Differential LDV measurements using flyable mirrors for the vibration assessment of remote structures

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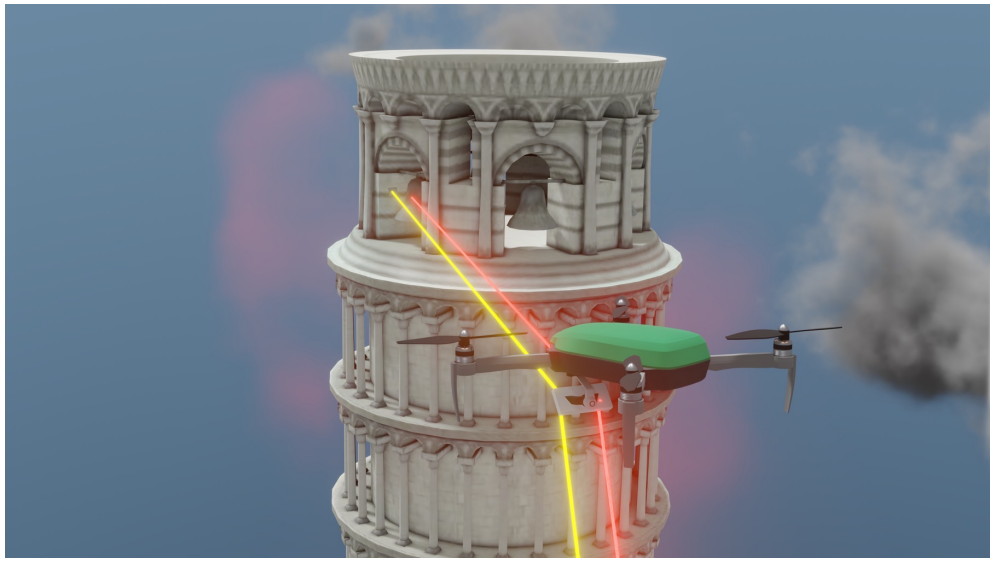
Background and motivation

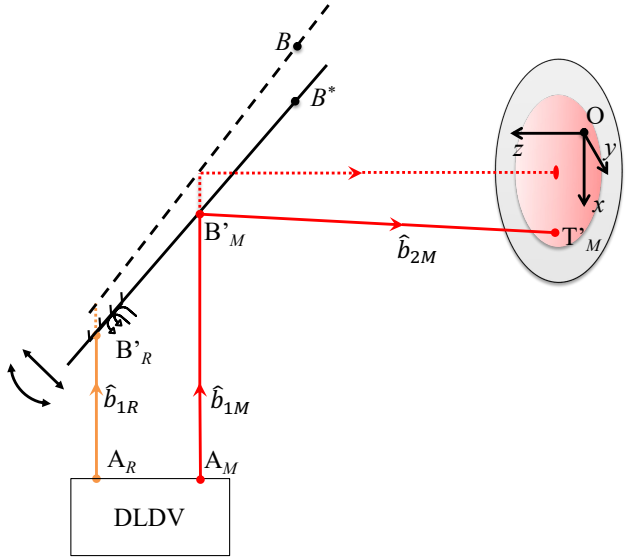
Instead of flying the LDV (problematic), let's just fly a mirror and use a *D*-LDV…

…but, which possible configuration to use?!:

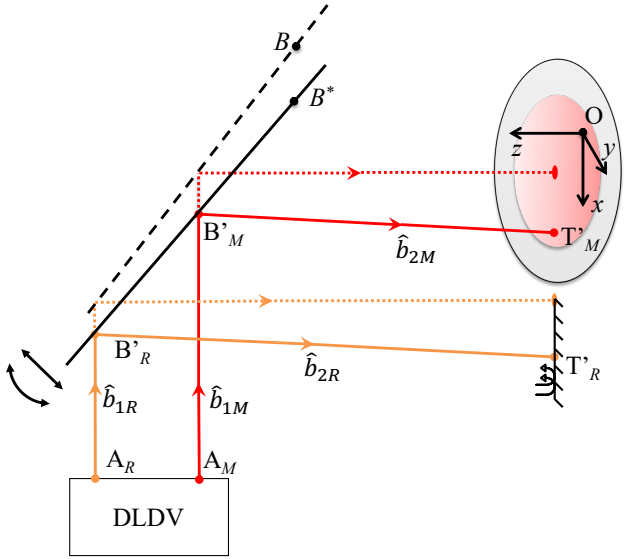


Mathematical modelling

Vector-based approach shows velocity sensitivity for each (all possible) scenarios:

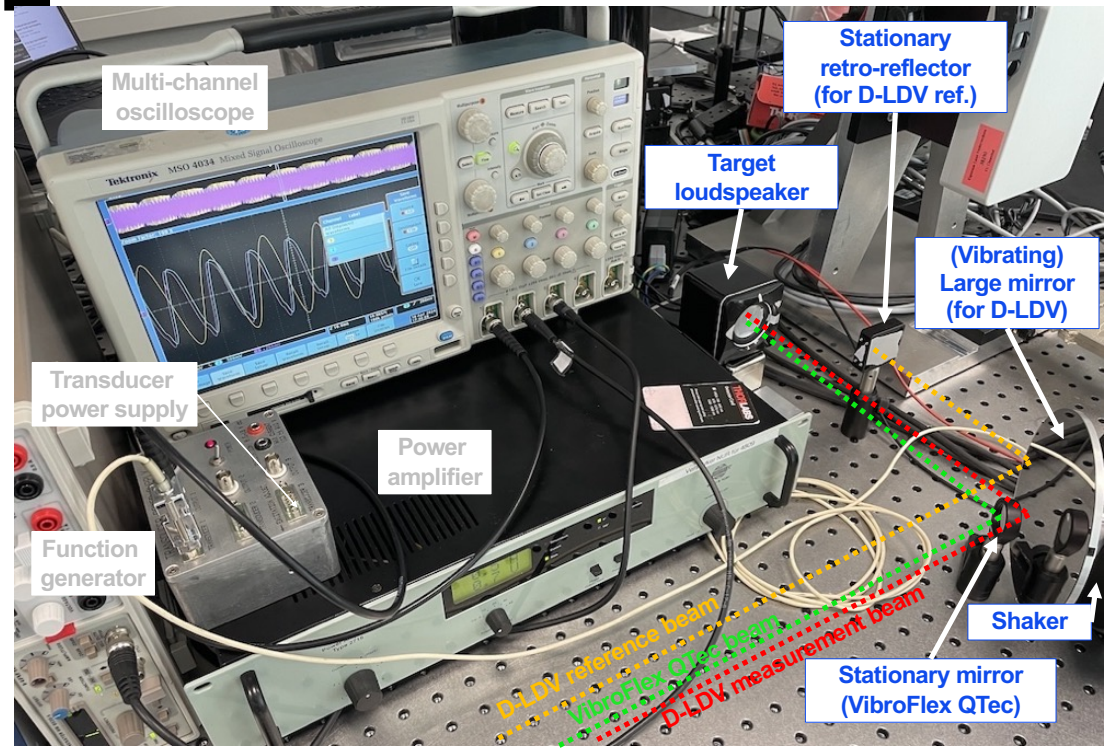


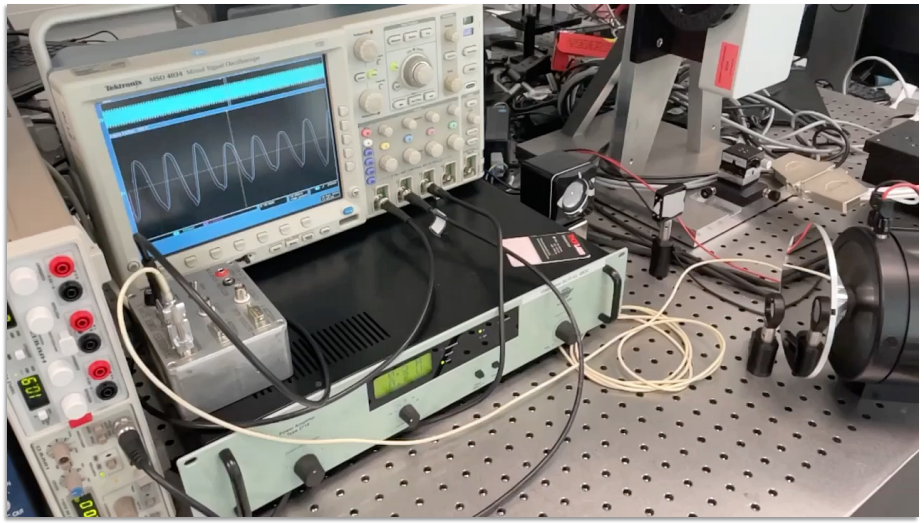
$$U_{m_{DLDV_a}} = -\hat{b}_{2_M} \cdot \vec{V_{T'_M}} + (\hat{b}_{2_M} - \hat{b}_{1_M}) \cdot \vec{V_{B'_M}} + \hat{b}_{1_R} \cdot \vec{V_{B'_R}}$$



$$U_{m_{DLDV_b}} = -\hat{b}_{2_M} \cdot \vec{V_{T'_M}}$$ ✓

Lab-based verification – mirror vibration…setup:

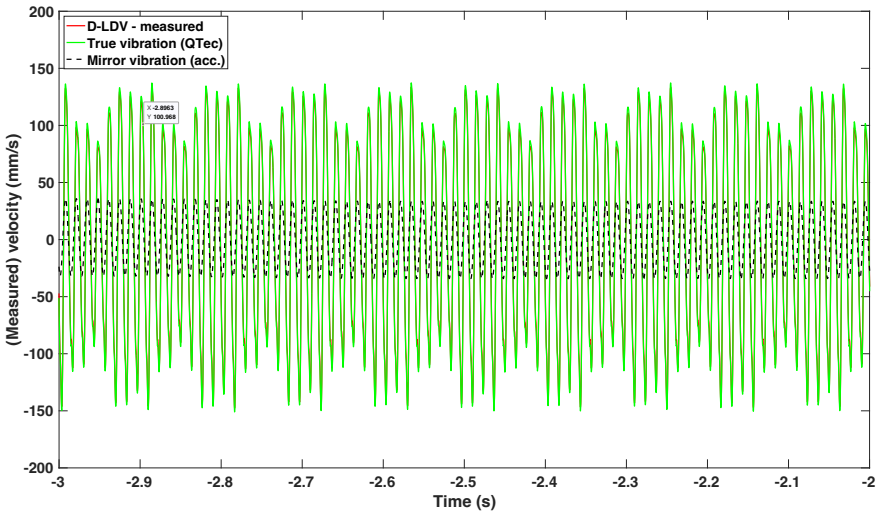


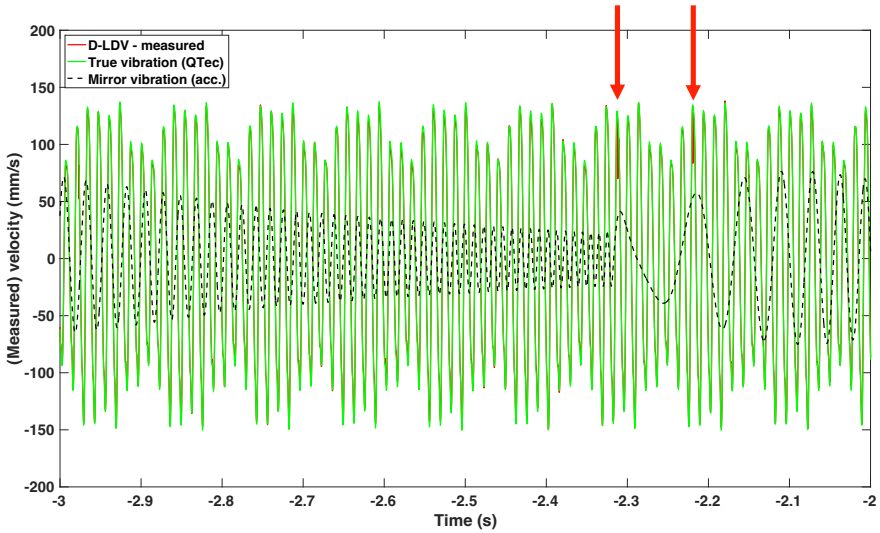


Lab-based verification – mirror vibration…results:

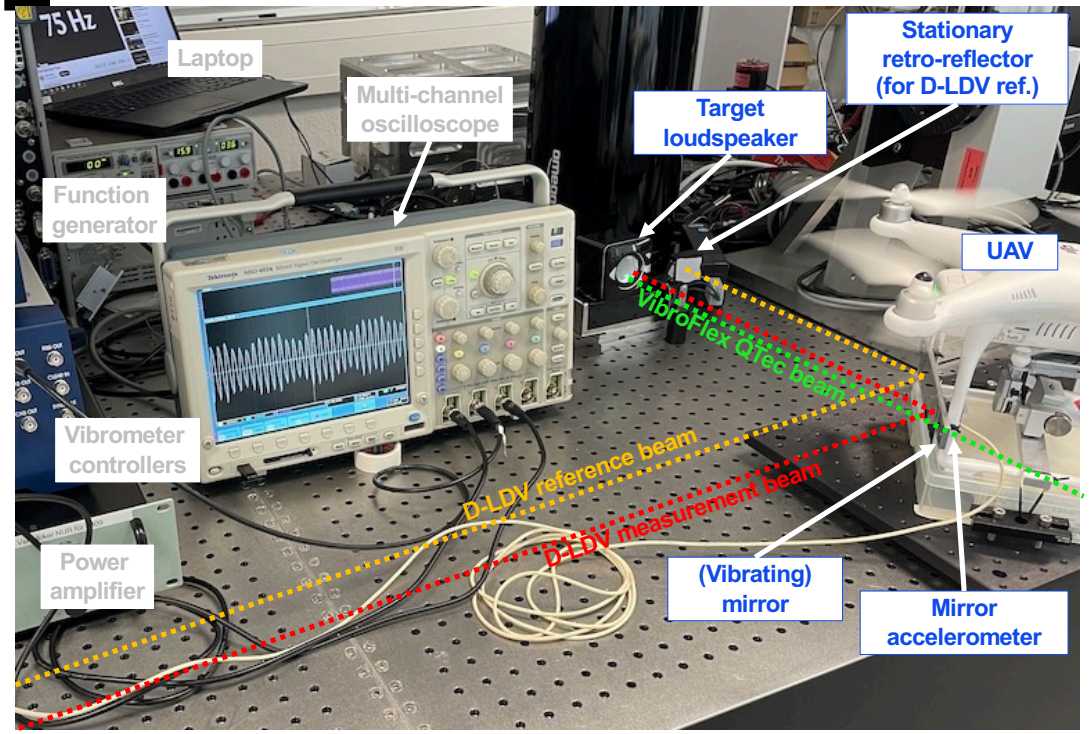
Excellent agreement in the presence of (translational) mirror vibration…

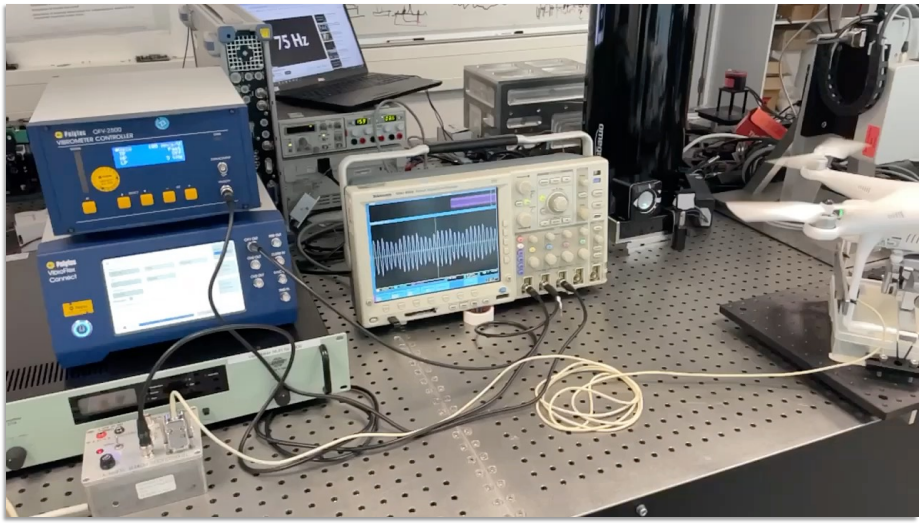
…**QTec** reference measurement vs. **mirror vibration** (velocity) vs. **D-LDV** measurement





Lab-based verification – (tethered) UAV vibration…setup:

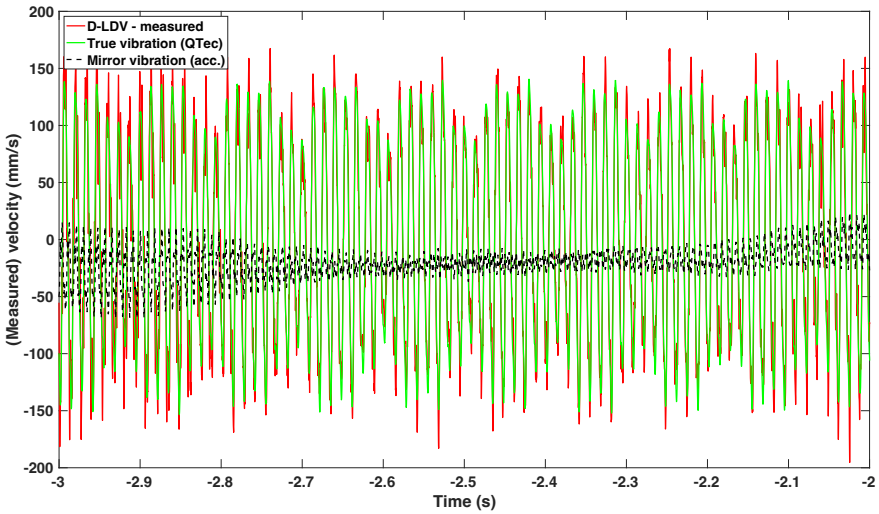


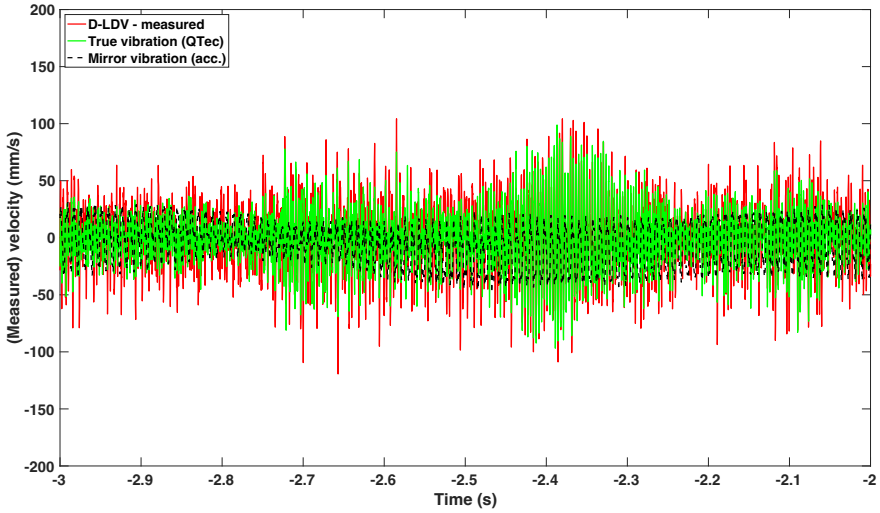


Lab-based verification – (tethered) UAV vibration…results:

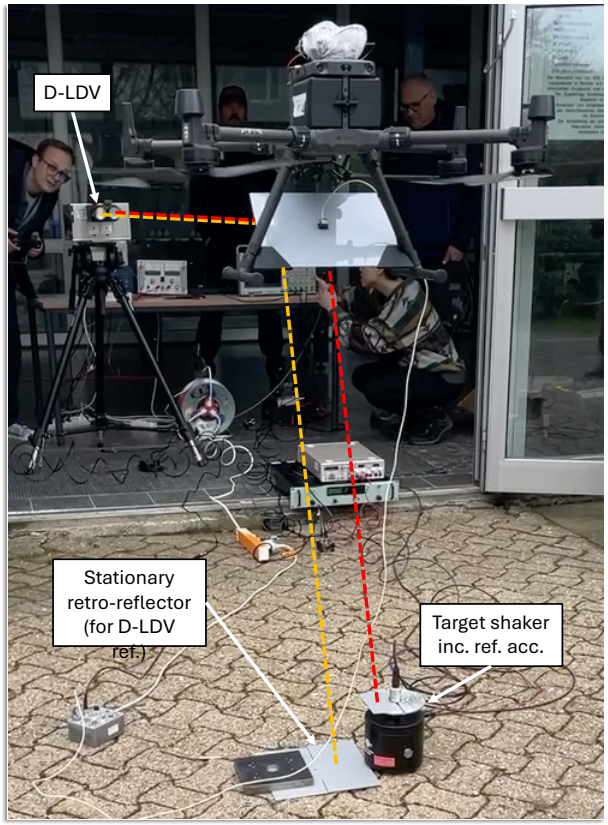
Reasonable? agreement, despite more complex mirror vibration, including rotation/bending…

…**QTec** reference measurement vs. **mirror vibration** (velocity) vs. **D-LDV** measurement





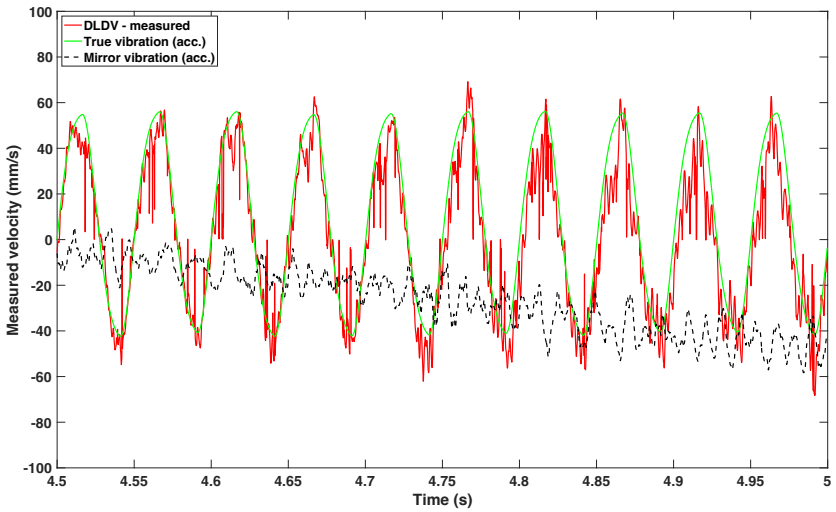
Field-based verification – UAV flyable mirror…setup:

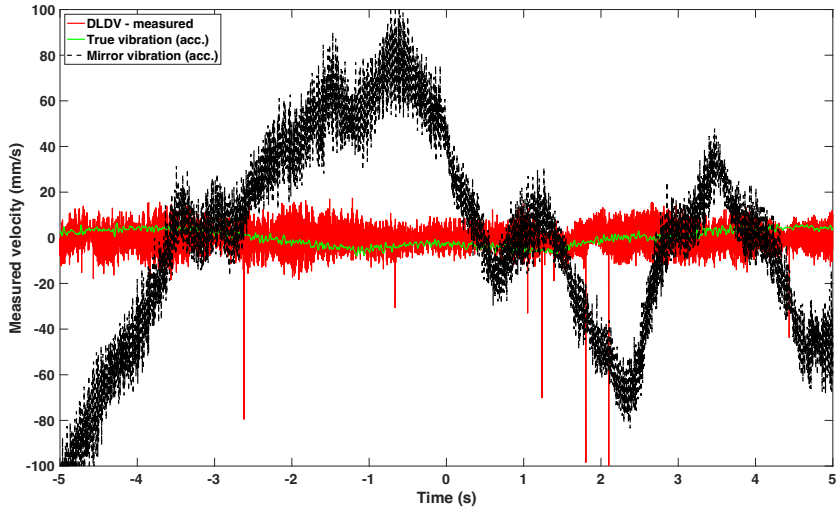


Field-based verification – (tethered) UAV vibration…results (20 Hz target vibration):

Promising? agreement, despite much more challenging measurement scenario…

…**Acc.** reference measurement (velocity) vs. **D-LDV** measurement; **mirror vibration** not used…





Summary and conclusions

Differential LDV explicitly shown to be inherently insensitive to (translational) vibration

- Not surprising that it's sensitive to angular vibration!?

Proper configuration for D-LDV measurements via Flyable Mirrors determined

- Both beams travel to and from the remote target of via the vibrating mirror

Series of increasing complex, experimental scenarios described

- Benchtop, vibrating mirror – *excellent* agreement
- Benchtop, tethered UAV – *reasonable* agreement
- Field-based, flyable mirror – *promising* agreement

Next steps should include:

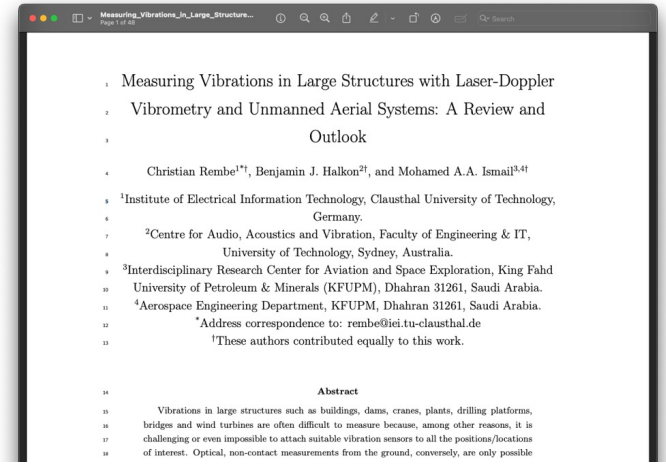
- Use of signal diversity (mitigate laser speckle sensitivity)
- Treatment of D-DLV sensitivity to angular vibration
- Integrated control of LDV pointing/UAV positioning

Some references

Differential Laser Doppler Vibrometer Measurements Using "Flyable Mirrors" for the Vibration Assessment of Remote Structures – under review MSSP:
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5189527

…and…

Measuring Vibrations in Large Structures with Laser-Doppler Vibrometry and Unmanned Aerial Systems: A Review and Outlook – recently accepted(!) Advanced Devices and Instrumentation (SPJ):
http://hdl.handle.net/10453/186218


Measuring Vibrations in Large Structures with Laser-Doppler Vibrometry and Unmanned Aerial Systems: A Review and Outlook

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Abstract

Vibrations in large structures such as buildings, dams, cranes, plants, drilling platforms, bridges and wind turbines are often difficult to measure because, among other reasons, it is challenging or even impossible to attach suitable vibration sensors to all the positions/locations of interest. Optical, non-contact measurements from the ground, conversely, are only possible

Thank you

Questions?

Credits (special thanks to!)

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IEI workshop…

Some (optional) further reading!

Halkon, BJ and Rothberg, SJ, Taking laser Doppler vibrometry off the tripod: correction of measurements affected by instrument vibration, *Opt. Las. in Eng.*, **99** (2017), DOI: 10.1016/j.optlaseng.2016.11.006

Halkon, BJ and Rothberg, SJ, Restoring high accuracy to laser Doppler vibrometry measurements affected by vibration of beam steering optics, *JSV*, **405** (2017), DOI: 10.1016/j.jsv.2017.05.014

Halkon, BJ and Rothberg, SJ, Establishing correction solutions for scanning laser Doppler vibrometer measurements affected by sensor head vibration. *MSSP*, **150** (2020), DOI: 10.1016/j.ymssp.2020.107255

Darwish, A, **Halkon, B**, Rothberg, SJ, Oberst, S, and Fitch, R, A comparison of time and frequency domain-based approaches to laser Doppler vibrometer instrument vibration correction, *JSV*, **520** (2022), DOI: 10.1016/j.jsv.2021.116607

Rothberg, S, … **Halkon, B**, et al., An international review of laser Doppler vibrometry: Making light work of vibration measurement, *Opt. Las. in Eng.*, **99**, (2017), DOI: 10.1016/j.optlaseng.2016.10.023