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BIANNUAL NEWSLETTER

DeepWave

IN THIS ISSUE

Overview

Greetings and welcome to the latest edition of the DeepWave Consortium Newsletter! In this second issue of 2024, we are thrilled to bring you the latest updates and news from our energetic team.

On page 3, explore our **research samples** section, where we present successful projects that highlight the innovative spirit and dedication of our members in addressing geophysical challenges. Continue to page 5 to read about **new team members** who recently joined us. These talented individuals bring fresh perspectives that will enhance the KAUST team, and we eagerly look forward to their contributions.

Our **recent publications** segment on page 6 showcases the latest scholarly articles authored by our members. These publications emphasize our commitment to academic excellence and make significant contributions to our fields of interest. Finally, stay informed with our **news** section on page 7 by reading through a roundup of noteworthy events, announcements, and updates within our consortium.

We hope you find this issue both informative and inspiring. Enjoy reading!

Find more about our consortium by either contacting us via e-mail [deepwave@kaust.edu.sa] or by visiting the DeepWave website [deepwave.kaust.edu.sa].

DeepWave is an industry funded research consortium at King Abdullah University of Science and Technology (KAUST), which focuses on the application of machine (deep) learning numerical algorithms to wave-equation-based processing, imaging, and inversion.

The application of these techniques extends to objectives ranging from global Earth discovery, to natural resources exploration, to subsurface monitoring as well as non-destructive testing and medical imaging.

Goal

To be a leading center for the research and development of machine learning algorithms on waveform data with applications ranging from the exploration and discovery of the Earth to reservoir characterization and monitoring for oil and gas, geothermal, and CO_2 storage purposes.

Mission

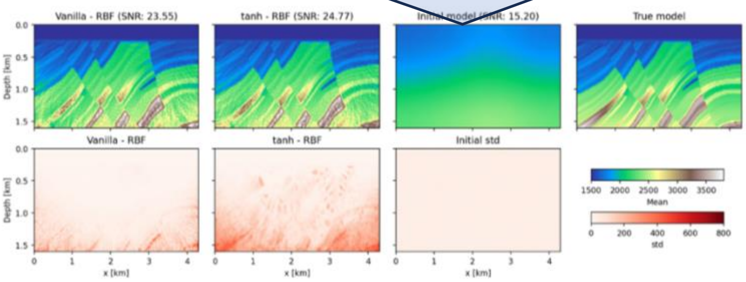
To foster an environment of effective research for the students and researchers that promotes seamless interaction with our sponsors.

Samples of DeepWave Research

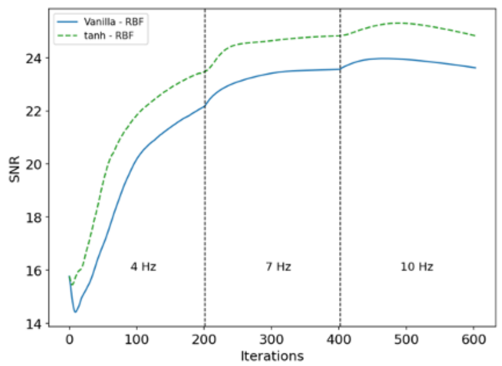
Annealed Stein Variational Gradient Descent for Improved Uncertainty Estimation in Full-Waveform Inversion

Miguel Corrales, Sean Berti, Bertrand Denel, Paul Williamson, Mattia Aleardi, Matteo Ravasi

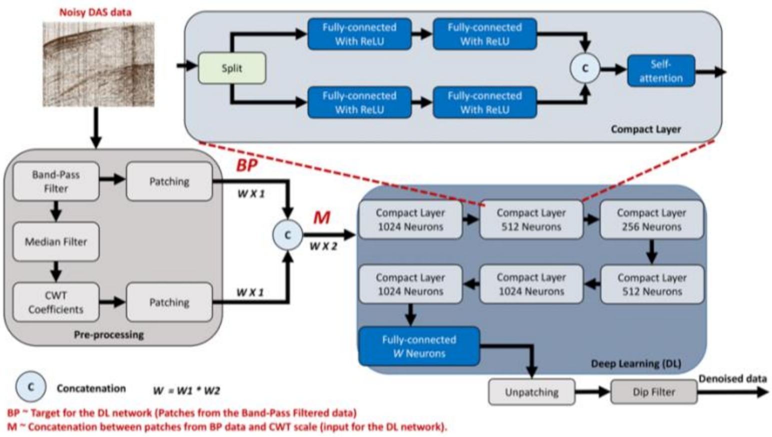
FWI is widely used to derive high-resolution subsurface velocity models from seismic data. However, its nonlinearity and ill-posed nature require a good starting model to avoid non-physical solutions. Bayesian inference offers a solution by evaluating the posterior probability with methods like Markov Chain Monte Carlo (MCMC), though they are computationally expensive in high-dimensional problems. Variational Inference (VI) provides a more efficient alternative, with Stein Variational Gradient Descent (SVGD) refining samples to approximate the target distribution. However, SVGD faces challenges in high-dimensional problems like mode and variance collapse. This study improves SVGD for FWI by introducing an annealed variant combined with a multi-scale strategy. Additionally, we utilize Principal Component Analysis (PCA) and clustering techniques in a 'post hoc' fashion to provide deeper statistical insights.



Mean and standard deviation comparison of the experiments using 200 particles for vanilla SVGD and annealed SVGD multi-scale scenario.



SNR evolution by iterations



Noise Attenuation in Distributed Acoustic Sensing Data Using a Guided Unsupervised Deep Learning Network

Omar M. Saad, Matteo Ravasi, and Tariq Alkhalifah

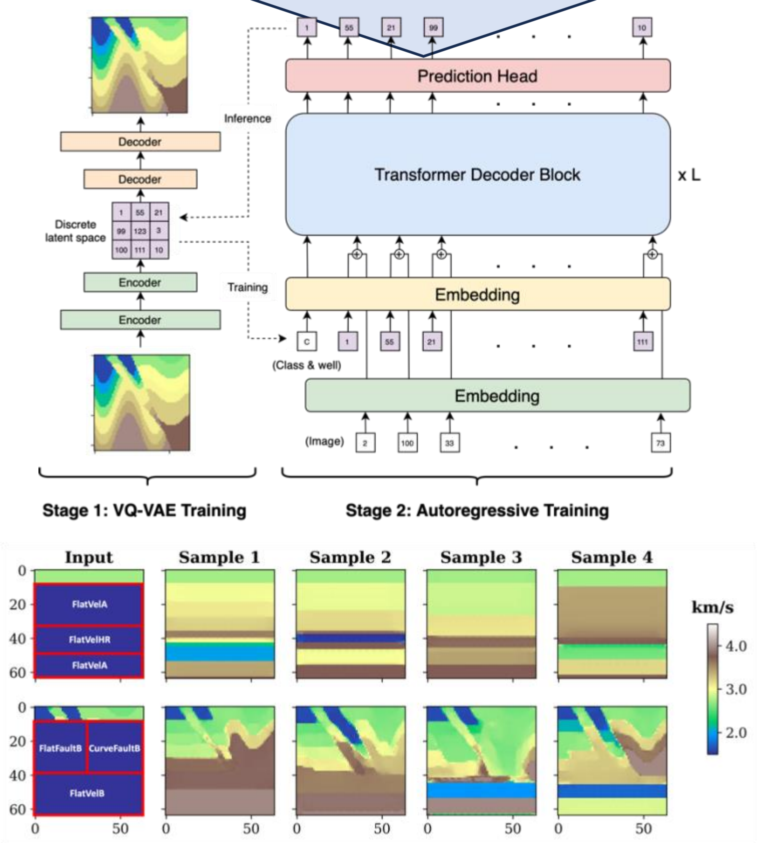
This study introduces a novel unsupervised deep learning method for denoising Distributed Acoustic Sensing (DAS), overcoming challenges posed by weak signals and noisy environments. By applying band-pass filtering and continuous wavelet transform in the preprocessing phase, a deep learning model is guided to reconstruct clean signals without the need for labeled data. The model efficiently processes 2D patches, transformed into 1D vectors, and leverages self-attention to capture spatial relationships. Comparative analyses using field data from the San Andreas Fault and geothermal energy datasets demonstrate robust denoising performance compared to benchmark methods.

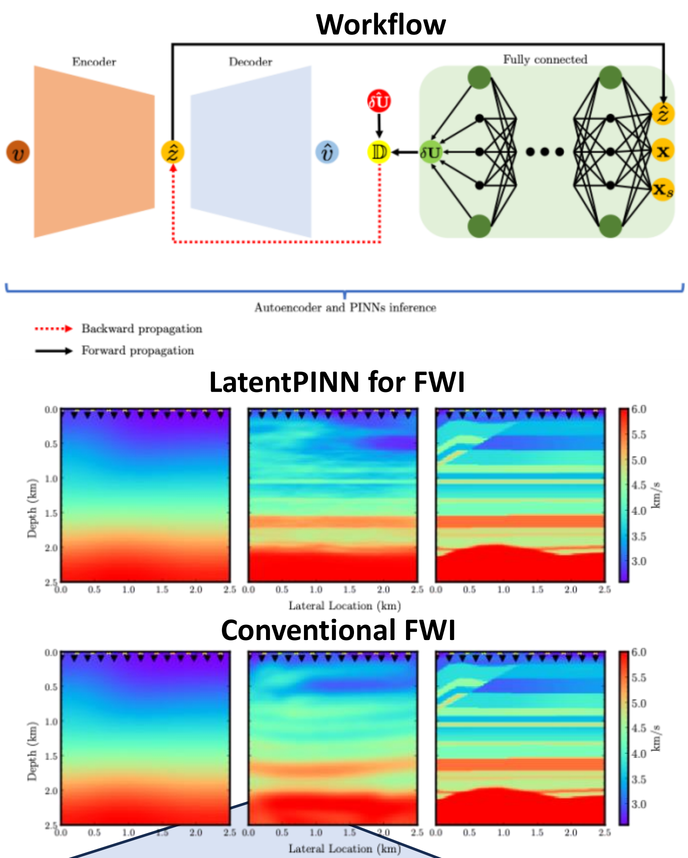
Samples of DeepWave Research

Propagating the prior from shallow to deep with a pre-trained velocity-model Generative Transformer network

Randy Harsuko, Shijun Cheng, and Tariq Alkhalifah

We present VelocityGPT, a novel seismic velocity model generator in an autoregressive framework. Utilizing the power of Generative Pre-trained Transformer (GPT) network, VelocityGPT can effectively propagate priors (shallow layer information, well, image) from top to bottom. This framework inherently allows for a spatially controllable sampling to locally constraint the generated velocity model, in contrast to common generative models like diffusion models or normalizing flow models that disregard spatial dependencies and resolution changes. We demonstrate the effectiveness of the framework on OpenFWI velocity dataset. We also show how the pretrained network can be upscaled to more realistic velocity model sizes.





Latent representation learning in physics-informed neural networks for full waveform inversion

Mohammad. H. Taufik, Xinquan Huang, and Tariq Alkhalifah

Full waveform inversion (FWI), a state-of-the-art seismic inversion algorithm relies on efficient numerical wave equation solver which necessitates discretization. To perform efficient discretization-free FWI for large-scale problems, we introduce physics-informed neural networks (PINNs) as surrogates for conventional numerical solvers with latent representation learning. We first append the input (source-receiver coordinate points) with the encoded velocity vectors, which are the latent representation of the velocity models using an autoencoder model. Through a series of numerical tests, the proposed framework shows a significant increase in accuracy and computational efficiency compared to the conventional FWI that can be attributed to implicit regularization introduced by the velocity encoding and physics-informed training procedures.

Daniel Wamriew | *Postdoctoral Fellow*

Tell us a bit about your educational background and previous research roles.

I hold a PhD in Petroleum Engineering from the Skolkovo Institute of Science and Technology (Skoltech) in Moscow, Russia. During my doctoral research, I focused on advancing the analysis and processing of microseismic data acquired through cutting-edge fiber optic Distributed Acoustic Sensing (DAS) systems. This involved developing novel algorithms and workflows tailored for real-time data analysis. Additionally, I applied deep learning models for the detection and localization of microseismic events, and velocity model inversion, all aimed at enhancing the precision and efficiency of subsurface monitoring in challenging environments.

What research projects have you completed or contributed to recently?

Currently, I am engaged in two highly impactful projects within the realm of microseismic monitoring. The first project explores the application of advanced diffusion models for the precise localization of microseismic events, pushing the boundaries of computational techniques in seismic data interpretation. The second project focuses on the development of Physics-Informed Neural Networks (PINNs) for the detection and localization of microseismic events and the inversion of moment tensors. These projects integrate cutting-edge machine learning with geophysical principles, offering new insights into seismic event characterization.

What are your first impressions being in the KAUST DeepWave team?

My first impressions of the KAUST DeepWave team have been overwhelmingly positive. The group is composed of highly skilled and motivated individuals, all working with a shared vision of pushing the frontiers of research. There is a strong emphasis on **teamwork**, which fosters a collaborative environment that enhances both individual and collective performance. Additionally, the leadership is exceptional, providing clear direction while maintaining an atmosphere of innovation and growth. It's truly a privilege to be part of such a dynamic and forward-thinking team.

Ning Wang | *PhD Student*

Ning holds both a Bachelor's and Master's degree in **Applied Geophysics** from Jilin University, China, where her research focused on **Geophysical Electromagnetic Methods**.

In 2024, she completed a two-month internship at Aramco (Dhahran). Her research interests include the Marchenko method, seismic-while-drilling, multi-dimensional data processing and imaging, and deep learning.

New Members

Our team is growing. Learn more about our new additions here.

Shaowen Wang | *Postdoctoral Fellow*

Tell us a bit about your educational background and previous research roles.

I received my B.E. degree in Exploration Technology and Engineering from Shandong University of Science and Technology in 2018. I then pursued and obtained a Ph.D. degree in Marine Geophysics from Ocean University of China in 2024. A part of my previous work involved developing software/packages that enabled other group members use deep learning (frameworks) for seismic data processing and inversion problems.

What research projects have you completed or contributed to recently?

I have participated into projects related to deep learning based seismic denoising. The types of noise this work dealt with are deblended noise, Shear wave noise from OBN Z-componentn data, erratic noise, vessel noise, gaussian-like noise etc. I also contributed to some acoustic and multi-parameter FWI projects, where different wave equations were used to perform inversion towards achieving various production goals. Recently, I've been working on an open-source seismic imaging package based on deep learning frameworks and implicit neural represeantation-based inverse problem.

What are your first impressions being in the KAUST DeepWave team?

Every member of DeepWave has their own area of expertise, and everyone is very kind to others, I'm really glad I came here. The research in Deepwave is very cutting-edge, which inspires me to further broaden my knowledge base.

Shuo Zhang | *PhD Student*

Shuo received both his Bachelor's degree in **Resources Exploration Engineering** and Master's degree in **Earth Exploration and Information Technology** from the China University of Geoscience (Beijing).

His research interests include seismic data processing, FWI, RTM, LSRTM, and Bayesian deep learning. Currently, he is exploring the use of the diffusion model to enhance FWI and LSRTM.

New Members

Our team is growing. Learn more about our new additions here.

Recent Publications

Abedi M.M.; Pardo D.; Alkhalifah T., "*Ensemble Deep Learning for Enhanced Seismic Data Reconstruction*", 2024, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2024.3401832.

Cheng S.; Alkhalifah T., "*Robust data driven discovery of a seismic wave equation*", 2024, Geophysical Journal International, 10.1093/gji/ggad446.

Cheng S.; Harsuko R.; Alkhalifah T., "*Meta-Processing: A robust framework for multi-tasks seismic processing*", 2024, Surveys in Geophysics, 10.1007/s10712-024-09837-9.

Harsuko R.; Alkhalifah T., "*Optimizing a transformer-based network for a deep-learning seismic processing workflow*", 2024, Geophysics, 10.1190/geo2023-0403.1.

Izzatullah M.; Alali A.; Ravasi M.; Alkhalifah T., "*Physics-reliable frugal local uncertainty analysis for full waveform inversion*", 2024, Geophysical Prospecting, 10.1111/1365-2478.13528.

Li Y.; Alkhalifah T.; Huang J.; Li Z., "*Characterizing the target of interest underlying a complex overburden with target-oriented elastic waveform inversion*", 2024, Journal of Geophysics and Engineering, 10.1093/jge/gxae038.

Liu S.; Birnie C.; Bakulin A.; Dawood A.; Silvestrov I.; Alkhalifah T., "*A self-supervised scheme for ground roll suppression*", 2024, Geophysical Prospecting, 10.1111/1365-2478.13522.

Liu S.; Cheng S.; Alkhalifah T., "*Gabor-Based Learnable Sparse Representation for Self-Supervised Denoising*", 2024, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2024.3353315.

Romero J.; Heidrich W.; Luiken N.; Ravasi M., "*Seismic Reservoir Characterization with Implicit Neural Representations*", 2024, Journal of Geophysical Research: Machine Learning and Computation, 10.1029/2024JH000275.

Saad O.M.; Ravasi M.; Alkhalifah T., "*Noise attenuation in distributed acoustic sensing data using a guided unsupervised deep learning network*", 2024, Geophysics, 10.1190/geo2024-0109.1.

Wang F.; Alkhalifah T., "*Learnable Gabor Kernels in Convolutional Neural Networks for Seismic Interpretation Tasks*", 2024, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2024.3365910.

Zhang W.; Guo X.; Ravasi M.; Gao J.; Sun W., "*Angle-dependent image-domain least-squares migration through analytical point spread functions*", 2024, Geophysics, 10.1190/geo2023-0499.1.

Zhang Z.; Alkhalifah T.; Liu Y., "*Full Dispersion-Spectrum Inversion of Surface Waves*", 2024, Journal of Geophysical Research: Solid Earth, 10.1029/2023JB028469.

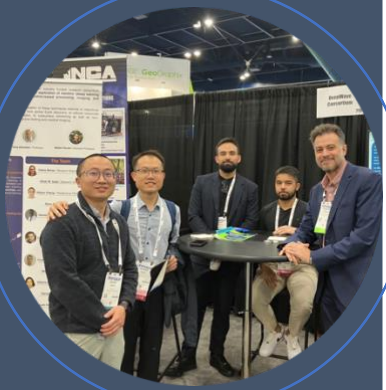
News

• New Sponsor

Petrobras has officially joined the DeepWave Consortium as its newest sponsor bolstering our mission to drive innovation and collaboration. We are excited to utilize their expertise and resources in future groundbreaking projects. Welcome aboard, Petrobras!

• Annual Meeting 2024

During the 2nd Annual Meeting, researchers from KAUST and representatives from our sponsoring companies gathered at the One Allen Center in Houston, TX. The meeting featured presentations of our latest research across five sessions, followed by engaging discussions where sponsors contributed insights and recommendations to help guide the consortium's future initiatives. This collaborative dialogue is crucial for steering our collective efforts moving forward.



• Presence in IMAGE 2024

DeepWave is excited to announce our participation in IMAGE 2024 in Houston, where we showcased our work to the community through nine oral presentations and eight posters this year. For a comprehensive list of all our presentations, click here. Additionally, DeepWave had a prominent presence in the technical exhibition, featuring a dedicated booth at the event. We had the chance to connect with fellow professionals and spread the word on the Consortium's mission and achievements.

• Tariq Alkhalifah @ KAUST Earth Sciences Seminar

As part of the Graduate Seminar series of Earth Sciences and Engineering (ErSE) and Earth Resources and Petroleum Engineering (ERPE) programs in KAUST Tariq presented his new talk titled "*From DALL-E to ChatGPT: How could we use generative models to discover the Earth?*". The graduate seminar is offered to ErSE/ERPE graduate students and aims to expose them on impactful research across the full bandwidth of Earth Sciences by hosting talks presented by KAUST faculty as well as world-renowned researchers from the rest of the scientific community.

• DeepWave on Github

Our [GitHub organization](#) has expanded thanks to the contributions of our team, now proudly hosting 31 stable repositories and 22 in development. These repositories are designed to facilitate seamless code sharing between DeepWave researchers and Consortium sponsors.

• PhD Graduates and Alumni

We are proud and happy for our KAUST member that recently received his PhD. **Xinquan Huang** defended his work on "*Neural PDE solvers and their applications in subsurface monitoring*" and will be continuing his research journey as a PostDoctoral Fellow in the School of Engineering and Applied Science at the University of Pennsylvania. **Nick Luiken**, a KAUST PostDoctoral Fellow working with us has now moved to NVIDIA as Deep Learning Solutions Architect. We're sure that they will both continue to be successful in their next endeavors.

Scope of research

The Consortium aims to deliver the most effective solutions to waveform processing, imaging, and inversion challenges across multiple scales.

We thank our **Industry Sponsors** for their support

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