Active monitoring of fracturing in quasi-brittle solids: an experimental study

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Abstract.
This study utilizes ultrasonic waves in a laboratory setting for an active ***remote*** sensing of a heterogeneous fracture in rock. In this vein, a two-step experimental procedure is performed as follows: **Step 1.** the fracture geometry and the spatiotemporal variation of its interface parameters (shear and normal stiffness) is computed from the measured ***near-field*** data [1,3], and **Step 2.** by taking advantage of the full-waveform inversion approach recently proposed in [2], *only* the ***remote*** wavefield measurements are deployed to recover the fracture geometry and its heterogeneous interfacial condition. The results of **Step 1** are regarded as the *ground-truth* and compared to those obtained in **Step 2** to illustrate the effectiveness of the remote sensing technique.
This is accomplished by taking advantage of the (high-resolution) non-contact sensing technology of the 3D Scanning Laser Doppler Vibrometer (SLDV) that is capable of monitoring triaxial waveforms, with frequencies up to 1MHz, on the surface of rock specimens with 0.1mm spatial resolution and O(nm) displacement accuracy. In this setting, laboratory experiments are performed as shown in Fig.1 on a slab-like granite specimen of dimension 0.96m × 0.3m × 0.03m under the plane stress condition. Two sets of ultrasonic measurements are performed: i) ***free-field.*** measured when the rock sample is intact i.e. *prior* to fracturing the specimen, and ii) ***total-field.*** measured *after* the granite slab is partially fractured in an MTS load frame in a three-point-bending configuration. Based on this, the *scattering* of ultrasonic waves by a fracture in rock — and thus its signature on the remote data, can be explicitly illustrated, by subtracting the *free-field* from the *total-field*. For each test-set, the rock sample is placed in a (manufactured) clamping structure (see Fig. 1) capable of applying an adjustable compressive stress (0MPa and 1MPa) to the specimen. The sample is, then, excited by a piezoelectric transducer generating in-plane shear waves at frequencies of 10 and 30kHz, while the 3D SLDV simultaneously records: i) ***near-field***. the full-field (in-plane) velocity response of the specimen over a dense rectangular grid covering the fracture, and ii) ***remote wavefield***. the particle velocities measured ***only*** on the external boundary of the specimen i.e. away from the fracture (see Fig. 1). **Step 1** is then followed by applying the methodology developed in [3] to the near-field SLDV data, in order to identify the fracture geometry as well as the heterogeneous distribution of the fracture's interfacial stiffness and its temporal variations. One should bear in mind that access to near-field data (of **Step 1)** is not generally possible in practice, and thus, **Step 2** must follow where the remote data (measured in practice) are used as an input to the full-waveform inversion algorithm [4] to recover both the fracture geometry and its heterogeneous boundary condition without iterations or any initial guess for the unknown variables. As mentioned before, the results obtained in **Step 2** (the inverse algorithm) are compared to those of **Step 1** for verification and validation purposes.

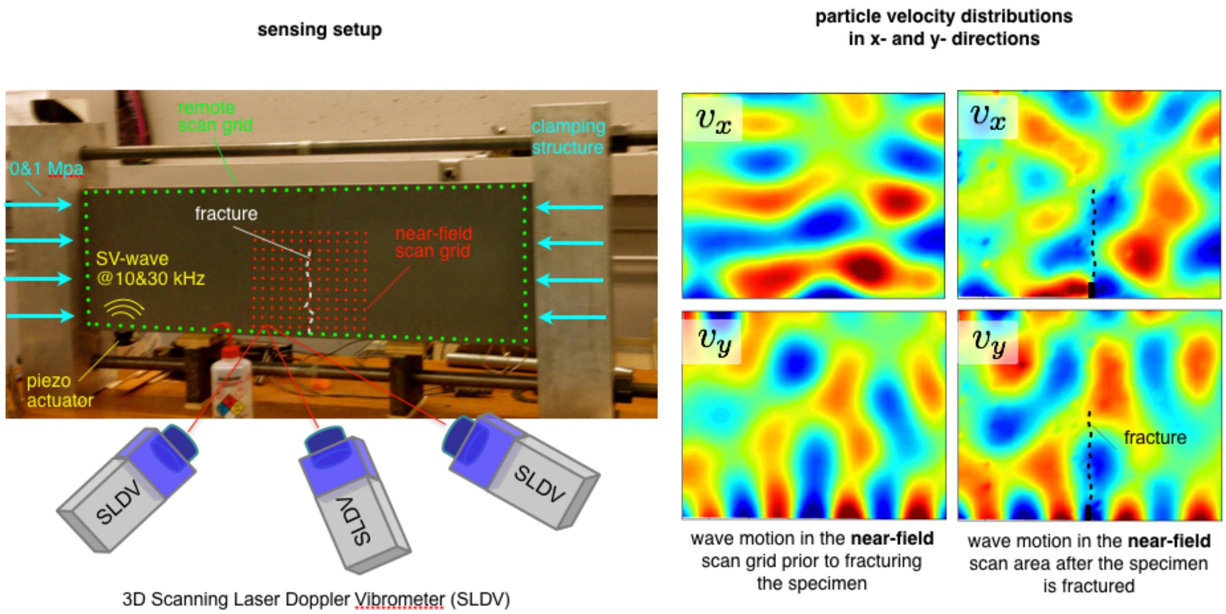

Figure 1. Sensing configuration and a snapshot in time of the wavefields measured by the 3D SLDV (in the near-field scan grid) before and after fracturing the granite specimen.

References.

[1] F. Pourahmadian and B. B. Guzina (2016). *Active ultrasonic imaging and interfacial characterization of stationary and evolving fractures in rock*. **ARMA2016**:16–803.

[2] F. Pourahmadian, B. B. Guzina, and H. Haddar (2016). *A synoptic approach to the seismic sensing of heterogeneous fractures: from geometric reconstruction to interfacial characterization*. submitted to **Geophysical Journal International**: arXiv preprint arXiv: 1610.07599.

[3] F. Pourahmadian, B. B. Guzina (2016). *Full-field seismic characterization of fracturing process in quasi-brittle materials*. submitted to **Physical Review Letters**.