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DAS microseismic monitoring workflow using orientation-aware ROI graph networks and gold-event screening

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Summary

Distributed Acoustic Sensing (DAS) enables dense microseismic monitoring in geothermal, hydraulic fracturing, and Carbon Capture and Storage (CCS) projects while strong horizontal "line'' noise and complex near-surface scattering often generate millions of false detections per stage. In a 2019 FORGE stimulation stage, a spectrogram-based detector produced ~2.9 million time–depth regions of interest (ROIs), only a small fraction of which are true induced events. For day-to-day monitoring, the real bottleneck is screening this ocean of DAS ROIs down to a few dozen high-quality candidates that are worth locating and interpreting.

We present an operational screening workflow built around an orientation-aware ROI graph neural network (ROI-GNN) and a lightweight human-in-the-loop QC loop. The workflow starts from DAS scoremaps, automatically collapses millions of ROIs into a few hundred machine-ranked candidates, and then uses a GUI-based QC step to define a small "gold'' event set for detailed waveform analysis. We demonstrate the approach on FORGE DAS data and discuss how it reduces analyst workload by orders of magnitude while preserving the most informative microseismic events.

Theory / Method / Workflow

DAS waveforms from the FORGE vertical fiber are converted to time–depth spectrograms using a B-E-DATE–type detector and treated as 2-D scoremaps in channel–time space (2000 Hz, 3-s windows). An orientation-aware ROI-GNN is used as the **screening engine**: DAS scoremaps are decomposed into overlapping ROIs, each ROI becomes a node in a spatio-temporal graph, a shallow graph convolutional network (GCN; Kipf and Welling, 2017) predicts an event probability for each node, and an orientation-sensitive attribute ("DipScore'') down-weights horizontal stripe noise and boosts dipping moveouts. In this contribution we treat this orientation-aware ROI-GNN as a black box that assigns each ROI a combined screening score.

On top of this engine, we build a practical monitoring workflow. For each stimulation stage, all ROIs are scored and sorted, and only a few hundred Tier-A candidates (highest scores) are exported to a custom GUI. The GUI shows, for each candidate, the full DAS scoremap window, the ROI patch, and the Max|score|(t) trace. The interpreter assigns a quick QC label (EVENT / NOISE / UNKNOWN) in a few seconds per ROI. These QC labels are used to define a small set of "gold'' events and to fine-tune a simple logistic-regression post-filter that further sharpens the ranking for subsequent stages. The workflow is designed so that one analyst can process an entire FORGE stage in hours rather than days.

Results, Observations, Conclusions

For the analyzed FORGE stage, the detector produced ~2.9 M ROIs. After screening with the orientation-aware ROI-GNN, only a few thousand ROIs remain above low thresholds, and ~200–300 Tier-A candidates per stage are passed to the GUI. GUI-based QC typically confirms on the order of 100 true event-like patches, which cluster around a smaller number of physical microseismic events. A strict “gold’’ threshold used for post-filter tuning yields ~40 high-purity ROIs per stage, almost all of which correspond to clear P–S moveouts on the DAS scoremaps. Figure 1 illustrates a representative FORGE window: gold-event ROIs (yellow rectangles) cluster along a dipping arrival while horizontal stripe noise is largely rejected, and the associated Max|score|(t) and DipScore(t) traces highlight the event time more clearly than simple amplitude alone.

From an operational perspective, this reduces the analyst’s workload by roughly three to four orders of magnitude while still capturing the most informative induced events. The workflow also provides a natural interface from DAS to existing waveform tools: gold events can be exported as time–depth windows for arrival-time picking with PhaseNet (Zhu and Beroza, 2019) and then into standard location and hazard-assessment workflows. We conclude that an orientation-aware ROI-GNN screening engine, wrapped in a lightweight QC loop, makes DAS-based microseismic monitoring far more practical for geothermal, hydraulic fracturing, and future CCS project.

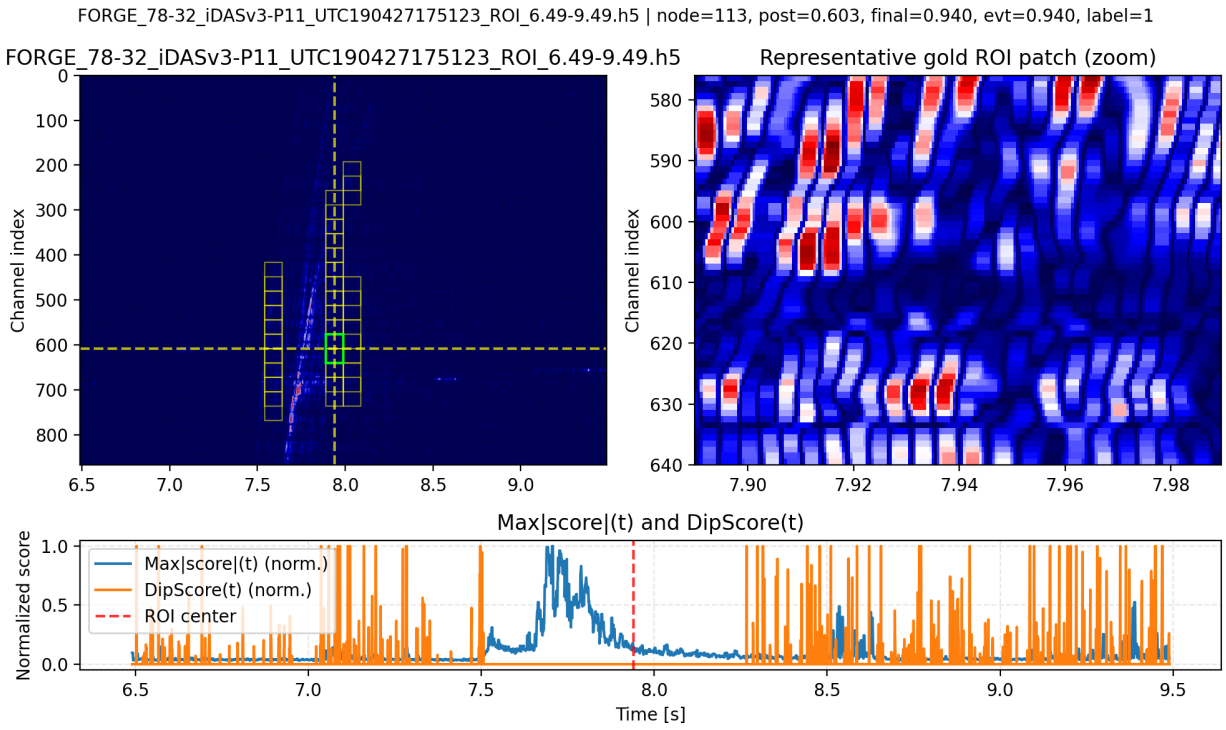


Figure 1. Example DAS scoremap and gold-event ROI from the FORGE stimulation stage.

(a) DAS scoremap in channel–time space, with all gold-event ROIs (postScore > 0.40, qc_label = 1) overlaid as yellow rectangles; the highlighted green rectangle marks the representative ROI used in panel (b). (b) Zoomed view of the representative gold ROI patch showing a clear dipping microseismic arrival. (c) Normalized Max|score|(t) (blue) and DipScore(t) (orange) for the same window, with the red dashed line indicating the ROI centre time. Together these panels illustrate how the screening workflow suppresses horizontal stripe noise and focuses on dipping event energy.

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