Spherical Normalization, Differential Encoding, and Complex-valued Convolutions for Deep Learning in Time-varying MIMO Channel State Estimation

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Contents

1 Introduction

Here is an example of a citation [1]. Citations are included in the `cited_works.bib` file.

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1.1 Introduction Section #1

For an example of a figure with subfigures, see Fig 1a or 1b.

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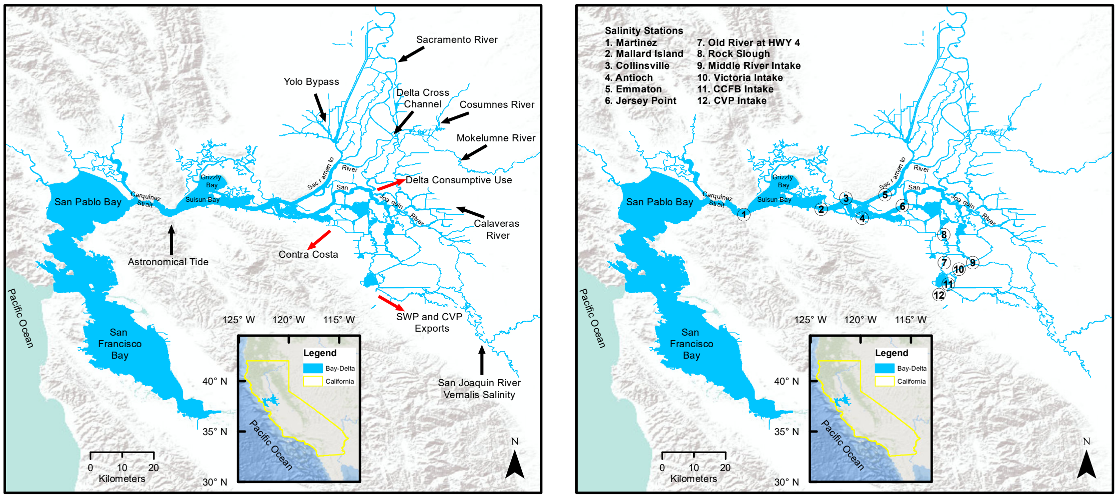

(a) ANN inputs and input locations.

(b) Locations of the 12 Study Salinity Stations.

Figure 1: ANN input and output locations in San Francisco Bay and Sacramento-San Joaquin Delta Estuary (Bay-Delta Estuary).

1.1.1 Introduction Subsection #1

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1.2 Introduction Section #2

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2 Spherical Normalization

Most work in deep learning for CSI estimation focuses on different neural network architectures, training frameworks, or hyperparameter tuning. However, the normalization used in these works is typically the same; the extrema (i.e., the minimum and the maximum) of the dataset are used to perform minmax scaling on the entire dataset,

$$\mathbf{H}_{k,\text{minmax}}(i,j) = \frac{\mathbf{H}_k(i,j) - \mathbf{H}_{\text{min}}}{\mathbf{H}_{\text{max}} - \mathbf{H}_{\text{min}}}$$

for $n \in [1, \ldots, N]$ given a dataset of N samples and i, j indexing the rows/columns of the CSI matrices. The resulting samples are cast to the range $[0, 1]$.

For image data, minmax normalization results in each image's color channels scaled to the range $[0, 1]$. The resulting distribution for each color channel is typically satisfactory for image tasks, as the variance is not much smaller than the range of the normalized data (see Fig. 2).

However, for CSI matrices, minmax normalization is applied to the real and imaginary channels of each element. For typical channel models and parameters, the distribution of channel elements (see Fig. 3) tends to have much lower variance than that of ImageNet. This smaller variance can be explained by the difference in the datasets' ranges – while the channels in image data (e.g., ImageNet) assume integer values between $[0, 255]$, the channels in CSI data (e.g., COST2100) assume floating point values smaller than 10^{-3}.

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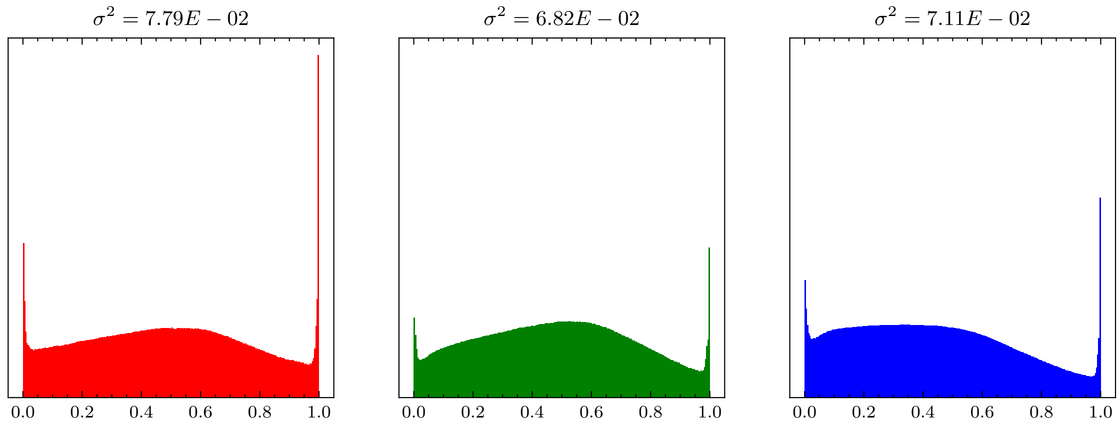

Figure 2: Distribution and variance of minmax-normalized ImageNet color channels ($N = 50000$) images.

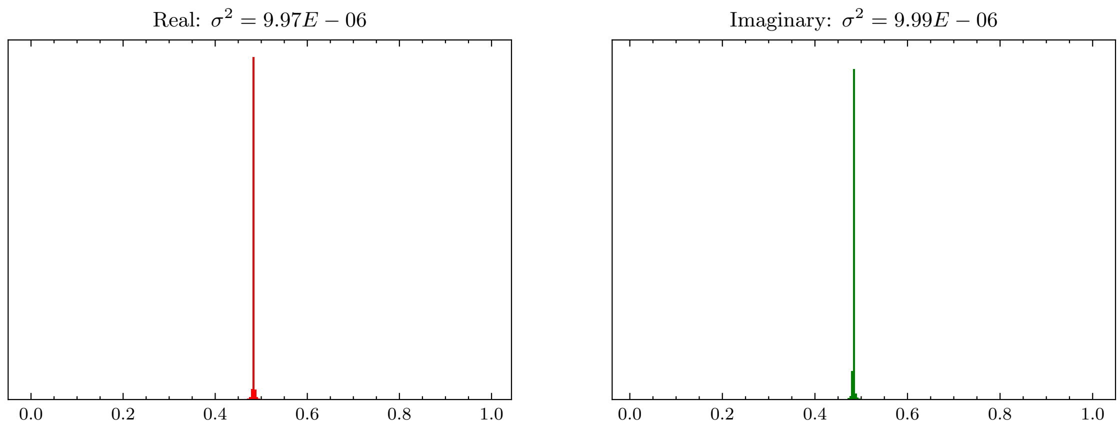

Figure 3: Distribution and variance of minmax-normalized COST2100 real/imaginary channels ($N = 99000$) images.

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2.1 Related Work

Several works have investigated normalization techniques for deep learning such as batch normalization [2], instance normalization [3], layer normalization [4], and group normalization [5]. These normalization techniques scale the outputs of latent layers in neural networks, which helps to solve the problem of covariate shift [2] where the mean and variance of changes between subsequent layers of the network.

Other works have studied normalization of the network's inputs. A number of works have investigated adaptive normalization techniques for time series estimation tasks [6–8]. In [9], the authors proposed a trainable input network which learns to shift, scale, and filter the unnormalized data while training the target network for a time series prediction task.

2.2 Methods

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2.2.1 Notation

For an example of a table, see Table 2.

Table 1: Notations

Variable	Definition
M	Number of input hydrological variables denoted in Fig. 1a
N	Number of data samples, or days, in dataset
T	Number of days' data used for estimation
T_r	Dimension of data after pre-processing
z_n	Time series used for estimating salinity level on day n, size is $\mathbb{R}^{M\times T}$
x_n	Pre-processed time series with size $\mathbb{R}^{M\times T_r}$ for day n
f	A convolutional filter with size $\mathbb{R}^{M\times T\times T_r}$
y_n	ANN-estimated salinity level for one or more locations on day n

2.2.2 Spherical Normalization

Rather than apply minmax normalization, which is adversely impacted by outliers, we propose spherical normalization. Before describing spherical normalization in detail, consider z-score normalization. Given a random variable, x, with mean μx and standard deviation μ. The z-score normalized version of this random variable is given as

$$z = \frac{x-\mu}{\sigma^2}. \tag{1}$$

Assuming x is normally distributed, the resulting random variable, z, is a standard normal distribution such that $z \sim \mathcal{N}(0,1)$. Inspired by z-score normalization, we seek a normalization scheme which adjusts the range of each channel sample. Under spherical normalization, each sample in the dataset is scaled by its power. Denote the k-th downlink CSI matrix of the dataset as $\mathbf{H}_d^k$. The spherically normalized version of the downlink CSI is given as

$$\check{\mathbf{H}}_d^k = \frac{\mathbf{H}_d^k}{\|\mathbf{H}_d^k\|_2}. \tag{2}$$

Observe that (2) is similar to (1) without the mean shift in the numerator[1] and with the power term of each CSI sample rather than the variance of the entire distribution. After

[1]Since the mean of COST2100 data is $\approx 10^{-10}$, we can safely ignore this mean shift in spherical normalization.

applying (2) to each sample, minmax scaling is applied to the entire dataset. The resulting dataset under spherical normalization can exhibit a larger variance than the same dataset under minmax scaling (compare Fig. 4 with Fig. 3). Beyond desirable properties in the input

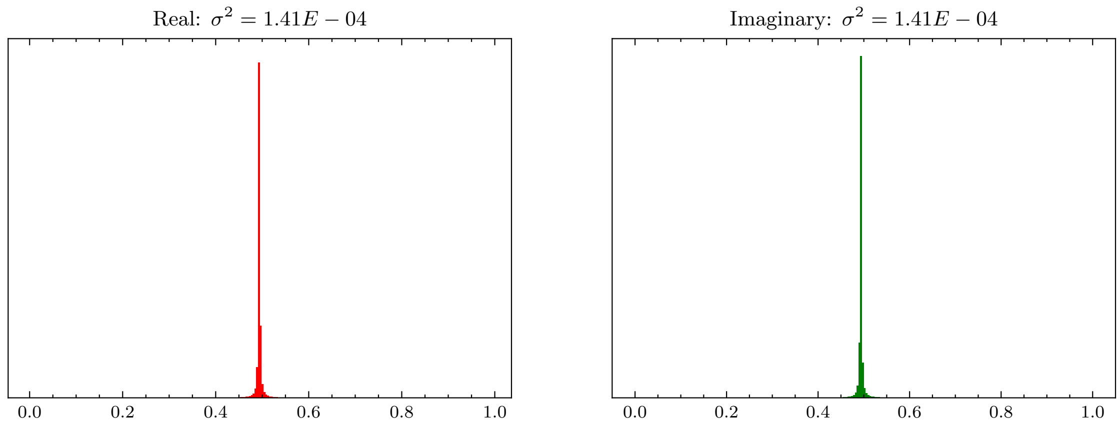


Figure 4: Distribution and variance of COST2100 real/imaginary channels under spherical normalization ($N = 99000$) images.

distribution, spherical normalization also results in an objective function which is better matched with the evaluation criterion. Neural networks for CSI estimation are optimized using the mean-squared error loss,

$$\text{MSE} = \frac{1}{N}\sum_{k=1}^{N} \|\mathbf{H}_k - \hat{\mathbf{H}}_k\|^2, \tag{3}$$

while channel state reconstruction accuracy is measured in terms of normalized mean-squared error,

$$\text{NMSE} = \frac{1}{N}\sum_{k=1}^{N} \frac{\|\mathbf{H}_k - \hat{\mathbf{H}}_k\|^2}{\|\mathbf{H}_k\|^2}. \tag{4}$$

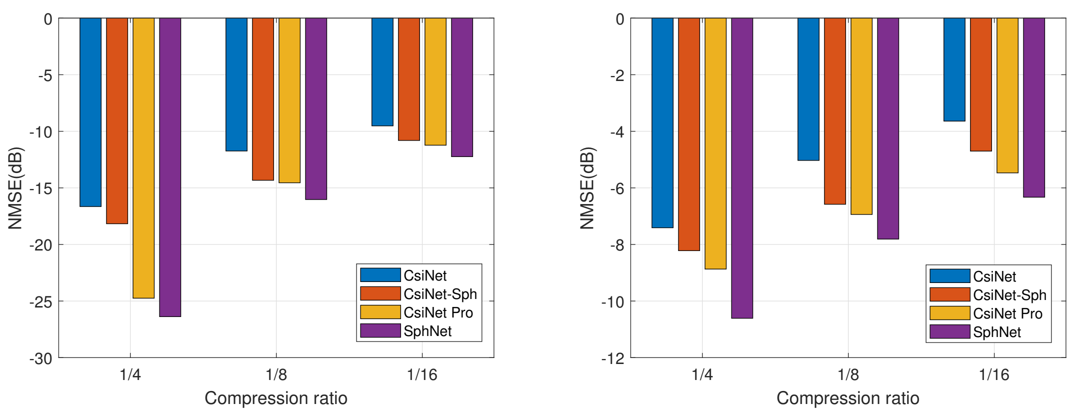
Observe that when the $\mathbf{H}_k$ ($\hat{\mathbf{H}}_k$) in (3) is replaced with $\check{\mathbf{H}}_k$ ($\hat{\check{\mathbf{H}}}_k$), we have

$$\frac{1}{N}\sum_{k=1}^{N}\|\check{\mathbf{H}}_k - \hat{\check{\mathbf{H}}}_k\|^2 = \frac{1}{N}\sum_{k=1}^{N}\left\|\frac{\mathbf{H}_k}{\|\mathbf{H}_k\|^2} - \frac{\hat{\mathbf{H}}_k}{\|\mathbf{H}_k\|^2}\right\|^2 \tag{5}$$

$$= \frac{1}{N}\sum_{k=1}^{N}\frac{\|\mathbf{H}_k - \hat{\mathbf{H}}_k\|^2}{\|\mathbf{H}_k\|^2}, \tag{6}$$

which is equivalent to (4). Thus, a neural network optimized with MSE as the loss function and trained using spherically normalized data is in fact being optimized with respect to NMSE of the original data.

Training on spherically normalized data and optimizing with respect to NMSE can yield better accuracy. Fig. **??** demonstrates this improvement for CsiNet and CsiNet Pro on the COST2100 dataset. For both networks, the number of



(a) Indoor (b) Outdoor

2.2.3 Methods Subsection #2

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3 MarkovNet: A Deep Learning-based Differential Autoencoder

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3.2 Methods

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$$x_{n,i}^{(m)} = \sum_{j=1}^{T} z_{n-j+1}^{(m)} \times f_{j,i}^{(m)}, \tag{7}$$

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4 Proposed Work

4.1 Proposed Work Section #1

4.1.1 Proposed Work Subsection #1

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4.1.2 Proposed Work Subsection #2

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5 Conclusion

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References

[1] T. Oetiker, H. Partl, I. Hyna, and E. Schlegl, “The not so short introduction to latex2ε,” *Electronic document available at http://www. tex. ac. uk/tex-archive/info/lshort*, 1995.

[2] S. Ioffe and C. Szegedy, “Batch normalization: Accelerating deep network training by reducing internal covariate shift,” in *International conference on machine learning*, pp. 448–456, PMLR, 2015.

[3] X. Huang and S. Belongie, “Arbitrary style transfer in real-time with adaptive instance normalization,” in *Proceedings of the IEEE International Conference on Computer Vision*, pp. 1501–1510, 2017.

[4] J. L. Ba, J. R. Kiros, and G. E. Hinton, “Layer normalization,” *arXiv preprint arXiv:1607.06450*, 2016.

[5] Y. Wu and K. He, “Group normalization,” in *Proceedings of the European conference on computer vision (ECCV)*, pp. 3–19, 2018.

[6] E. Ogasawara, L. C. Martinez, D. De Oliveira, G. Zimbrão, G. L. Pappa, and M. Mattoso, “Adaptive normalization: A novel data normalization approach for non-stationary time series,” in *The 2010 International Joint Conference on Neural Networks (IJCNN)*, pp. 1–8, IEEE, 2010.

[7] S. Nayak, B. B. Misra, and H. S. Behera, “Impact of data normalization on stock index forecasting,” *International Journal of Computer Information Systems and Industrial Management Applications*, vol. 6, no. 2014, pp. 257–269, 2014.

[8] X. Shao, “Self-normalization for time series: a review of recent developments,” *Journal of the American Statistical Association*, vol. 110, no. 512, pp. 1797–1817, 2015.

[9] N. Passalis, A. Tefas, J. Kanniainen, M. Gabbouj, and A. Iosifidis, “Deep adaptive input normalization for time series forecasting,” *IEEE transactions on neural networks and learning systems*, vol. 31, no. 9, pp. 3760–3765, 2019.