Advances in Contact-Based Non-Destructive Evaluation using Unmanned Aerial Vehicles

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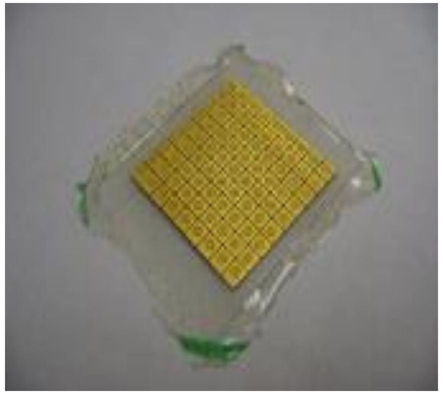
1.

1. Non-Destructive Testing, Available: http://www.quality2013.eu/wp-content/uploads/2015/07/Nondestructive-Testing.jpg, Accessed 7/11/17

Introduction

CUE Background

- Founded in 1980
- Based in Electronic & Electrical Engineering
- 11 Academics; 25 postdocs;
  35 research students; 7 support staff
- Backgrounds in EEE, Mechanical Eng, Physics, Polymer Science, Biology, Mathematics
- **Strong Industrial Focus**
  - **Founding member of RCNDE**
- **Excellent range of facilities:**
  - **Phased Array Controllers**
  - **Robotic Manipulators**
  - **Transducer Fabrication**
  - **Fusion Welding Cells**
  - **Precision Motion Tracking**
  - **Materials Characterisation**



Introduction

Motivation for automated NDE

- Desire for faster, cheaper, safer inspection
- Applications across the energy sector
- Physical health assessment for remaining useful life decisions
- Industry demands more rigorous inspection techniques
- Provides a data rich, fully traceable, objective inspection report

1. Skyspecs Automated Wind Turbine Inspection, Available: https://skyspecs.com/wp-content/uploads/2019/02/skyspecs_automated_inspection2.png, Accessed 19/08/2020
2. Corrosion Management For Storage Facilities Using NDT, Available: https://nexxis.com/corrosion-management-for-storage-facilities-using-ndt/, Accessed 20/08/2020
3. Cyberhawk UAV Inspetion – Shell, Available: https://www.youtube.com/watch?v=71_NYF-5tnk, Accessed 24/06/2020

Introduction

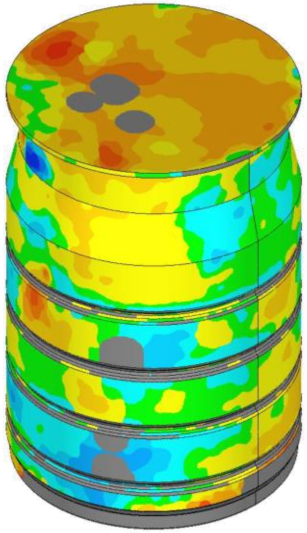
Non-Destructive Evaluation with UAVs

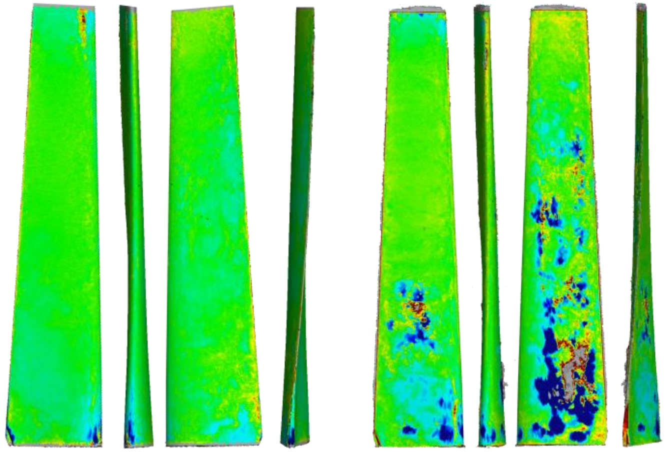
Benefits of aerial systems:

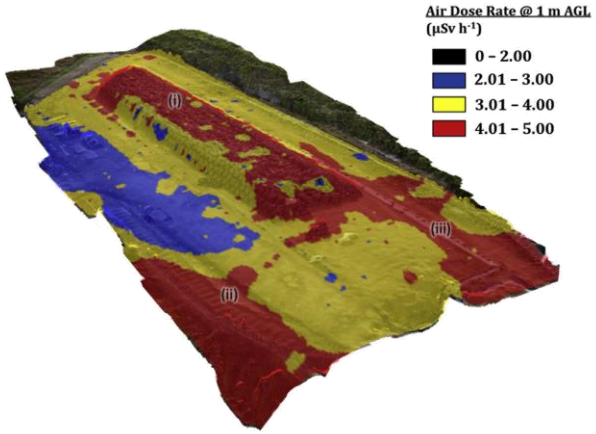
- Safety
- Mobility
- Cost effectiveness

Existing applications:

- Visual screening
- Photogrammetric reconstruction
- Data fusion and localisation





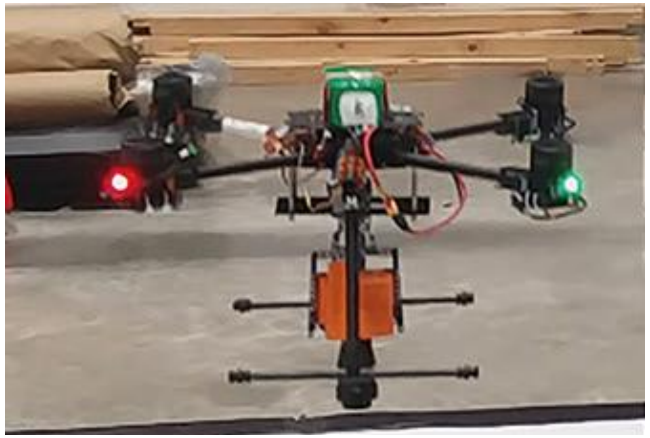


Limited to surface exposed features

1. R. A. Clark *et al.*, ‘Autonomous and scalable control for remote inspection with multiple aerial vehicles’, *Robotics and Autonomous Systems*, vol. 87, pp. 258–268, Jan. 2017, doi: 10.1016/j.robot.2016.10.012.
2. D. Zhang, R. Watson, G. Dobie, C. MacLeod, A. Khan, and G. Pierce, ‘Quantifying impacts on remote photogrammetric inspection using unmanned aerial vehicles’, *Engineering Structures*, vol. 209, p. 109940, Apr. 2020, doi: 10.1016/j.engstruct.2019.109940.
3. D. T. Connor *et al.*, “Application of airborne photogrammetry for the visualisation and assessment of contamination migration arising from a Fukushima waste storage facility,” *Environ. Pollut.*, vol. 234, pp. 610–619, Mar. 2018, doi: 10.1016/j.envpol.2017.10.098.

Introduction

Aerial Ultrasonic NDE



Ultrasonic inspection:

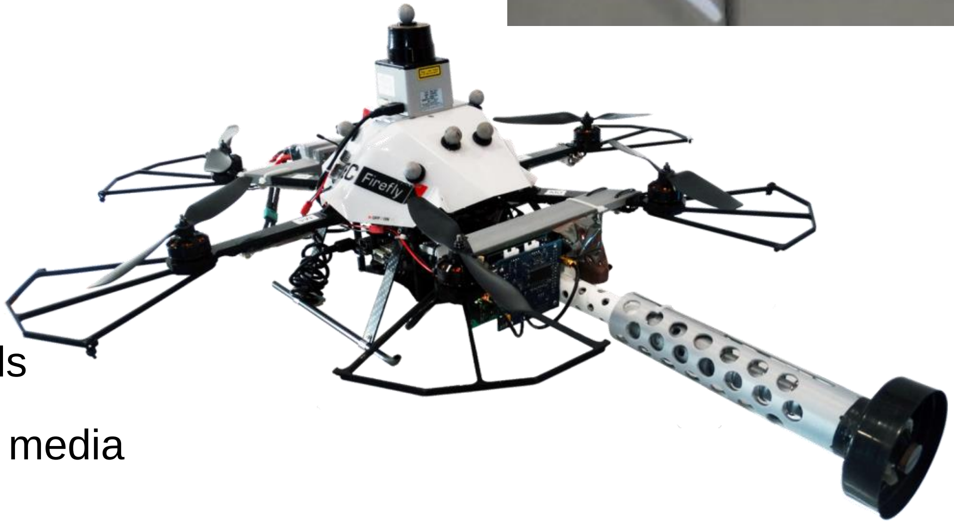
- Established principles and applications
- Rigorous quantitative data acquisition
- Volumetric structural health measurement

Applications:

- Corrosion monitoring
- Crack detection & sizing

Limiting factors:

- Signals in complex materials
- Requires acoustic coupling media



Comparatively limited UAV deployment

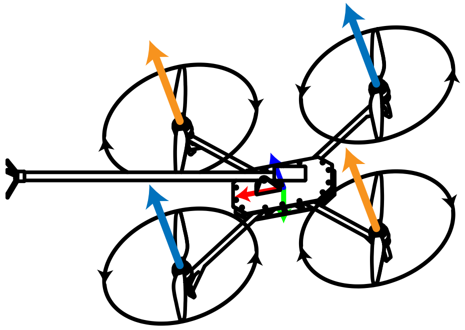
1. L. M. González-deSantos, J. Martínez-Sánchez, H. González-Jorge, F. Navarro-Medina, and P. Arias, 'UAV payload with collision mitigation for contact inspection', *Automation in Construction*, vol. 115, p. 103200, Mar. 2020, doi: 10.1016/j.autcon.2020.103200.
2. R. Jarvis, A. Farinha, M. Kovac, and F. Cegla, 'NDE sensor delivery using unmanned aerial vehicles', *Insight - Non-Destructive Testing and Condition Monitoring*, vol. 60, no. 8, pp. 463–467, Aug. 2018, doi: 10.1784/insi.2018.60.8.463.
3. B. B. Kocer, T. Tjahjowidodo, M. Pratama, and G. G. L. Seet, 'Inspection-while-flying: An autonomous contact-based nondestructive test using UAV-tools', *Automation in Construction*, vol. 106, p. 102895, Oct. 2019, doi: 10.1016/j.autcon.2019.102895.
4. D. Zhang, R. Watson, C. MacLeod, G. Dobie, W. Galbraith, and G. Pierce, 'Implementation and evaluation of an autonomous airborne ultrasound inspection system', *Nondestructive Testing and Evaluation*. Feb. 2021, doi: 10.1080/10589759.2021.1889546

Challenges of Aerial Ultrasonics

UAV Platform Dynamics

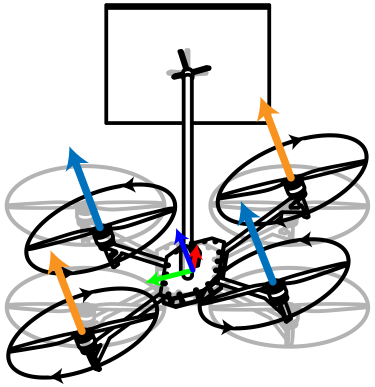
Environmental interaction

Interaction Mechanism



Tilted Body

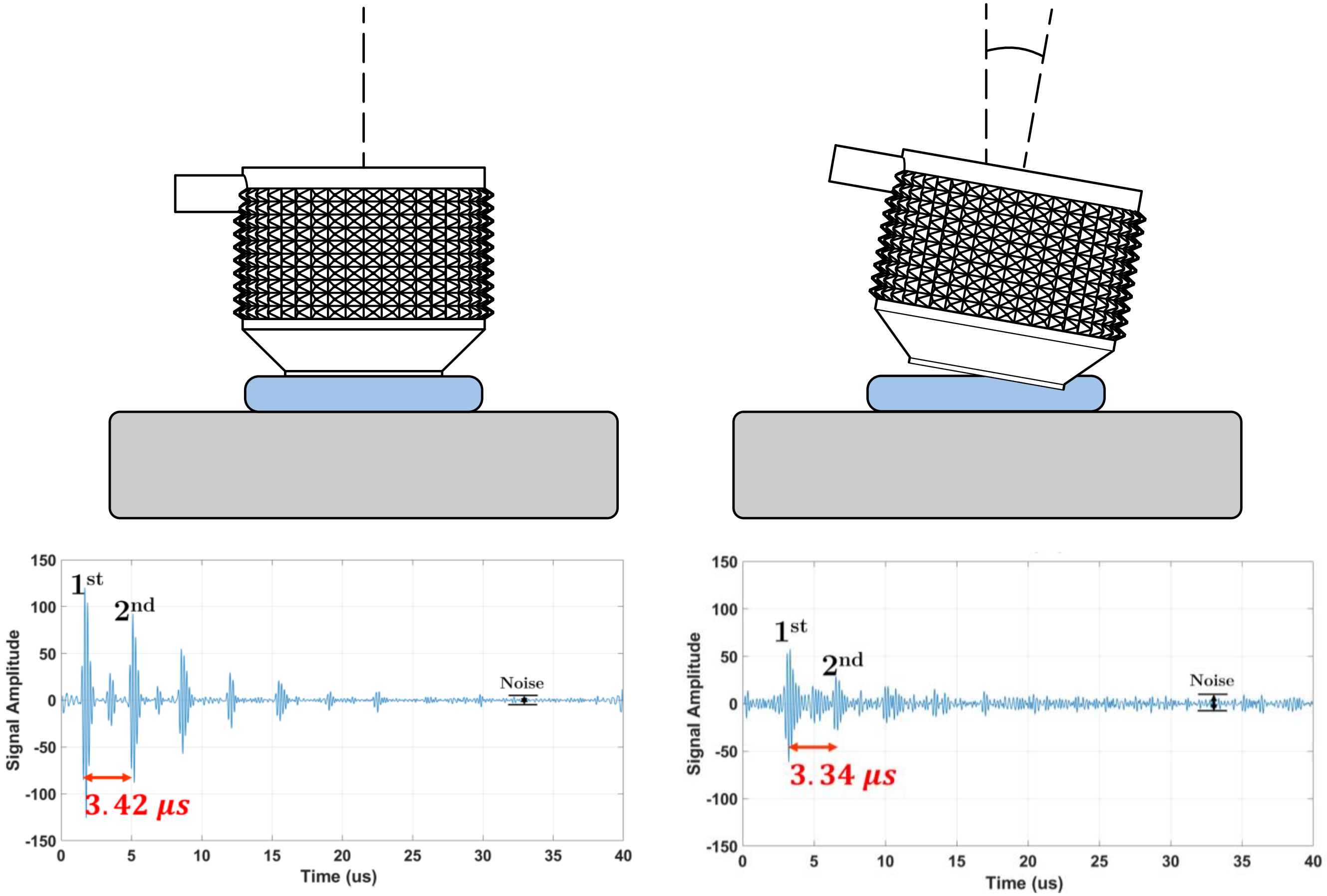
Disturbance Rejection



Roll into gust

Acoustic Coupling

Gel application & Relative orientation



Aerial Robotics

Platform design for environmental interaction

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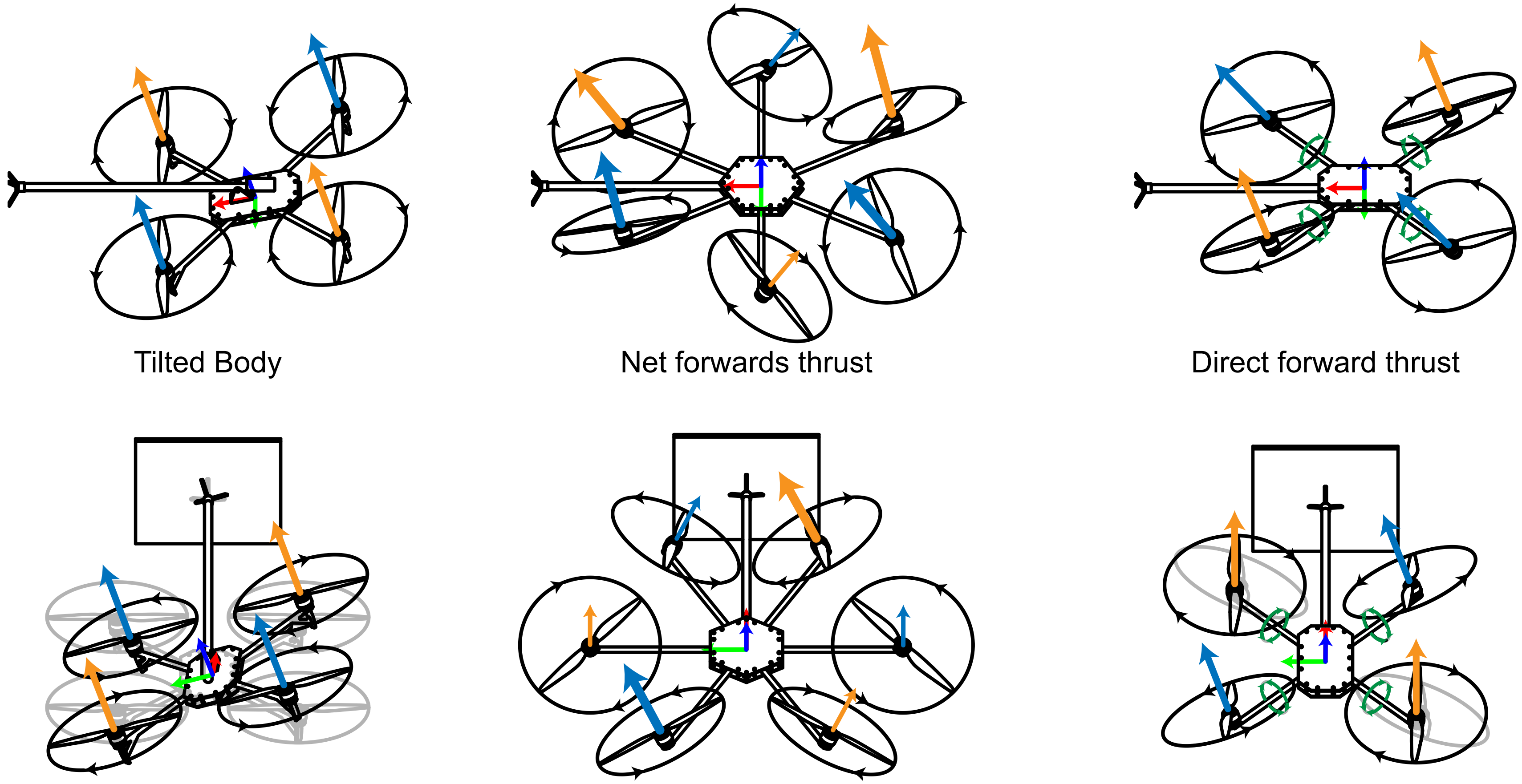
Under-Actuated | **Fully or Over-Actuated**

Unidirectional Thrust | Multidirectional Thrust | Vectored Thrust

Interaction Mechanism | **Disturbance Rejection**



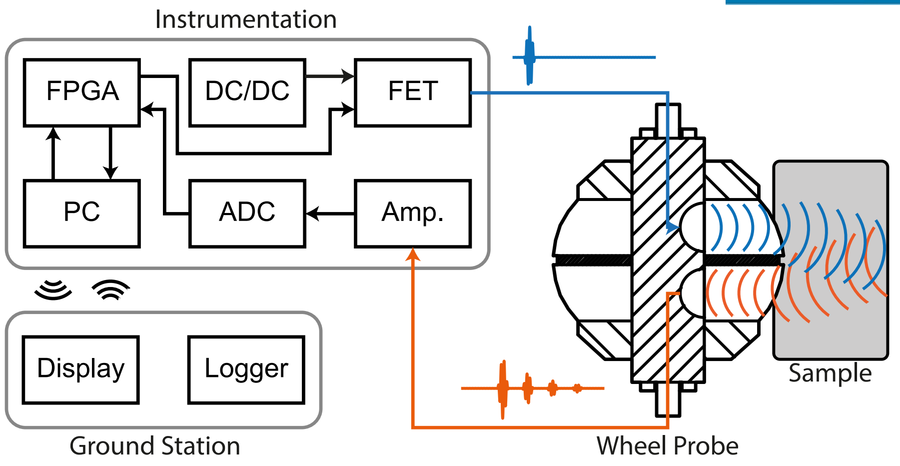
Tilted Body | Net forwards thrust | Direct forward thrust

Roll into gust | Alter thrust composition | Vector towards distrubance

An Improved Inspection System

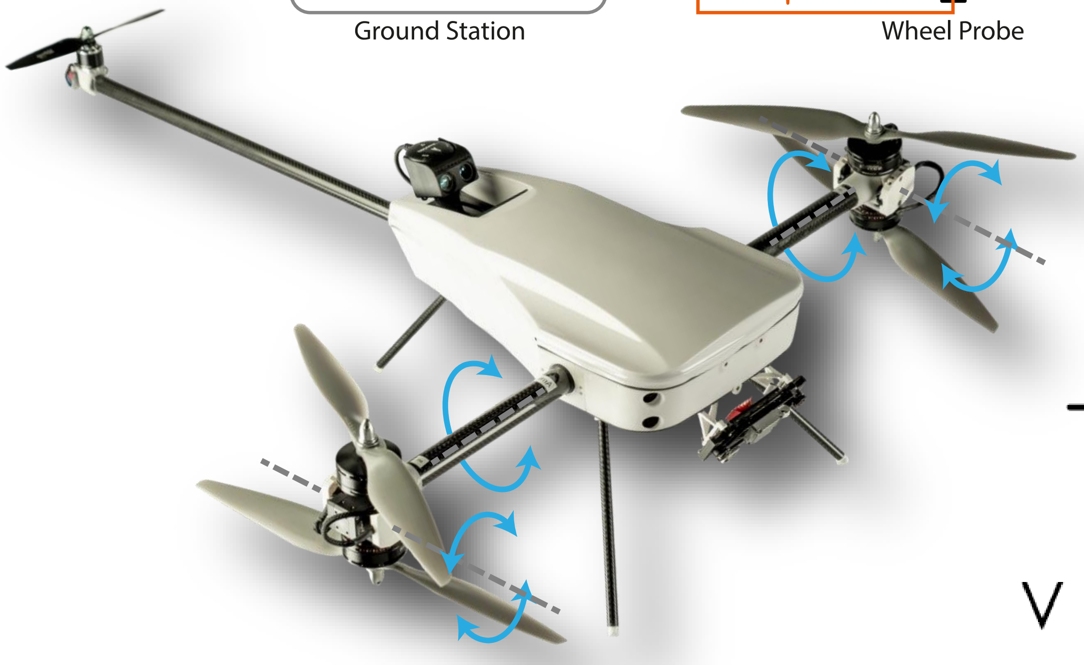
Transducer:

- Dry-coupled dual-element wheel probe
  - Mitigates issues associated with coupling gel
  - Better suited to scanning
  - Can be customised to application
- Integrated instrumentation



Upgraded UAV Platform:

- Voliro Dragonfly
  - Over-actuated system
  - Efficient, fully-vectored thrust
- Enables physical interaction
  - Stable environmental force exertion
  - Strong disturbance rejection



Performance Quantification?

1. R. J. Watson *et al.*, 'Deployment of Contact-Based Ultrasonic Thickness Measurements Using Over-Actuated UAVs', in *European Workshop on Structural Health Monitoring*, Cham, 2021, pp. 683–694. doi: 10.1007/978-3-030-64594-6_66.


Point Measurement
Repeatability

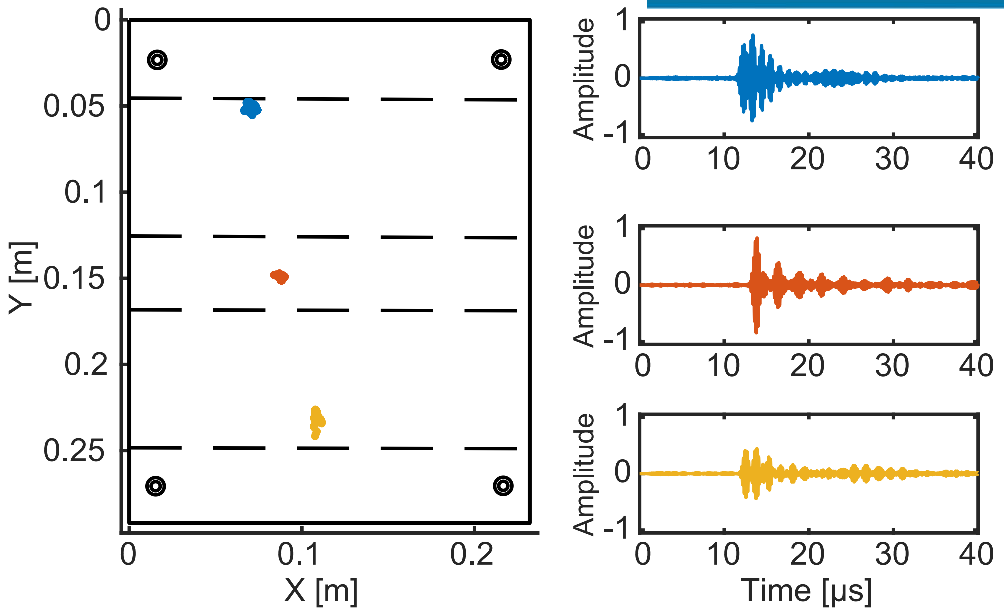

Underside Access of
Overhanging Structures

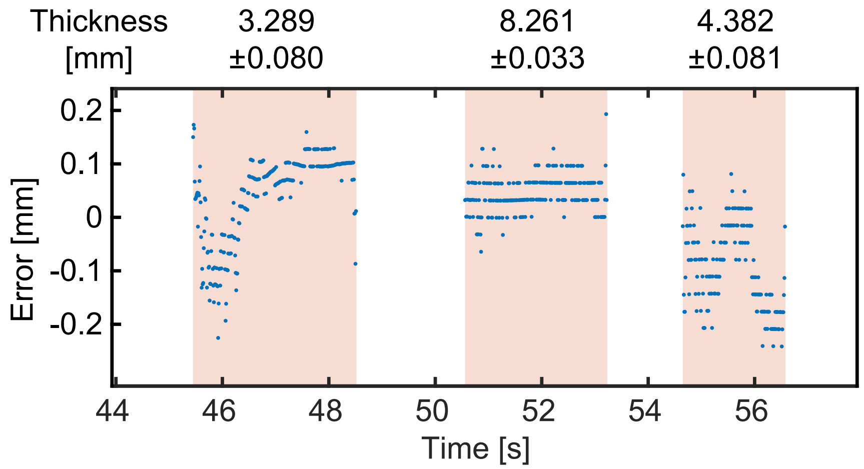
Results: Point Contact Inspection

Ultrasonic Measurement Accuracy

- Combining pose and contact identification
  - Can compare to nominal geometry for corrosion mapping
  - Repeated measurements allow construction of thickness map
  - Allows profiling of target over time
- Quantitative assessment
  - Comparison to independently captured reference geometry
  - Errors:

Number of Readings	Mean Absolute Error (mm)	5th Percentile Error (mm)	Mean Error (mm)	95th Percentile Error (mm)
766	0.0766	-0.1766	0.0112	0.1068



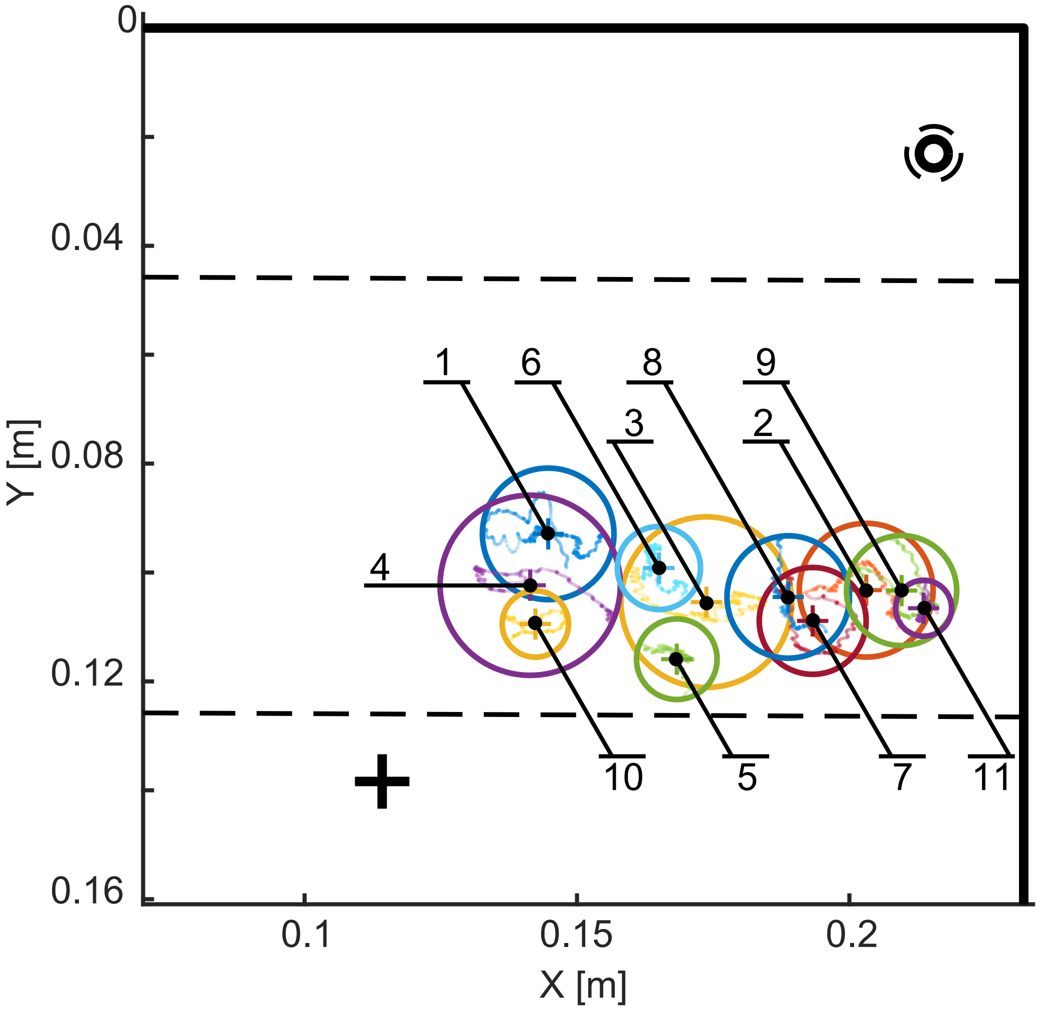


Results: Point Contact Inspection

Positioning accuracy and repeatability

- Effect of control versus measurement
- Mean distance to target: 73 mm
- Grouping radius: 37 mm
- Max. pose uncertainty: 16.55 mm
- Average Thickness MAE: 0.095 mm

Point Number	Number of Samples	Center (X, Y) [mm]		Position Uncertainty Radius [mm]	Thickness MAE [mm]	SNR [dB]	Distance to Target [mm]
1	653	144.71	92.91	12.08	0.106	29.79	54.74
2	323	203.08	103.25	12.29	0.111	39.39	95.54
3	385	173.75	105.45	15.67	0.142	35.32	68.01
4	320	141.41	102.35	16.55	0.036	39.40	45.13
5	323	168.31	115.93	7.40	0.079	39.53	58.55
6	393	165.04	99.17	7.63	0.155	39.96	64.17
7	308	193.27	108.89	9.81	0.073	36.63	84.35
8	260	188.77	104.50	11.24	0.072	38.92	81.87
9	351	209.58	103.32	10.11	0.148	31.58	101.58
10	242	142.36	109.46	6.09	0.091	33.02	40.34
11	204	213.62	106.56	5.14	0.029	38.86	104.35




Dynamic Scanning
Data Acquisition

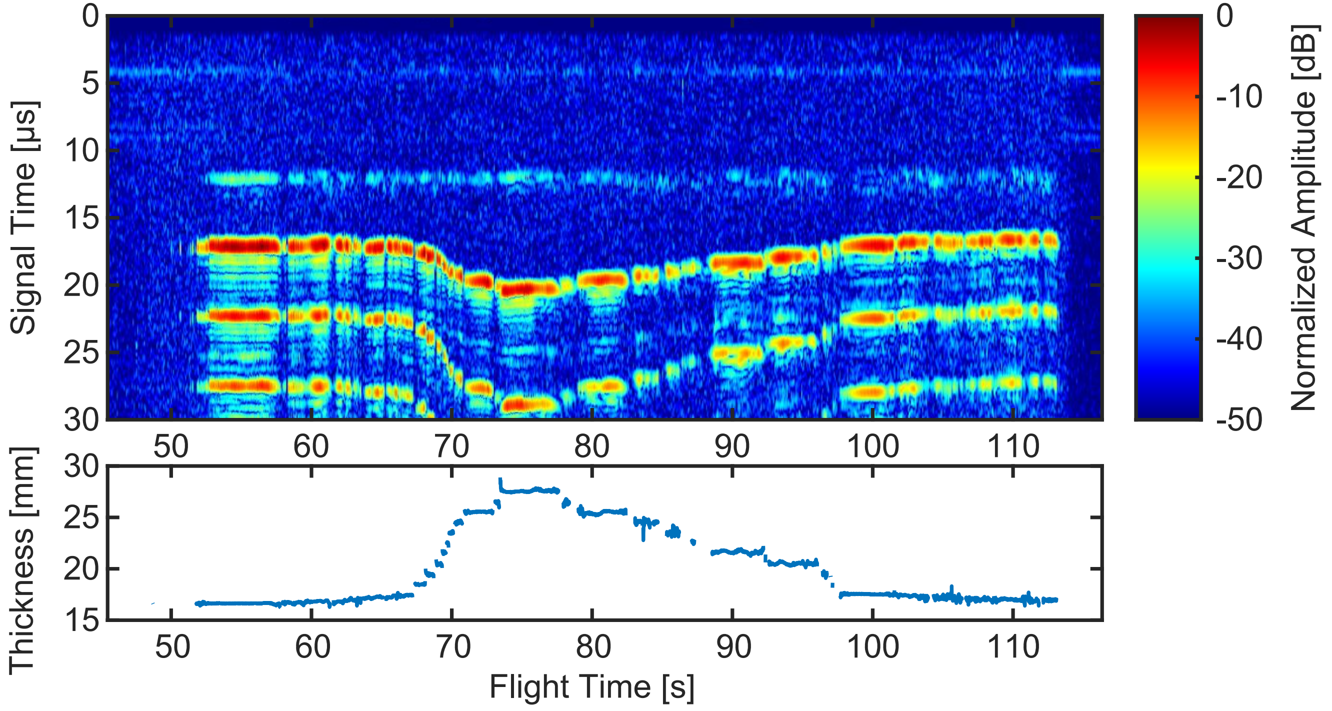
Results

Scanning Acquisition:

- Provides a “B-Scan” cross-sectional view through component
- All features in 0.71 m swept path captured in under 65 s
- Usable measurements at success rate of 86.44 %
- Largest region of null coverage 10.9 mm
- Errors:

Number of Readings	Mean Absolute Error (mm)	5th Percentile Error (mm)	Mean Error (mm)	95th Percentile Error (mm)
5197	0.2788	-1.0553	-0.1416	0.7389

Successfully resolved all features in swept path



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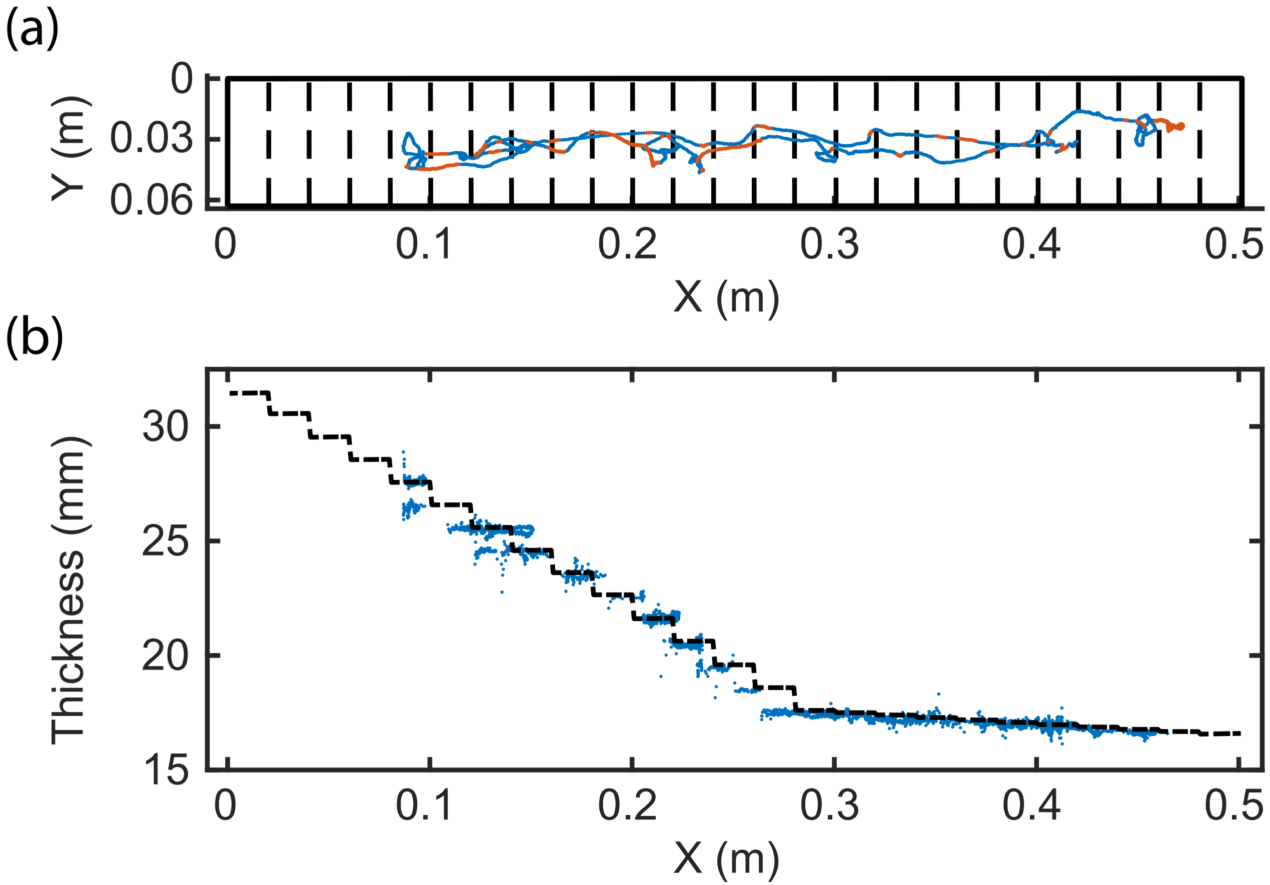
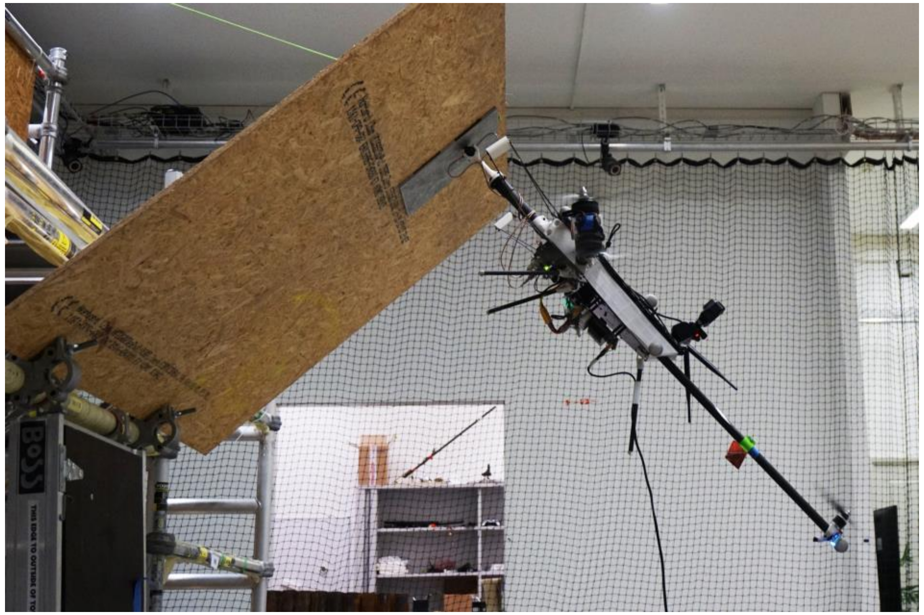
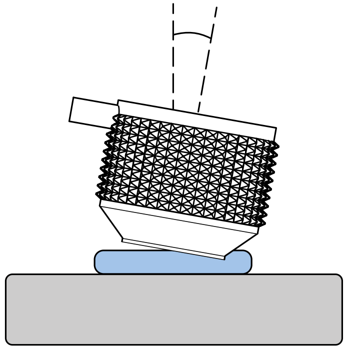
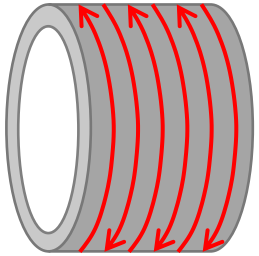


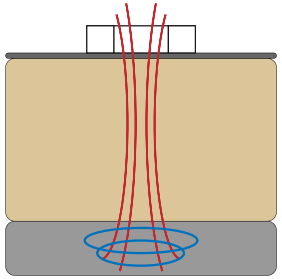
Conclusions

- Identified challenges of contact aerial NDE
- Demonstrated & Quantified UAV UT
  - Integrate advanced aerial manipulator platform with dry-coupling wheel transducer
  - Significant improvement to stability during point measurement
  - Measurement localisation for inspection reporting and tracking
- Pursuing capability advancement
  - Multicopter platform development
  - Expansion of NDE sensing modes









Thank You

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