ISSUE 03
SPRING 2024

BIANNUAL NEWSLETTER

IN THIS ISSUE

Overview

Welcome to our latest edition of the DeepWave Consortium Newsletter! In this issue, we're excited to share with you news and updates from our vibrant team.

Dive into our **research samples** section (page #3), where we showcase successful research projects from our team. These pieces reflect the spirit and dedication of our members to develop innovative solutions to geophysical problems. We are also thrilled to introduce our **new members** (page #5) who have joined us during these last months. Each brings a fresh perspective that will enrich the KAUST team, and we look forward to their contributions.

Our **recent publications** segment (page #6) highlights the latest scholarly journal articles authored by our members. These works contribute significantly to our fields of interest and demonstrate our commitment to academic excellence. Lastly, stay informed with our **news** section (page #7), which provides a roundup of noteworthy events, announcements, and updates within our consortium.

We hope you find this issue informative and inspiring. Happy 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 CO2 storage purposes.

Mission

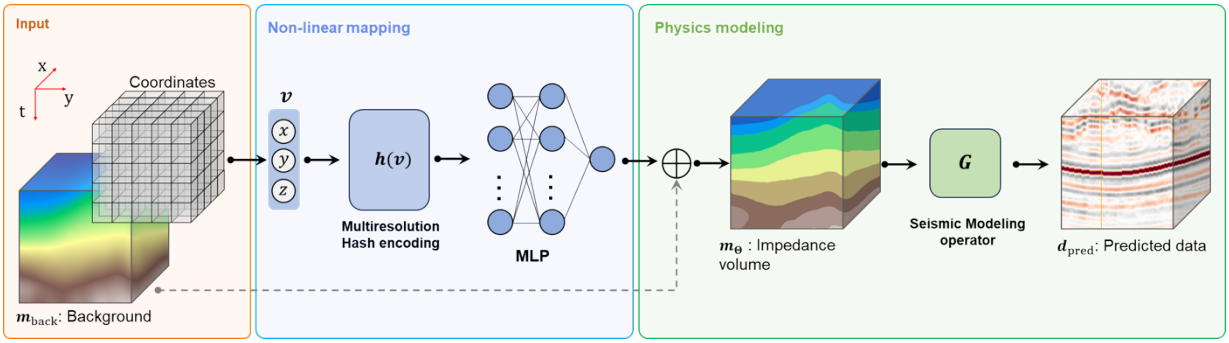
To foster an environment of effective research for the students and researchers that promotes seamless interaction with our sponsors.

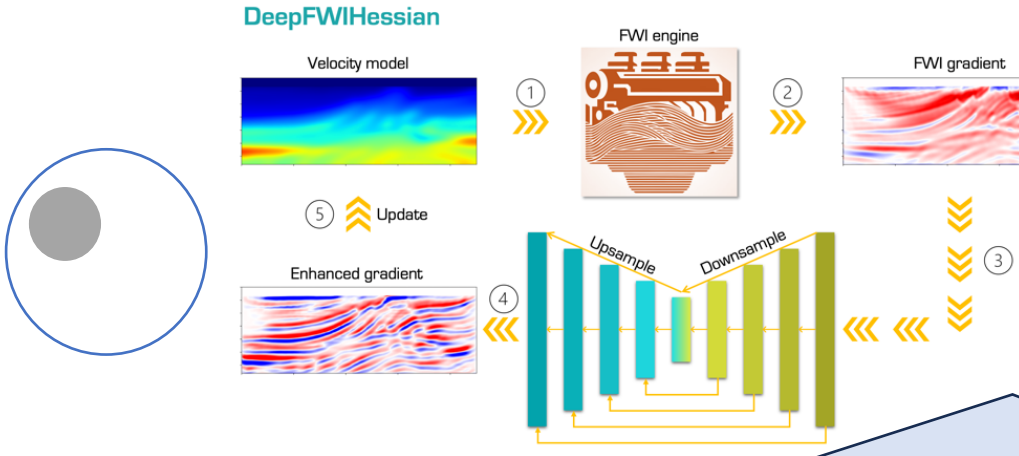
Samples of DeepWave Research

Seismic reservoir characterization with implicit neural representations

Juan Romero, Wolfgang Heidrich, Nick Luiken, Matteo Ravasi

This work introduces IntraSeismic, an innovative hybrid seismic inversion framework that integrates implicit neural representations with the physical principles of seismic modeling. This approach achieves remarkable performance in static and dynamic pre-stack and post-stack seismic inversion, offering faster convergence rates, the ability to incorporate hard constraints like well data directly into the inversion process, and efficient uncertainty quantification. Furthermore, IntraSeismic provides a compact representation of subsurface models, which can significantly enhance data storage and provide a faster mean to random access during subsequent analysis and visualization.





A deep learning-based inverse Hessian for Full Waveform Inversion: Application to the Volve data

Mustafa Alfarhan, Matteo Ravasi, Fuqiang Chen, and Tariq Alkhalifah

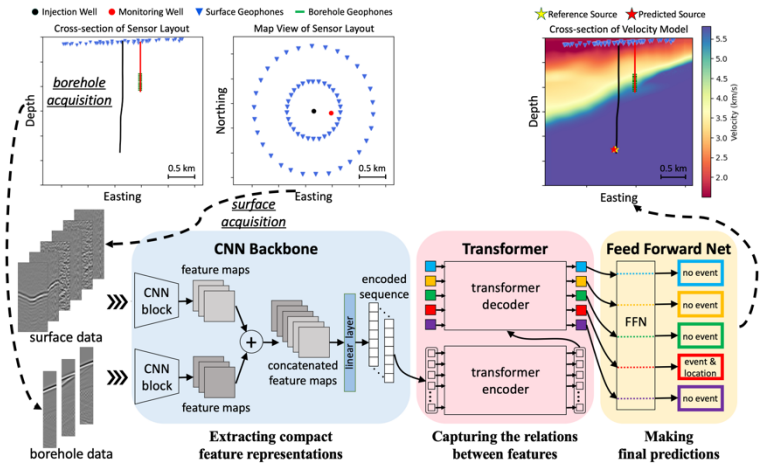
A framework that approximates the Hessian from a linearized wave equation, commonly used in Least-Squares Migration (LSM). It enhances the traditional method by using a deep neural network instead of non-stationary compact filters to learn the relationship between the Full Waveform Inversion (FWI) gradient and its blurred Hessian counterpart. This approach allows the network to serve as an approximate inverse Hessian, improving the FWI convergence. Once trained, the network's weights are transferred to subsequent FWI iterations to accelerate convergence. The effectiveness of this approach has been demonstrated on two synthetic and one field datasets.

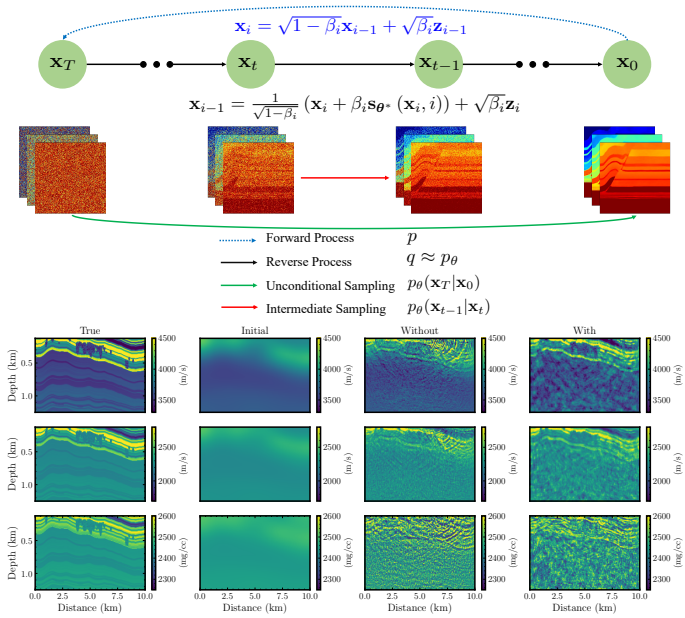
Samples of DeepWave Research

Deep learning-based 3D microseismic event direct location using simultaneous surface and borehole data

Yuanyuan Yang, Omar M. Saad, and Tariq Alkhalifah

A new paradigm, which utilizes the simultaneous recordings from surface and borehole seismic sensors, is proposed to directly locate microseismic events in 3D based on the elastic medium assumption. The proposed method has potent compatibility for embracing diverse datasets and a strong ability to model complex dynamics and interactions between multiple datasets. The usage of both surface and borehole data in one application allows us to utilize effective information in the available data while avoiding their inherent weaknesses, as the network is trained (optimized) to do so. The feasibility and potential of this method is demonstrated through the synthetic analysis and a field application on passive seismic data at the Utah FORGE geothermal site.





Learned regularizations for multi-parameter elastic full waveform inversion using diffusion models

Mohammad H. Taufik, Fu Wang, and Tariq Alkhalifah

Elastic full waveform inversion (EFWI) promises to account for the Earth's elastic nature and corresponding reflectivity, which is often disregarded in the commonly used acoustic FWI. However, EFWI usually requires a more sophisticated recording apparatus and empirical formulations to mitigate parameters cross-talks. To overcome these limitations, we introduce learned regularization using diffusion models. Only the vertical component of the particle velocity is used to invert the elastic parameters during the experiments. Ranging from synthetic to land field data, we show that our framework solves the illumination effects from an imperfect acquisition setup and provides more realistic elastic parameter ratios than the conventional EFWI with negligible additional cost.

Xinru Mu | *Postdoctoral Fellow*

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

I studied at the *China University of Petroleum* (East China) with a major in Geophysics from 2013 to 2023 and obtained both **undergraduate** and **doctoral** degrees. As a visiting doctoral student in 2021-2022, I conducted one year of **research** at the *Chinese University of Hong Kong*.

What research projects have you completed or contributed to recently?

I recently completed projects on the topics of attenuation-compensated LSRTM in TTI media, high-efficiency viscoelastic RTM, and pseudoelastic pure P-mode wave propagation modeling. Next, I will focus on using machine learning to achieve P/S wave separation in isotropic and anisotropic media. In addition, using machine learning to improve LSRTM imaging accuracy.

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

The KAUST DeepWave team members were keen to make me feel part of the group and early on I identified their dedication and strong background in using machine learning to solve geophysical problems.

Vittoria De Pellegrini | *PhD Student*

Vittoria holds a **Bachelor degree** in Civil Engineering from *University of Padua* (Italy), and a **master's degree** in Petroleum Engineering from *Polytechnic of Turin* (Italy).

She joined Aramco Overseas Company B.V. in the Netherlands as a 3-month geophysics intern in 2022. Her research interests are deep-water salt reservoirs, borehole geophysics, petrophysics, rock physics, generative adversarial networks (GANs), and deep learning.

Arturo Ruiz Sanchez | *MSc Student*

Arturo received his **Bachelor degree** in Geophysics at the *National Autonomous University of Mexico*.

His research interests are seismic processing, seismic data denoising, deep learning and self-supervised learning.

Muhammad Iqbal Khatami | *MSc Student*

Iqbal received his **Bachelor degree** from *Institut Teknolgi Bandung* (Indonesia).

His research interests are seismic processing, computational geophysics and inverse problems.

New Members

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

Recent Publications

Corrales M.; Hoteit H.; Ravasi M., "*Seis2Rock: A Data-Driven Approach to Direct Petrophysical Inversion of Pre-Stack Seismic Data"*, 2024, Earth and Space Science, 10.1029/2023EA003301.

Izzatullah M.; Alkhalifah T.; Romero J.; Corrales M.; Luiken N.; Ravasi M., "*Posterior sampling with convolutional neural network-based plug-and-play regularization with applications to poststack seismic inversion*", 2024, Geophysics, 10.1190/GEO2023-0035.1.

Huang X.; Alkhalifah T., "*Microseismic Source Imaging Using Physics-Informed Neural Networks With Hard Constraints*", 2024, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2024.3366449.

Brandolin F.; Ravasi M.; Alkhalifah T., "*PINNslope: Seismic data interpolation and local slope estimation with physics informed neural networks*", 2024, Geophysics 89 (4), 1-61, 10.1190/geo2023-0323.1.

Taufik M.H.; Wang F.; Alkhalifah T., "*Learned Regularizations for Multi-Parameter Elastic Full Waveform Inversion Using Diffusion Models*", 2024, JGR Machine Learning and Computation 1 (1), 10.1029/2024JH000125.

Alali A.; Alkhalifah T., "*Integrating U-Nets Into a Multiscale Full-Waveform Inversion for Salt Body Building*", 2023, IEEE Transactions on Geoscience and Remote Sensing", 10.1109/TGRS.2023.3310886.

Luiken N.; Ravasi M.; Birnie C., "*Integrating self-supervised denoising in inversion-based seismic deblending*", 2023, Geophysics, 10.1190/geo2023-0131.1.

Wang F.; Huang X.; Alkhalifah T., "*A Prior Regularized Full Waveform Inversion Using Generative Diffusion Models*", 2023, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2023.3337014.

Huang X.; Alkhalifah T., "*GaborPINN: Efficient Physics-Informed Neural Networks Using Multiplicative Filtered Networks*", 2023, IEEE Geoscience and Remote Sensing Letters, 10.1109/LGRS.2023.3330774.

Harsuko R.; Alkhalifah T., "*StorSeismic: A New Paradigm in Deep Learning for Seismic Processing*", 2022, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2022.3216660

News

• New Sponsors

We are thrilled to announce that the DeepWave Consortium family has expanded with the addition of two dynamic sponsors: INPEX and OXY! These forward-thinking companies bring fresh perspectives, innovative ideas, and we look forward to collaborating closely with them on impactful initiatives. Welcome aboard, INPEX and OXY!

• Mid-year Meeting 2024

The Consortium Mid-year 2024 Meeting was held on February 6-7, 2024 in KAUST. The event was hybrid and comprised of 5 sessions covering the domains of Microseismic monitoring, Processing and modeling, Reservoir characterization and FWI. Participants exceeded 80 and many contributed with feedback during the Q&A sessions.

• Presence in EAGE 2024 & IMAGE 2024

The members of DeepWave will be joining both EAGE 2024 in Oslo and IMAGE 2024 in Houston. We're excited to be sharing our work with the community through our 19 accepted oral presentations and 1 accepted poster in EAGE this year. Click here to see the comprehensive list of all our presentations in Oslo. DeepWave will also be hosting a booth in this year's IMAGE Technical exhibition in Houston.

- **DeepWave on Github**

More repos have been added in our Github organization as a result of the contribution of our team. The organization is proudly hosting 26 stable repos and 28 repos under development. All are created to provide seamless sharing of codes between the DeepWave researchers and the Consortium sponsors.

- **PhD Graduates**

We are proud and happy for our KAUST members that recently received their PhD. **Abdullah Alali** defended his work on "*Advances of deep learning in geophysical challenges: 4D seismic processing and salt inversion*". **Muhammad Izzatullah** defended his work on "*The applicability and scalability of probabilistic inference in deep-learning-assisted geophysical inversion applications*". We're sure that they will 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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