

# Zero-Shot Denoising of Distributed Acoustic Sensing Data using Deep Priors

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In recent years, deep learning-based methods have been successfully applied to problems across many different fields [10, 8, 3], including solving various inverse problems. One such problem is image denoising, which aims to recover a clean image  $x$  from a noisy observation  $y = x + n$ , where  $n$  represents the noise. There exist multiple supervised approaches to solve this problem [19, 4], however most of them need large datasets of (un)paired clean-noisy samples for the training process. While this might not be a problem for ordinary images, in different domains, such as medical imaging or distributed acoustic sensing (DAS), acquiring such datasets can be difficult or even impossible. This led to the development of different self-supervised approaches, removing the need for clean samples. However, a lot of these methods still require large datasets of noisy samples [12], make assumptions about the underlying noise model [13], or are not well suited for noise that is spatially correlated [2].

One exception to this is the deep image prior (DIP) [14], as it does not make any assumptions about the noise model and is an untrained approach, meaning that it works on a single noisy sample and instead only relies on the deep neural network structure in order to regularize the solution space. Our work can be divided into two main sections:

First of all, we are going to explain the general ideas behind DIP and highlight its differences in comparison with other self-supervised approaches. Then we are going to implement DIP and verify its practicability on different image denoising tasks in order to obtain a baseline for future experiments. After that, we are going to look at various follow up papers that try to improve on the original DIP performance, for example with regard to early stopping [15, 9] or better weight initialization [18, 1]. We are going to implement these improvements and compare them to our baseline.

In the second section, we are going to apply these methods to DAS data and deal with issues that might be specific to the underlying noise model [17]. We are also going to experiment with different loss functions, combining the DIP with existing self-supervised approaches [5, 2, 16]. Finally, we are going to run comprehensive experiments on different DAS datasets, comparing our results to other deep-learning based methods [11, 7, 17], as well as classical, non-deep learning methods, e.g. BM3D [6].

## References

- [1] Riccardo Barbano et al. “An Educated Warm Start for Deep Image Prior-Based Micro CT Reconstruction”. In: *IEEE Transactions on Computational Imaging* 8 (2022), pp. 1210–1222. ISSN: 2573-0436. DOI: [10.1109/tci.2022.3233188](https://doi.org/10.1109/tci.2022.3233188). URL: <http://dx.doi.org/10.1109/TCI.2022.3233188>.

- [2] Joshua Batson and Loic Royer. *Noise2Self: Blind Denoising by Self-Supervision*. 2019. arXiv: [1901.11365 \[cs.CV\]](#).
- [3] Tom B. Brown et al. *Language Models are Few-Shot Learners*. 2020. arXiv: [2005.14165 \[cs.CL\]](#).
- [4] Jingwen Chen et al. “Image Blind Denoising with Generative Adversarial Network Based Noise Modeling”. In: June 2018, pp. 3155–3164. DOI: [10.1109/CVPR.2018.00333](#).
- [5] Hyungjin Chung and Jong Chul Ye. *Deep Diffusion Image Prior for Efficient OOD Adaptation in 3D Inverse Problems*. 2024. arXiv: [2407.10641 \[cs.CV\]](#).
- [6] Kostadin Dabov et al. “Image Denoising by Sparse 3-D Transform-Domain Collaborative Filtering”. In: *IEEE Transactions on Image Processing* 16.8 (2007), pp. 2080–2095. DOI: [10.1109/TIP.2007.901238](#).
- [7] Martijn van den Ende et al. “A Self-Supervised Deep Learning Approach for Blind Denoising and Waveform Coherence Enhancement in Distributed Acoustic Sensing Data”. In: *IEEE Transactions on Neural Networks and Learning Systems* 34.7 (2023), pp. 3371–3384. DOI: [10.1109/TNNLS.2021.3132832](#).
- [8] Ian J. Goodfellow et al. *Generative Adversarial Networks*. 2014. arXiv: [1406.2661 \[stat.ML\]](#).
- [9] Yeonsik Jo, Se Young Chun, and Jonghyun Choi. *Rethinking Deep Image Prior for Denoising*. 2021. arXiv: [2108.12841 \[eess.IV\]](#).
- [10] Alex Krizhevsky, Ilya Sutskever, and Geoffrey E Hinton. “ImageNet Classification with Deep Convolutional Neural Networks”. In: *Advances in Neural Information Processing Systems*. Ed. by F. Pereira et al. Vol. 25. Curran Associates, Inc., 2012. URL: [https://proceedings.neurips.cc/paper\\_files/paper/2012/file/c399862d3b9d6b76c8436e924a68c45b-Paper.pdf](https://proceedings.neurips.cc/paper_files/paper/2012/file/c399862d3b9d6b76c8436e924a68c45b-Paper.pdf).
- [11] S Lapins et al. “DAS-N2N: machine learning distributed acoustic sensing (DAS) signal denoising without clean data”. In: *Geophysical Journal International* 236.2 (Nov. 2023), pp. 1026–1041. ISSN: 0956-540X. DOI: [10.1093/gji/ggad460](#). URL: <https://doi.org/10.1093/gji/ggad460>.
- [12] Jaakko Lehtinen et al. *Noise2Noise: Learning Image Restoration without Clean Data*. 2018. arXiv: [1803.04189 \[cs.CV\]](#).
- [13] Nick Moran et al. *Noisier2Noise: Learning to Denoise from Unpaired Noisy Data*. 2019. arXiv: [1910.11908 \[eess.IV\]](#).
- [14] Dmitry Ulyanov, Andrea Vedaldi, and Victor Lempitsky. “Deep Image Prior”. In: *International Journal of Computer Vision* 128.7 (Mar. 2020), pp. 1867–1888. ISSN: 1573-1405. DOI: [10.1007/s11263-020-01303-4](#). URL: <http://dx.doi.org/10.1007/s11263-020-01303-4>.
- [15] Hengkang Wang et al. “Early Stopping for Deep Image Prior”. In: *Transactions on Machine Learning Research* (2023). ISSN: 2835-8856. URL: <https://openreview.net/forum?id=231ZzrLC8X>.
- [16] Yaochen Xie, Zhengyang Wang, and Shuiwang Ji. *Noise2Same: Optimizing A Self-Supervised Bound for Image Denoising*. 2020. arXiv: [2010.11971 \[cs.CV\]](#).
- [17] Zitai Xu et al. “SelfMixed: Self-supervised mixed noise attenuation for distributed acoustic sensing data”. In: *GEOPHYSICS* 89.5 (2024), pp. V415–V436. DOI: [10.1190/geo2023-0640.1](#). URL: <https://doi.org/10.1190/geo2023-0640.1>.

- [18] Kevin Zhang et al. *MetaDIP: Accelerating Deep Image Prior with Meta Learning*. 2022. arXiv: [2209.08452 \[cs.CV\]](#).
- [19] Wangmeng Zuo, Kai Zhang, and Lei Zhang. “Convolutional Neural Networks for Image Denoising and Restoration”. In: *Denoising of Photographic Images and Video: Fundamentals, Open Challenges and New Trends*. Ed. by Marcelo Bertalmío. Cham: Springer International Publishing, 2018, pp. 93–123. ISBN: 978-3-319-96029-6. DOI: [10.1007/978-3-319-96029-6\\_4](#). URL: [https://doi.org/10.1007/978-3-319-96029-6\\_4](https://doi.org/10.1007/978-3-319-96029-6_4).