Chapter 16
Multi Channel Laser Radar for acousto-seimics

W. Zhou, O. Enriquez, G. Pandraud, E. Margallo, J. L. Rubio, and F. Beekman

Abstract We present a novel application of multichannel laser radar (MLR) for non-contact acousto-seismic measurements in granular geomorphic models, targeting early detection of fault propagation and subsurface deformation. Using Ommatidia's Q2 system, featuring 65 phase-coherent channels, we conducted controlled laboratory experiments on sandbanks, simulating fault-like discontinuities. Broadband excitations were introduced to generate elastic wavefields, with the Q2 system capturing simultaneous amplitude and phase responses across the measurement domain.

This dense spatial sampling enables wavefront inversion, allowing reconstruction of propagation paths, dispersion characteristics, and localized strain anomalies associated with evolving fault structures. The study highlights the capability of MLR to overcome limitations of traditional contact-based sensing by providing high-fidelity, real-time vibration mapping without mechanical perturbation of the medium. Embedded SpeckleGuard^{TM} signal diversity further enhances measurement robustness under challenging granular scattering conditions.

Our results demonstrate that multichannel laser radar can serve as a powerful tool for non-invasive subsurface imaging and real-time deformation monitoring in analogue geomechanical models.

Keywords Multichannel Laser Radar · Acousto-Seismics · Wavefront Inversion · Geomorphology · Fault Detection · Non-Contact Vibration Measurement

Introduction

Ommatidia's Q-series Multichannel Laser Radar (MLR) has already been successfully deployed in civil engineering and structural health monitoring (SHM) applications [1, 2]. However, its extension to high-resolution distributed systems for geomechanical studies is a more recent development. This work investigates whether such an emerging non-contact technology can be effectively applied to acousto-seismic analyses, leveraging the latest 65-channel MLR to enable subsurface fault detection in granular geomorphic structures. Granular materials—such as sand—serve as analogues for studying fault dynamics, as their response to stress or excitation provides valuable insight into subsurface structure evolution.

Driven by the limitations of mechanical contact sensors and the need for real-time, minimally intrusive monitoring in laboratory-scale geomorphological models, our approach integrates broadband excitation with synchronized spatial acquisition. Previous work employing Laser Doppler Vibrometry (LDV) on dry granular materials (e.g., Bodet et al. [3], Zaccherini et al. [4]) used mechanical shakers to generate acoustic waves within the sample. However, inserting a shaker into the medium causes structural deformation during experiments and constrains the mobility of the source, thereby limiting the ability to perform comprehensive spatial surveys.

Building on these efforts, [5] demonstrated a non-contact approach in which an acoustic wave is generated at the surface via a remotely pulsed laser, with signals subsequently recorded by a separate LDV. While such configurations successfully capture surface wave sensitivity to small elasticity changes, they remain sequential and alignment-dependent, increasing

W. Zhou · F. Beekman
Utrecht University, Earth Simulation Lab, Princetonlaan 4, 3584 CB Utrecht, The Netherlands
e-mail: w.zhou@uu.nl; w.w.w.beekman@uu.nl

O. Enriquez · G. Pandraud · E. Margallo · J.L. Rubio
Ommatidia LiDAR, Faraday Street 7, 28049 Madrid, Spain
e-mail: oscar-enriquez@ommatidia-lidar.com; gregory@ommatidia-lidar.com; eduardo@ommatidia-lidar.com; jose@ommatidia-lidar.com

Kristin B. Zimmerman, PhD (eds.), *Computer Vision and SLDV for Structural Dynamics, 2026, Vol. 6*, Conference Proceedings of the Society for Experimental Mechanics Series, https://doi.org/10.1007/978-8-743-81445-0_16

experimental complexity. By contrast, our proposed method significantly simplifies acquisition by enabling simultaneous multichannel measurements across the entire field of view—eliminating the need for scanning mechanisms and precise repositioning. In the following sections, we focus on sand, a representative granular medium that presents notable challenges in data acquisition and post-processing due to speckle effects and heterogeneous scattering.

Test Set up

In the current work the experimental setup the Q2 MLR system is placed at 90° above test media, allowing a complete coverage of the sandy zone (Figure 1). Current set ups have been used in measuring Quay walls in Amsterdam at a fixed position [2]. The sand bank is composed of two sections; the separation mimicking a fault. Measurements were conducted across the fault with an excitation placed in the sand and applied to study natural fault mechanics. In some cases, one section of the sand medium was loaded to introduce artificial discontinuities. The vibrational response was captured across 65 acquisition points, providing phase-coherent datasets suitable for inversion.

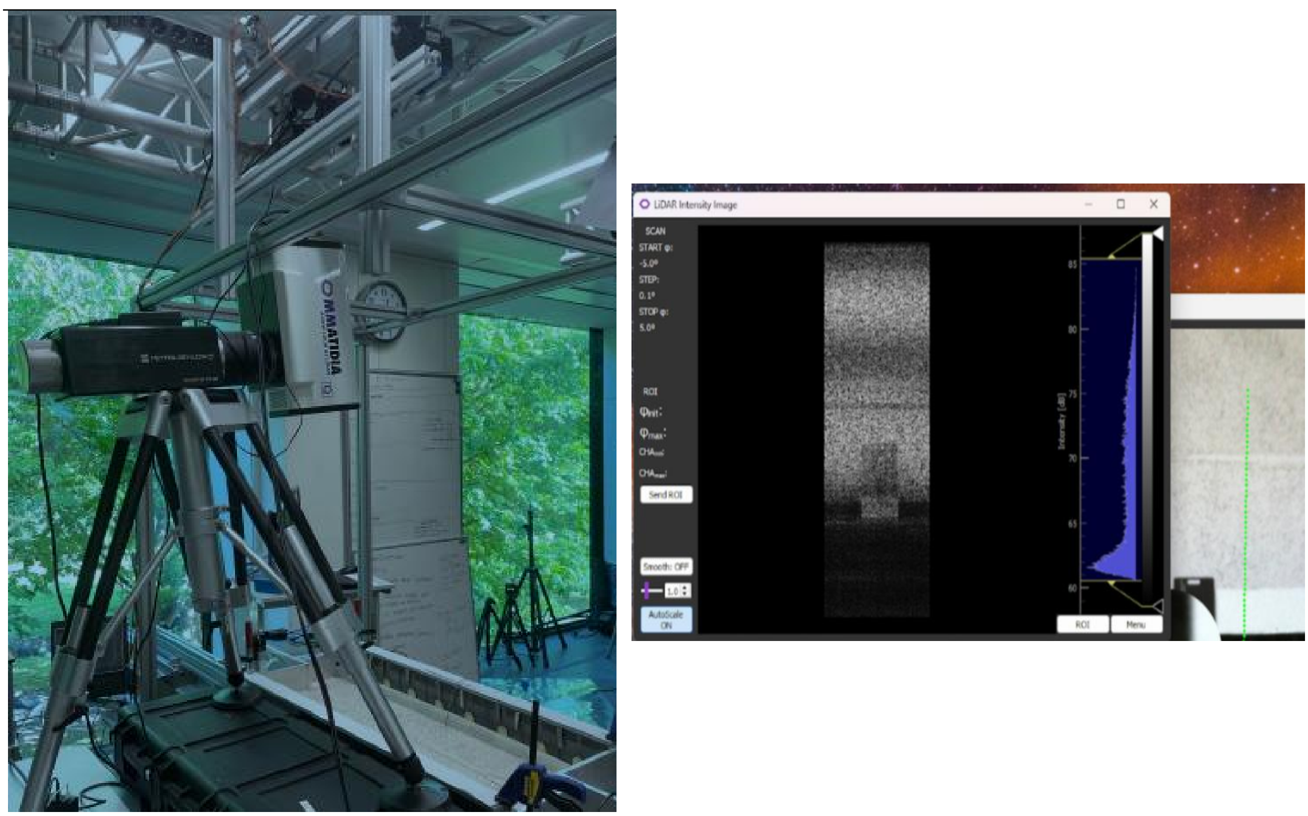

Fig. 1 *Right:* The Q2 Multichannel Laser Radar (MLR) positioned directly above the sandbank during testing, providing full overhead coverage of the experimental domain. *Left:* RGB image of the sandbank surface showing the distribution of the 65 measurement channels across the fault zone.

Measurement Procedure for Granular Material Models

To monitor the deformation of analogue models during an experimental run, we mimic (see Figure 1 left) the concept of seismic imaging widely used in field subsurface exploration at laboratory scale. In field studies, a source creates an elastic wavefield that travels into the subsurface. Reflected, refracted and diffracted waves are subsequently detected by a geophone array placed at the surface. By collecting data for a sufficiently large combination of source and receiver positions, inferences about medium parameters (e.g. *P* and *S* wave speeds) as wells as a reconstruction of the subsurface can be made [6].

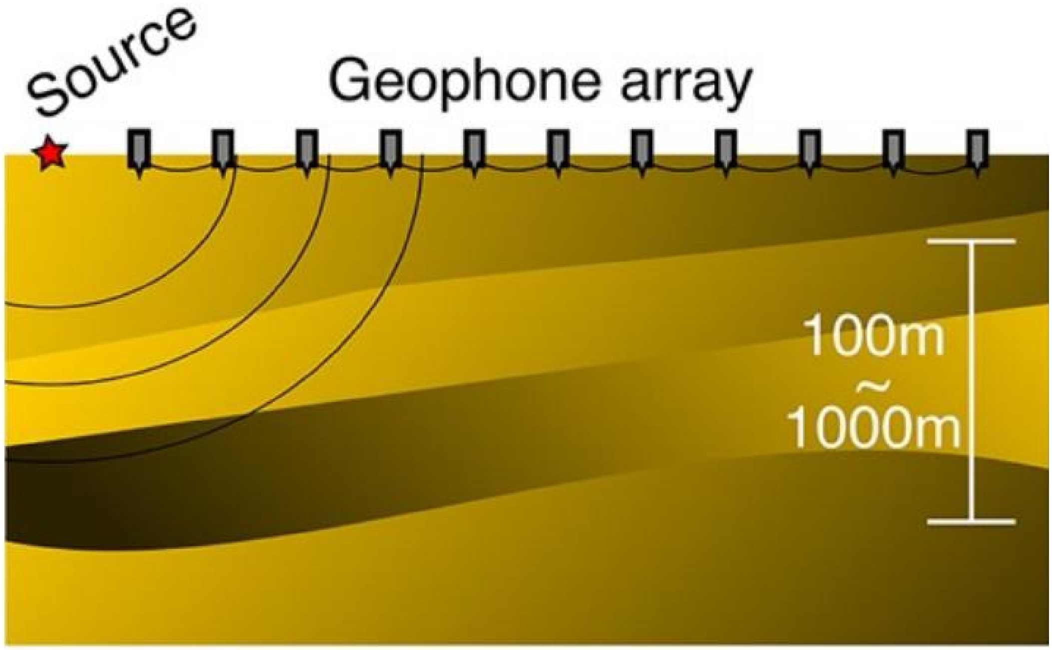

Fig. 2 Acousto-seismic field study

Experimental Results

We report here two types of experimental measurements designed to investigate the influence of fault geometry and deformation on wave propagation within the granular medium. In the first configuration, the sandbank remained stable, allowing us to analyze how the fault structure affects the propagation and reflection of elastic waves under controlled conditions. In the second configuration, a portion of the sandbank was mechanically displaced, altering the geometry of the fault to simulate an earthquake-like event and assess the corresponding changes in wave behavior.

Fixed configuration

In the stable configuration, the Q2 Multichannel Laser Radar (MLR) operated in its active excitation mode, generating a linear chirp signal ranging from 1 to 5 kHz over 1 s with an amplitude of 200 mV. A series of single-line measurements was performed across the fault to validate system accuracy and assess baseline response characteristics. Even without advanced post-processing, these initial scans revealed discernible differences in amplitude and phase across the discontinuity.

Applying wavefront inversion techniques to these datasets—commonly used in geomorphological studies to infer how disturbances propagate through space and time—enabled the mapping of fault propagation paths and the identification of high-strain zones (Figure 3). The reconstructed wavefields show strong agreement with acousto-seismic field analogues, exhibiting consistent arrival times, wave mode separation, and dispersion patterns, thereby validating the capability of the Q2 system for high-fidelity, non-contact subsurface imaging in granular media.

Shear test

In this second experiment, the same excitation parameters as in the stable configuration were maintained—namely, a 1–5 kHz chirp with 1 s duration and 200 mV amplitude. Measurements were conducted along a single line crossing the fault zone over a 10-second acquisition period. During the test, one side of the sandbank was gradually displaced, introducing a shear deformation that altered the fault geometry and mimicked an earthquake-like slip event.

The resulting measurements revealed that the granular surface produced significant speckle-induced noise in the raw data (Figure 4, left), a common challenge in laser-based vibrometry on rough, heterogeneous media such as sand. However, the Q2 system's embedded signal diversity module, SpeckleGuard^{TM}, effectively mitigated these artifacts by combining multiple phase-diverse signals. This enhancement substantially improved measurement accuracy and sensitivity, resulting in clearer and more reliable vibrometric data suitable for subsequent analysis and inversion.

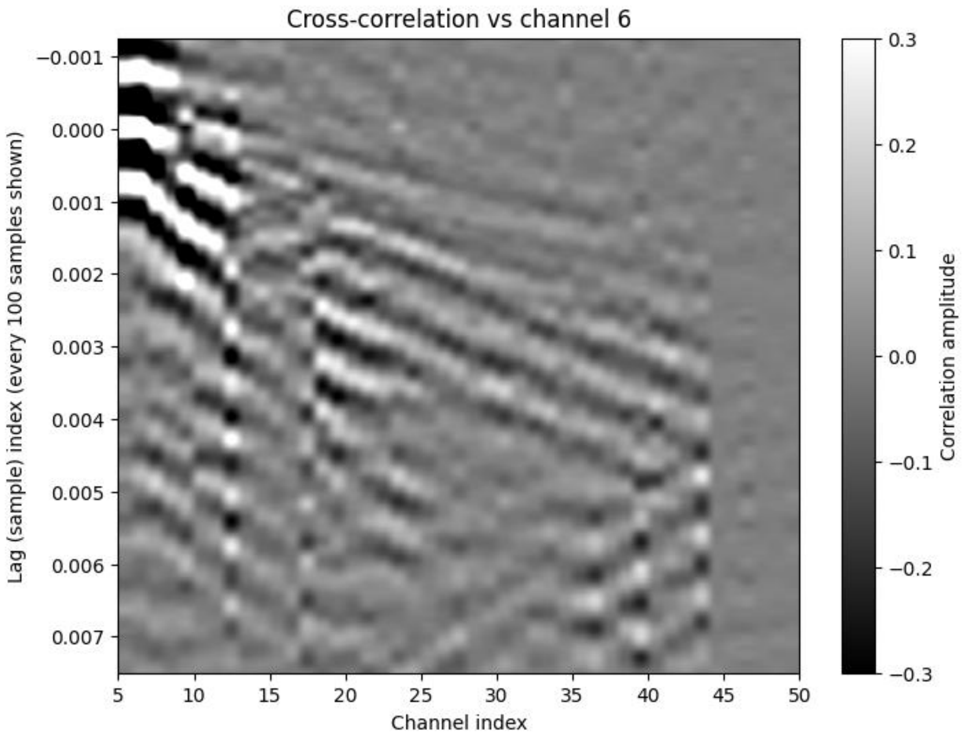

Fig. 3 Fault amplification and reflection at the boundary as extracted from a single line measurement.

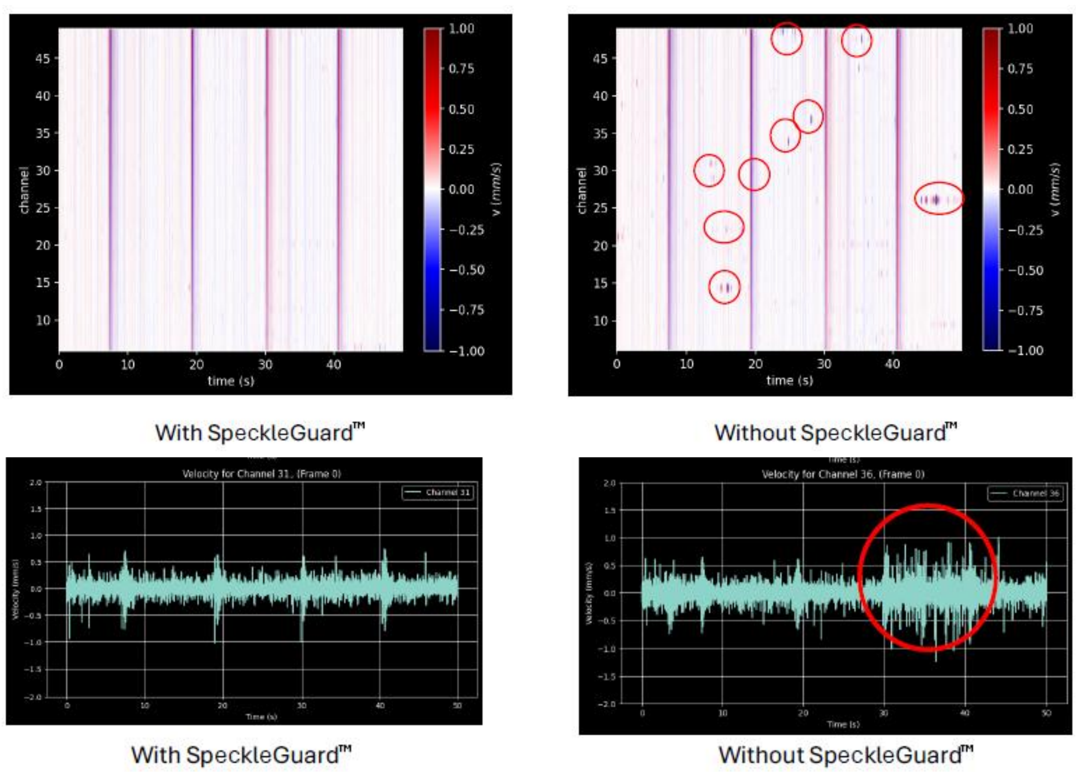

Fig. 4 Effect of signal diversity on vibration measurements acquired over the sand surface. *Top:* Raw signals recorded across all channels, showing the strong speckle-induced noise typical of granular media. *Bottom:* Processed signal from Channel 36, located on the opposite side of the fault relative to the excitation point, after applying the SpeckleGuard$^{\mathrm{TM}}$ diversity algorithm, illustrating the improved clarity and signal fidelity achieved through speckle mitigation.

Conclusion

This study confirms the effectiveness of high-resolution, non-contact LDV for structural analysis in granular geomorphic models. The proposed method yields dense vibration datasets suitable for reconstructing subsurface elasticity maps and fault evolution in near real time. Combining sensor innovation with robust signal processing, our platform enhances the ability to monitor and understand deformation processes in both Earth analogue and planetary environments.

References

1. O'Brien, S.A. *et al.* (2025). High-Sensitivity Vibration Monitoring of La Marota Viaduct Using a Novel 128-Channel Laser Radar System. In: Caetano, E., Cunha, Á. (eds) Experimental Vibration Analysis for Civil Engineering Structures. EVACES 2025. Lecture Notes in Civil Engineering, vol 674. Springer, Cham. https://doi.org/10.1007/978-3-031-96110-6_9
2. ter Meulen, D.W.B., Cabboi, A., Brownjohn, J.M.W., Antonini, A. (2025). Vibration-Based Monitoring of the Historic Quay Walls of Amsterdam. In: Cunha, Á., Caetano, E. (eds) Experimental Vibration Analysis for Civil Engineering Structures. EVACES 2025. Lecture Notes in Civil Engineering, vol 676. Springer, Cham. https://doi.org/10.1007/978-3-031-96114-4_9
3. Bodet L., Dhemaied A., Martin R., Mourgues R., Rejiba F., Tournat V., 2014. Small-scale physical modeling of seismic-wave propagation using unconsolidated granular media, Geophysics, 79(6), T323–T339..10.1190/geo2014-0129.1
4. Zaccherini R., Palermo A., Marzani A., Colombi A., Dertimanis V.K., Chatzi E.N., 2022. Geometric and material attenuation of surface acoustic modes in granular media, Geophys. J. Int., 230(1), 288–297..10.1093/gji/ggac076
5. J Smits et al., Non-contacting laser-based acousto-seismics at the laboratory scale: towards near-real-time monitoring of granular analogue models, *Geophysical Journal International*, Volume 238, Issue 1, July 2024, Pages 485–495,
6. Sheriff R.E., Geldart L.P., 1995. Exploration Seismology, 2nd edn, Cambridge Univ. Press.10.1017/CBO9781139168359