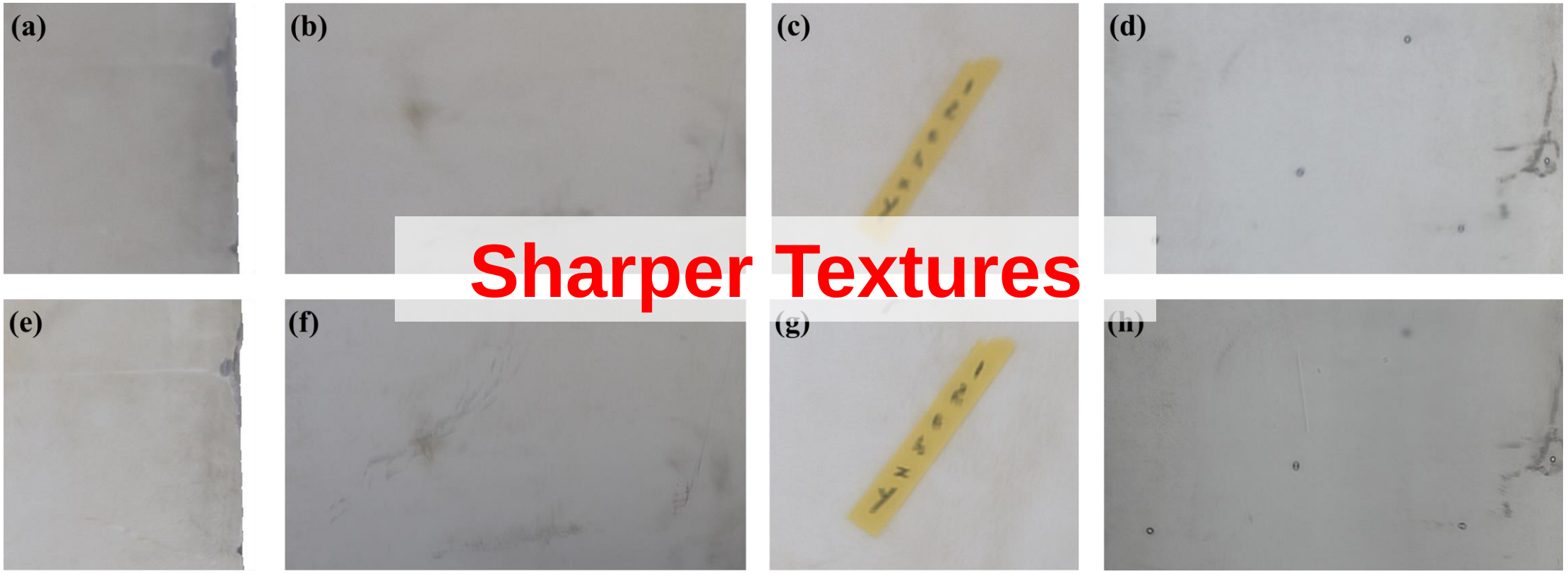
Laser Maintained Standoff



	Mean Error (mm)	Standard Deviation Error(mm)	Peak-to-peak Error (mm)
Circular	0.3853	1.56	13.56
Laser-based Path	0.3098	1.29	5.09

Photogrammetric Inspection

Laser Maintained Standoff



Textures on the reconstructed model (a)~(d) without laser (e)~(h) with laser

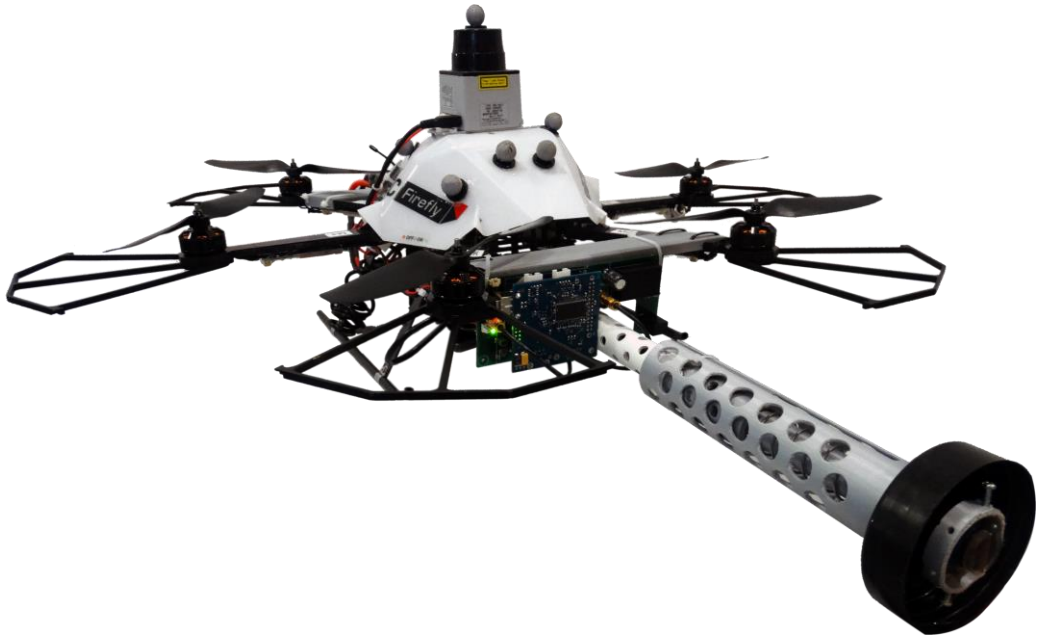
Photogrammetric Inspection
Other Parameters

- Environmental Brightness Condition
  - Poor light condition, doubled the error.
- Motion Blur
  - Increase the standard deviation and peak-to-peak error by almost a factor of two, compared with a manual inspection result.
- Over the range of parameter values studied, the poorest scenario was observed to cause a degradation in reconstruction error by a factor of **13** versus the optimal.

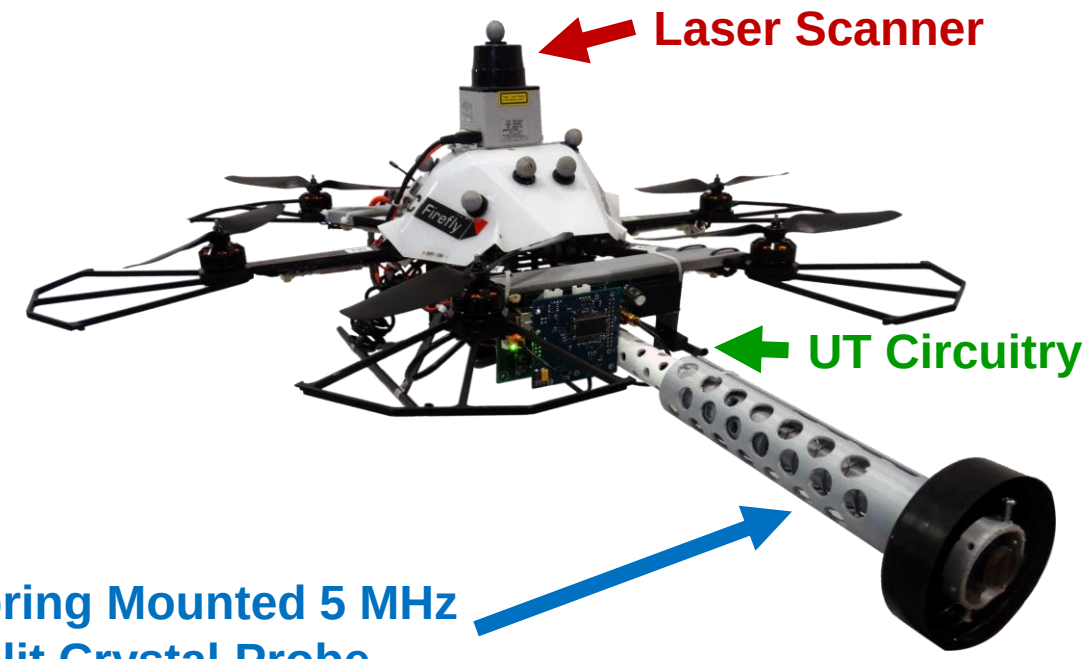
Photogrammetry offers surface inspection,
What about **internal structures**?

Ultrasonic Inspection

- To perform detailed and internal structural inspections, we developed an autonomous UAV system to deploy ultrasonic thickness measurement of a vertical aluminium sample.



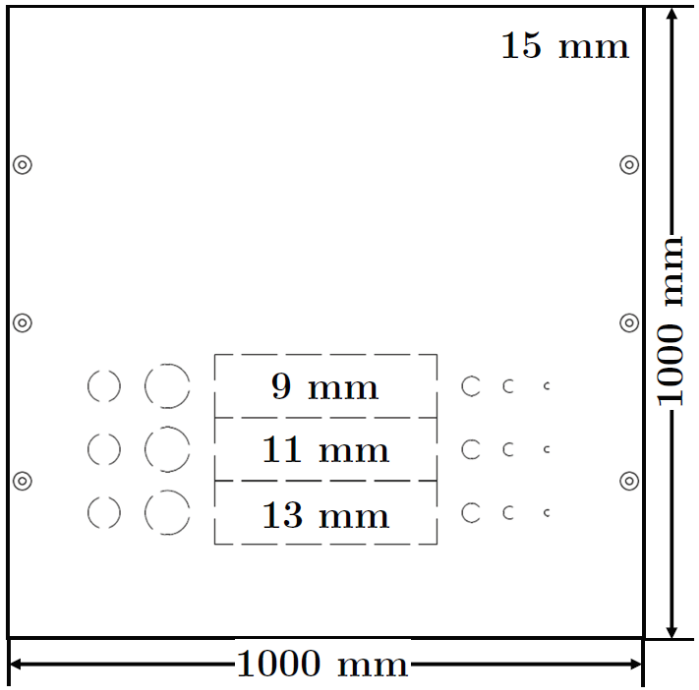
Ultrasonic Inspection

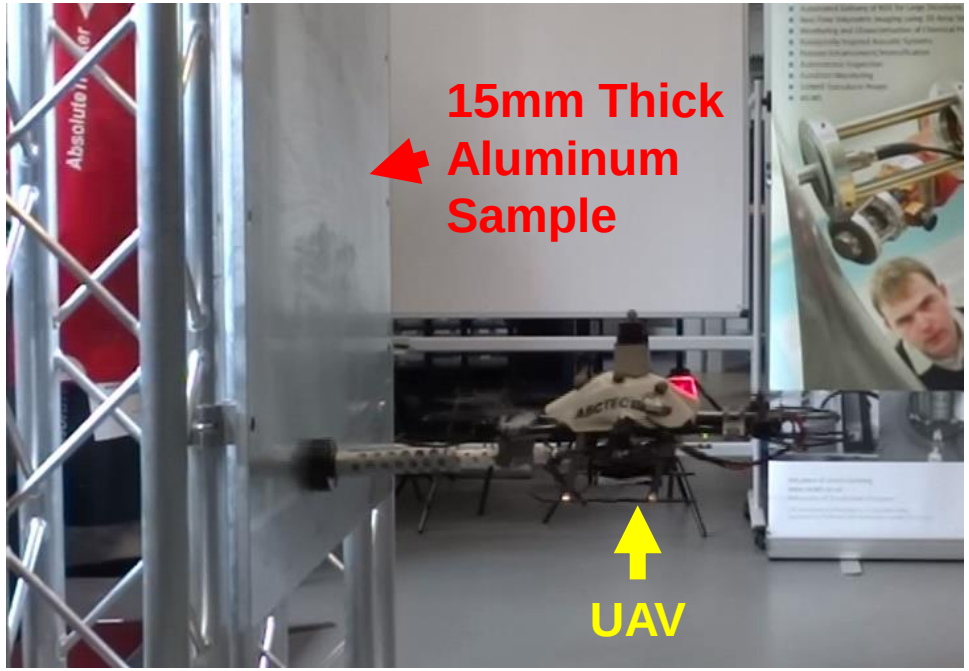


- Fully autonomous flight control, covering approach, measurement and retraction.
- The ultrasonic transceiver was fully integrated into the UAV.
- An ultrasound generation and acquisition circuity was integrated into the UAV system. This excites a 5 MHz split crystal (10mm) probe with a 180 V pulse.
- The probe is a conventional contact probe, manufactured by GB Inspections.

Ultrasonic Inspection

- A 1000x1000x15 mm aluminium plate was fabricated to simulate an industrial asset.





Ultrasonic Inspection

Measurement Flight Path

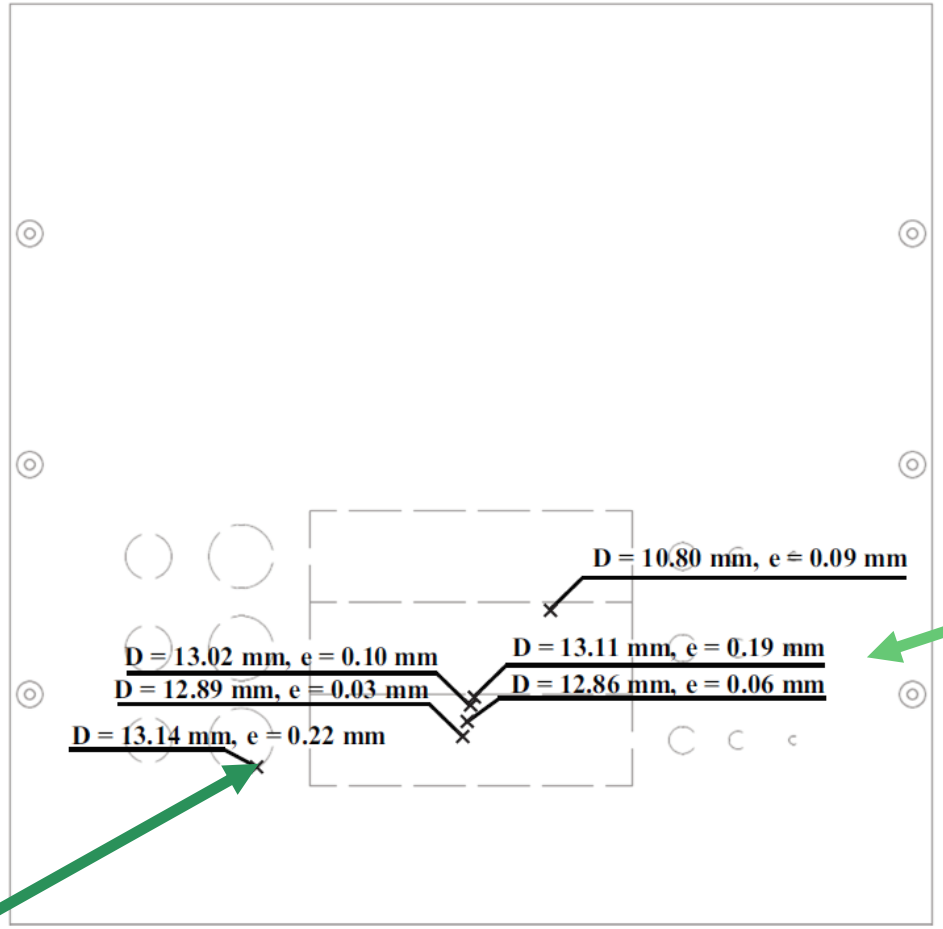
The UAV initially rises to a certain height and stabilise itself.

The UAV is guided closer to the asset until the ultrasonic probe at the front of the arm contacts the inspection surface.

The UAV retreats to a large standoff distance. The UAV thereby leaves the asset surface and makes ready for the next point measurement.

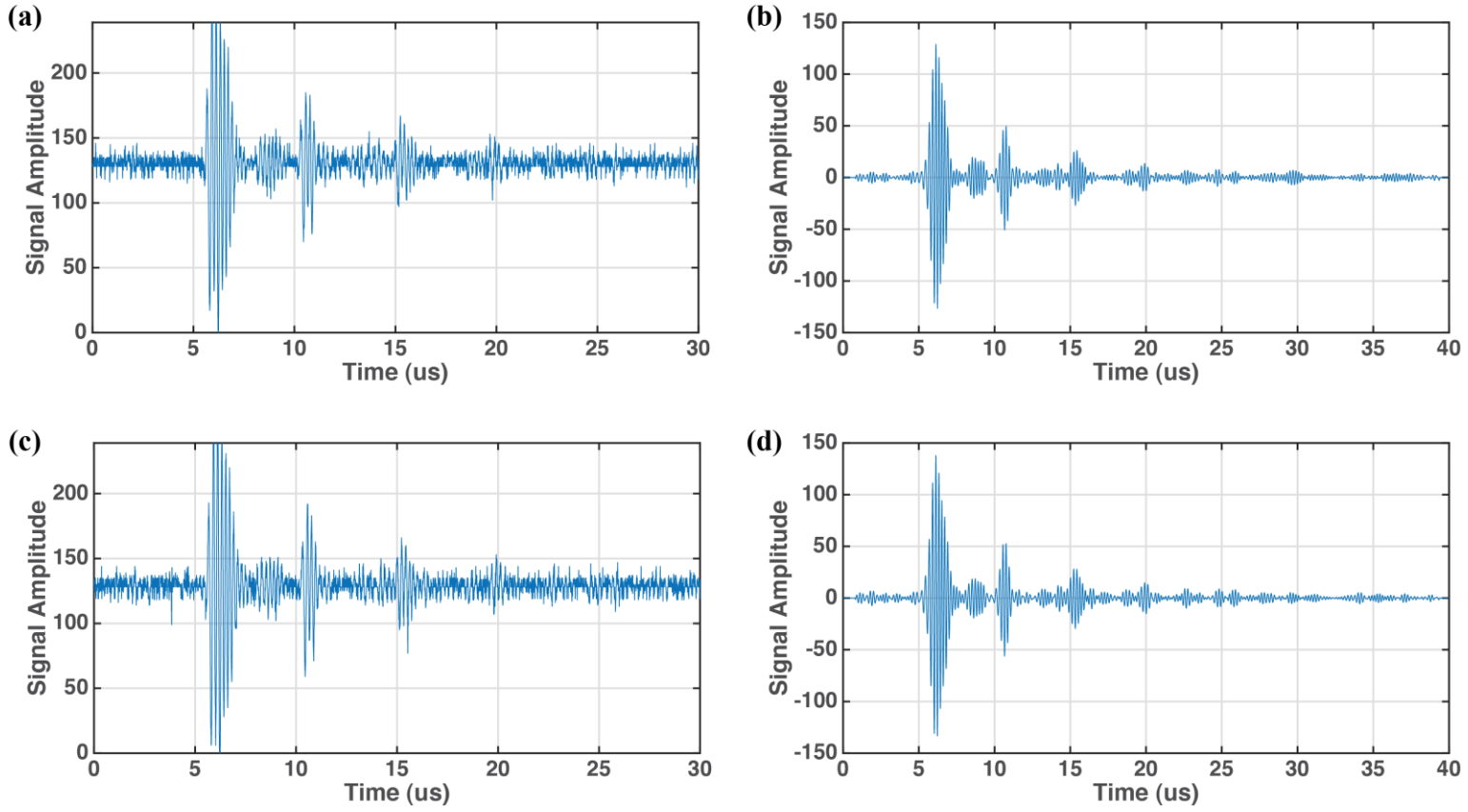
Ultrasonic Inspection

Results



Ultrasonic Inspection
Constraints

- Electrical Noise

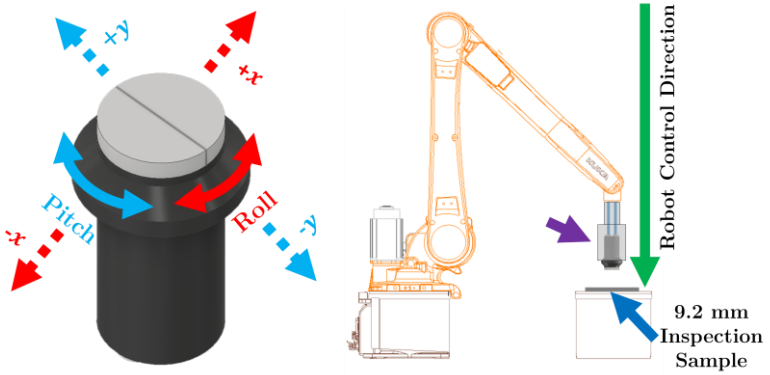


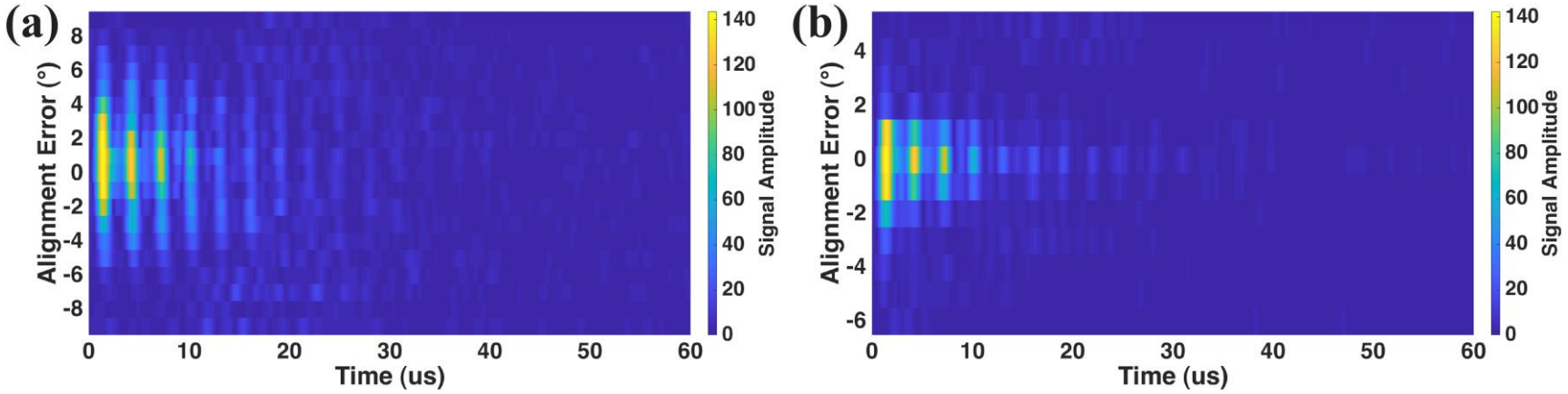
Thickness measurement signals (a) raw A-scan when the motors were stationary (b) processed A-scan when the motors were stationary (c) raw A-scan when the motors were rotating (d) processed A-scan when the motors were rotating

Ultrasonic Inspection

Constraints

- The inspection accuracy depends on:
  - Probe Alignment Angle
    - ± 6° on roll angle and ± 3° on pitch angle





A-scan signals with different transducer alignment errors (a) the transducer roll angle was adjusted between ±9° (b) the transducer pitch angle was adjusted between ±6°

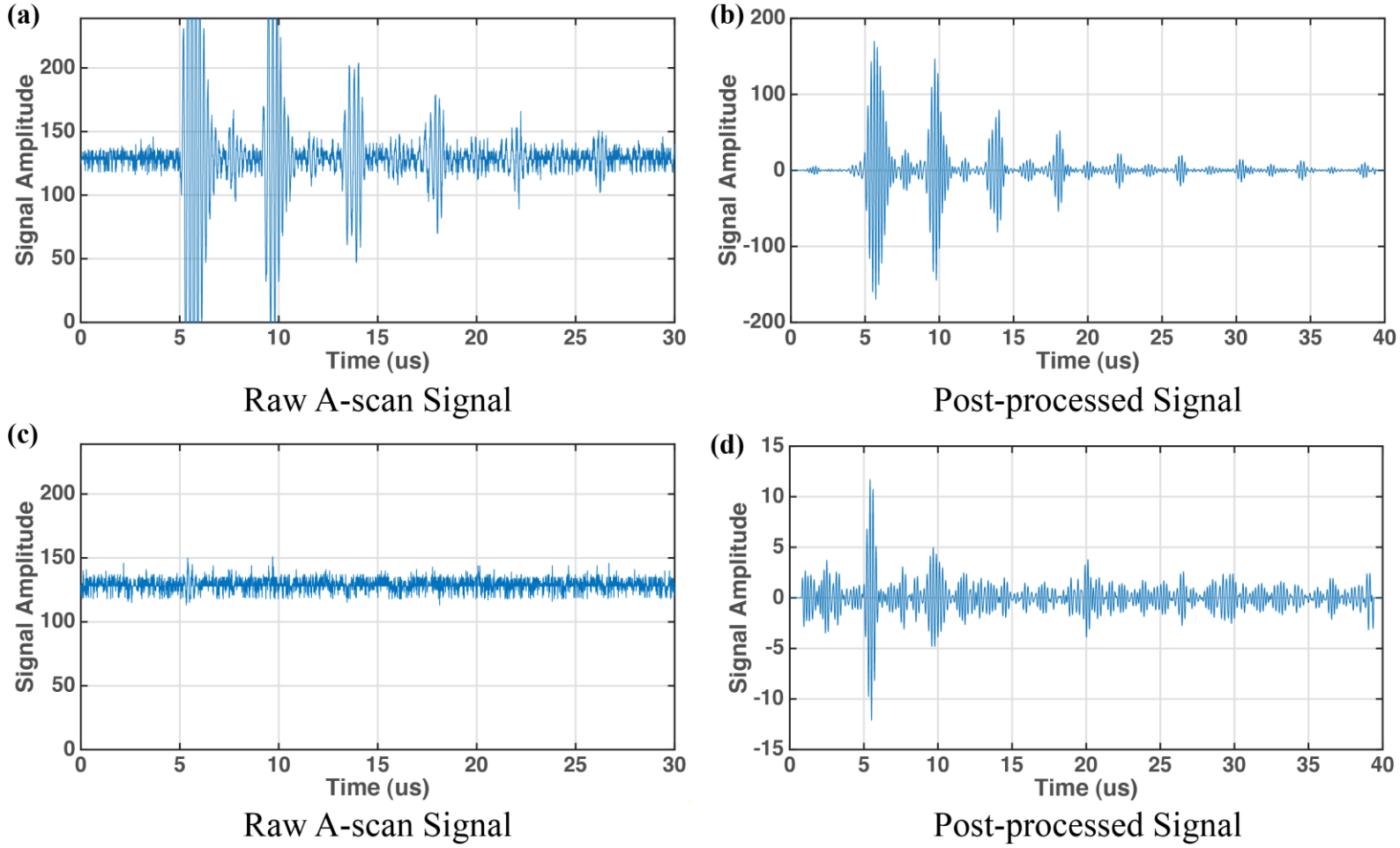
Ultrasonic Inspection

UAV Positional Accuracy

- Near-surface aerodynamic challenges
- UAV payload mass capacity
- These increased the yaw angle error from 1.19° to 2.71°, positional error from 24.01 mm to 63.26 mm.
- Such positional error may represent an obstacle in terms of repeatability, but a meaningful inspection may be conducted so long as the precise deployment position can be accurately recorded.

Ultrasonic Inspection

Results



(a)(b) are from the measurements with 1.21° pitch error and 0.07°yaw error
(c)(d) are from the inspection with 1.61° pitch error and 2.01°yaw error

Conclusions

- ✓Successfully implemented remote photogrammetric inspection of wind turbine blades with UAV.
- ✓UAV standoff was maintained by the laser scanner, which improved inspection accuracy.
- ✓Successfully implemented contact-based ultrasonic inspection of a vertical mounted aluminium sample with UAV.

Future Works

- For photogrammetric inspections:
  - Further improved inspections accuracy
  - Enhanced inspection visualisations, such as defects classification.
  - Outdoor inspection trial
- For ultrasonic inspections:
  - We are investigating alternative mechanical solutions to lessen the challenges of probe alignment and weight.
  - Dry-coupled wheel probe is under investigation.

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Thanks

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