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Neural networks and state estimation

Xuelei Chen

Agenda

- Introduction to neural network
- Recurrent neural networks for electric grid analysis
    - Problem statement
    - Method description
    - Experimental result
    - Conclusion
- Neural networks for robust spectra reconstruction
    - Problem statement
    - Method description
    - Experimental result
- Conclusion

Introduction to neural network

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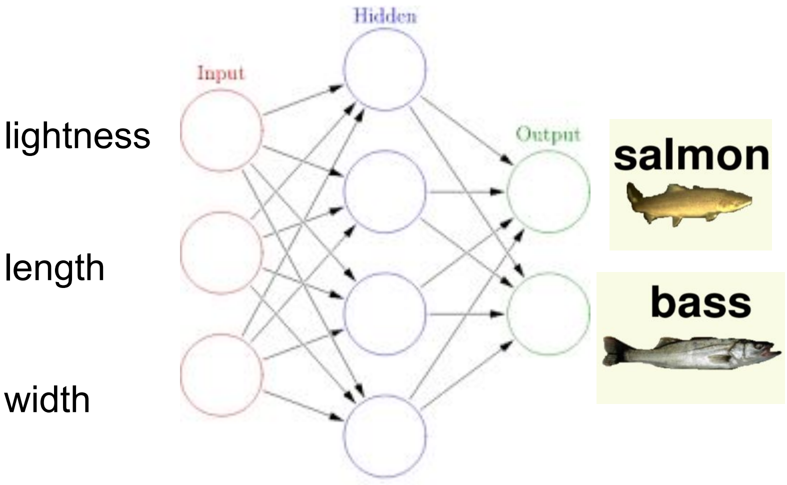
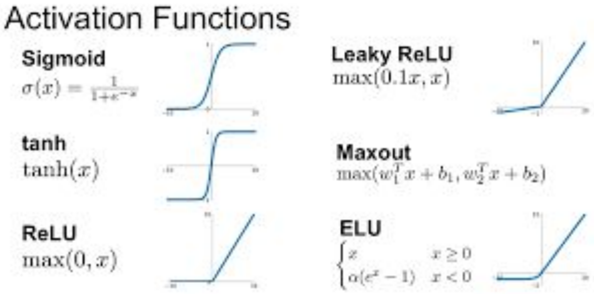
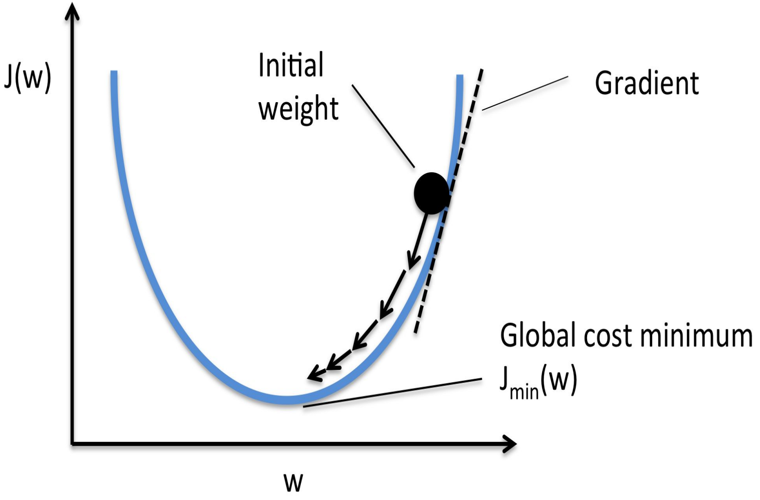
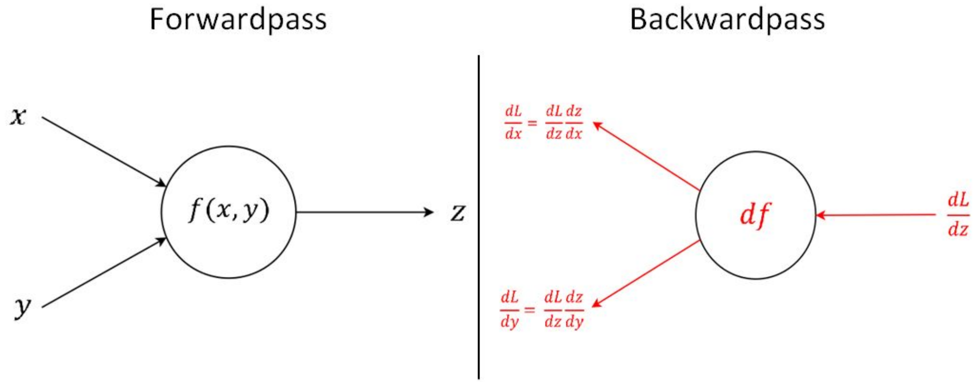


$\rightarrow$: act(w*x+b)



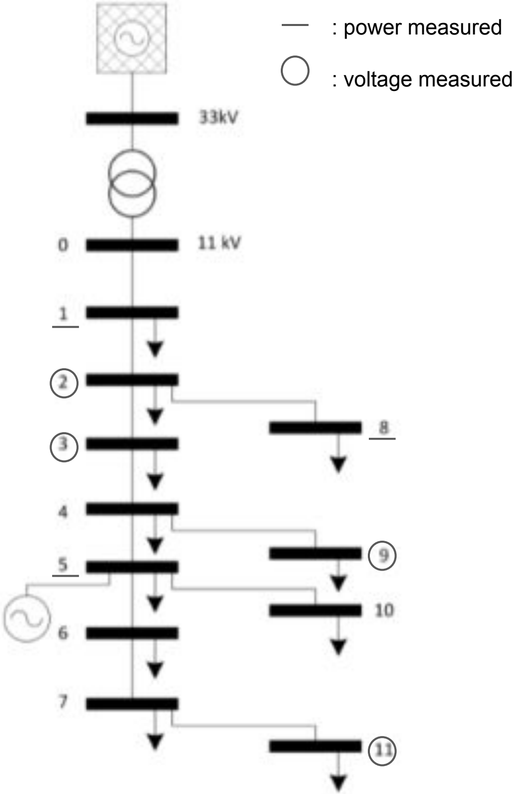
Introduction to neural network





RNNs for electric grid analysis

Problem Statement



Goal:

- Online state estimation with incomplete measurement.
    - Power Value

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Method Description

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Case 1: one-layer NN

$$x(k+1) = w_k * \sigma\left(x(k)\right) + g(k)$$

Case 2: two-layer NN

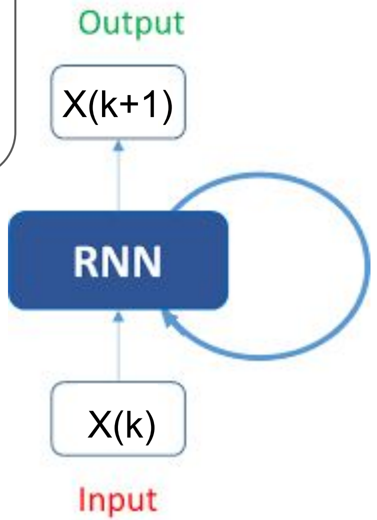
$$x(k+1) = w_{2,k} * \sigma\left[w_{1,k} * \sigma\left(x(k)\right)\right] + g(k)$$

- State equation:

$$\boldsymbol{x}_k = f(\boldsymbol{x}_{k-1}, \boldsymbol{u}_{k-1}, \boldsymbol{w}_{k-1})$$

- Measurement equation:

$$\boldsymbol{z}_k = h(\boldsymbol{x}_k, \boldsymbol{v}_k)$$



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Method Description

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Learning Method:

- Joint Estimation: EKF for weight parameter + EKF for state (power)
- Kalman Filter: Using Extended Kalman Filter to update w^ and x^ alternatively

Algorithm (Pseudocodes):

- ❑ Initialize w0,x0
- ❑ For *k* in timepoints:
  - ❑ A priori forecast: wf(k) = w(k-1)
  - ❑ For *i* in itersteps:
    - ❑ KF updating w^(k)
    - ❑ When updating converges, break
  - ❑ A priori forecast: xf(k) = RNN(w^(k), x(k-1))
  - ❑ For *j* in itersteps:
    - ❑ KF updating x^(k)
    - ❑ When updating converges, break
  - ❑ S^(k) = Sm(k) + x^(k)

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Experimental Results

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iter		200	400	500	600	800	1000
Joint	RNN-1	0.2724	0.2694	0.2693	0.2704	0.2764	**0.2849**
	RNN-2	**0.2705**	**0.2659**	**0.2645**	**0.2647**	**0.2732**	0.3008

Table 1: Mean Squared Error (10^-2) of estimation results using 1-layer RNN and 2-layer RNN

iter		400	500	550	600
RNN-2	Adaptive AR[1]	4.2785			
	Only State	0.4245			
	Only Weight	0.2664	0.2650	0.2648	0.2650
	Joint	**0.2659**	**0.2645**	**0.2644**	**0.2647**

Table 3: Mean Squared Error (10^-2) of estimation results using only-state method, only-weight method and Joint method

	Time/s
RNN-1	0.6223
RNN-2	0.8041

Table 2: Computation time for one time points' estimation

[1]Makarava, N., Lin, G., Eichstädt, S., Adaptive quasi-dynamic state estimation for MV and LV grids, EURASIP Journal on Advances in Signal Processing

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Experimental Results

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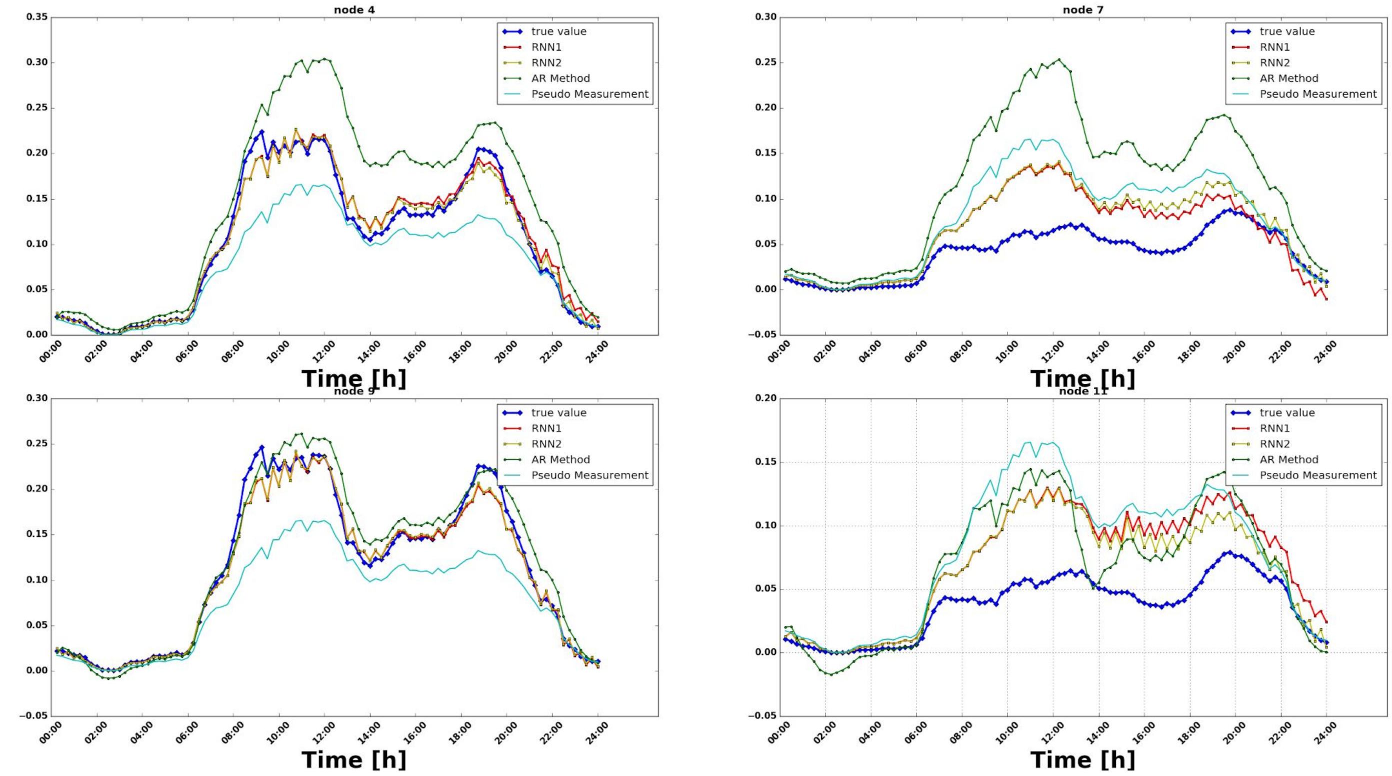

Power measured at:
[1, 5, 8]
Voltage measured at:
[2, 3, 9, 11]

Power to be estimated:
[2, 3, 4, 6, 7, 9, 10,11]

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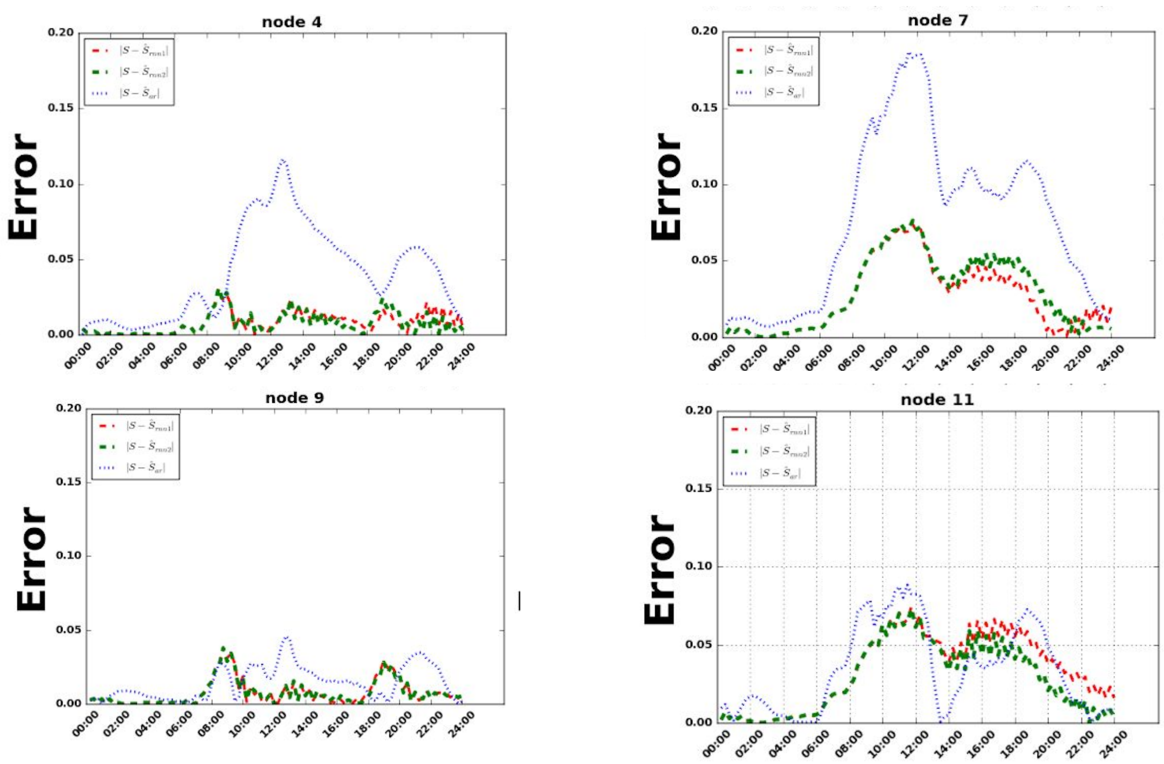
Experimental Results



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Power measured at:
[1, 5, 8]
Voltage measured at:
[2, 3, 9, 11]

Power to be estimated:
[2, 3, 4, 6, 7, 9, 10,11]

Mean Absolute Error of estimation (node 4, node 7, node 9, node 11) using AR_Adaptive, RNN1 and RNN2 method

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Experimental Results

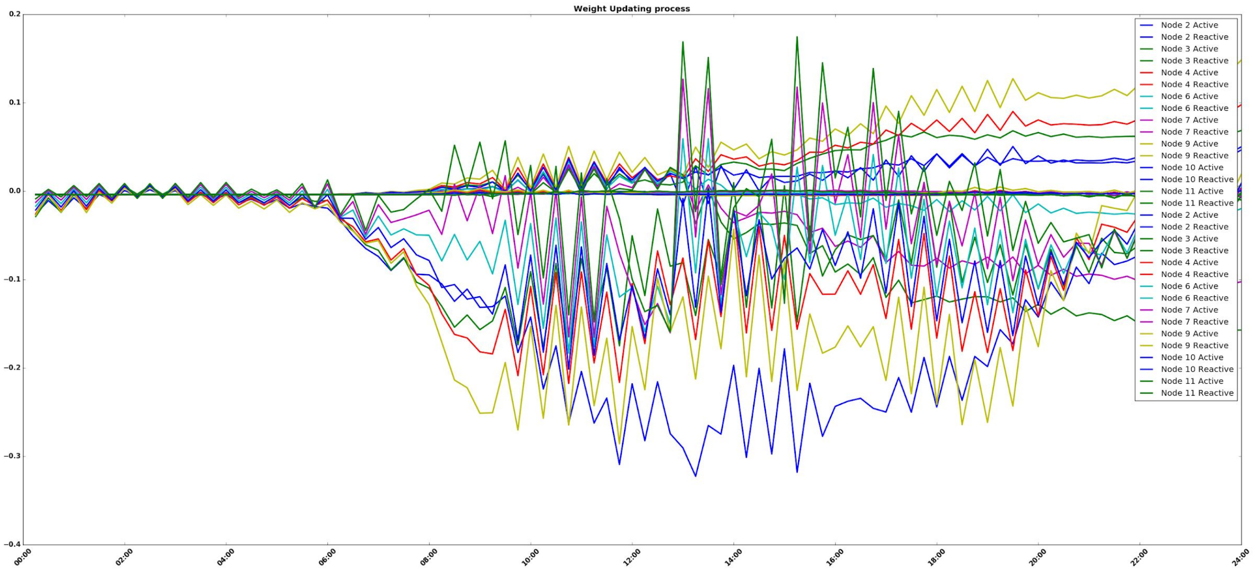

Fig 1: Updating process of weights in the 1st layer.

8 nodes' active and reactive powers need to be estimated.

2 layer RNNs.

Parameter numbers: 8*2*2=32

Experimental Results

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Two edge cases:

Power measured at:
[1]
Voltage measured at:
[2,3,4,5,6,7,8,9,10,11]

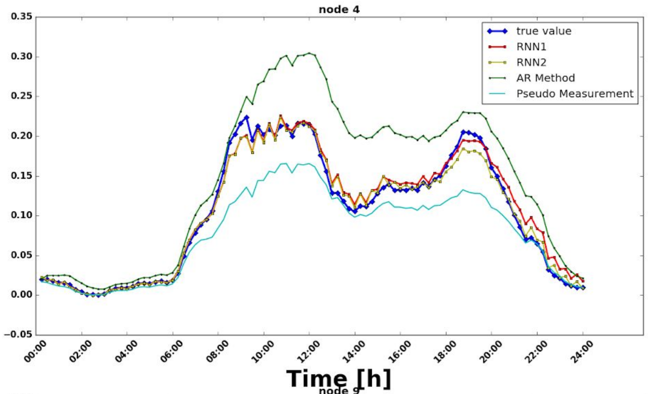
Power to be estimated:
[2,3,4,5,6,7,8,9,10,11]

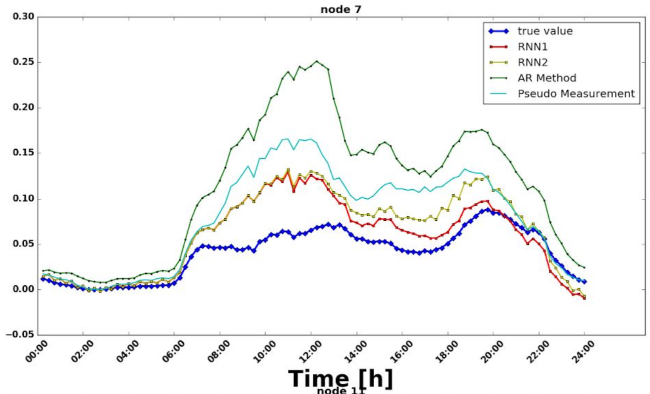
Power measured at:
[1, 3, 4, 5, 6, 7, 8, 9, 10, 11]
Voltage measured at:
[2]

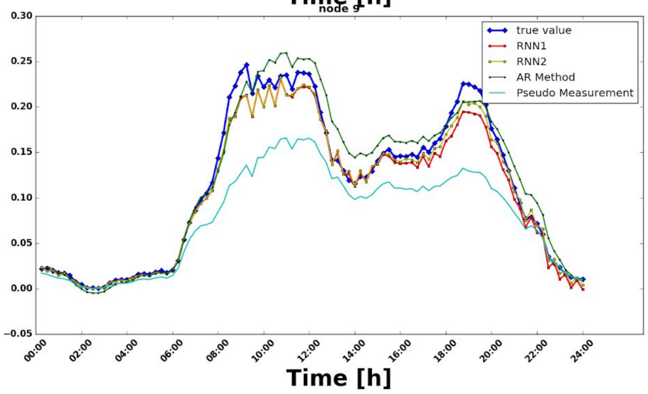
Power to be estimated:
[2]

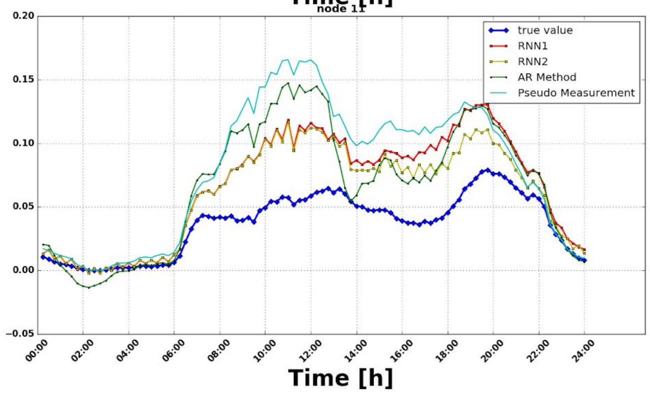
RNNs for electric grid analysis

Experimental Results









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Power measured at:
[1]
Voltage measured at:
[2,3,4,5,6,7,8,9,10,11]

Power to be estimated:
[2,3,4,5,6,7,8,9,10,11]

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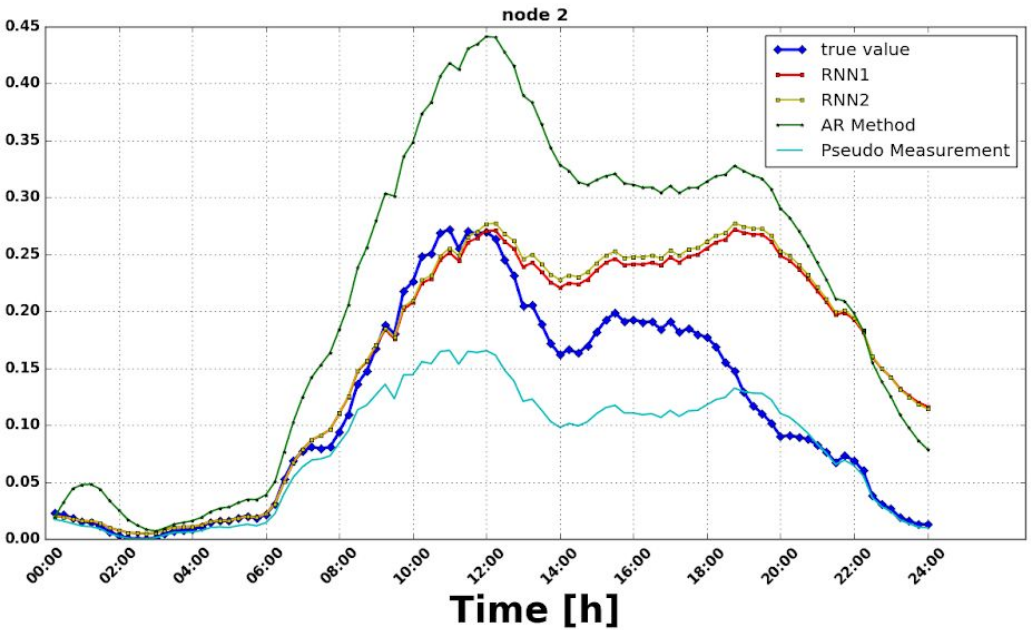
Experimental Results



Power measured at:
[1, 3, 4, 5, 6, 7, 8, 9, 10, 11]
Voltage measured at:
[2]

Power to be estimated:
[2]

RNNs for electric grid analysis

Conclusion

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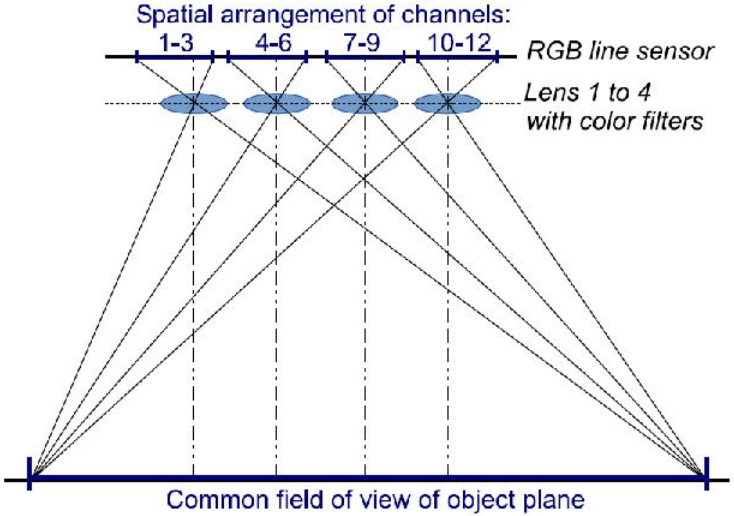
- RNN-bases estimation method can achieve great improvement with respect to the state-of-the-art.
- 2-layer RNN is slightly better than 1-layer RNN on this estimation task.
- RNN-based joint estimation is slightly better than RNN-based single estimation on this task.

NNs for robust spectra reconstruction
Problem statement



Reflectance spectra: 380~730nm
Camera response: 12 channel

Dataset description:
240 samples
sp: (240,351)
cr: (240,12)

split

180 samples for training
sp_train: (180,351)
cr_train: (180,12)

60 samples for testing:
sp_train: (60,351)
cr_test: (60,12)

NNs for robust spectra reconstruction
Method description

sp: (180,351)
cr: (180,12)

tr: (12,351)

$tr = pinv(cr) * sp$

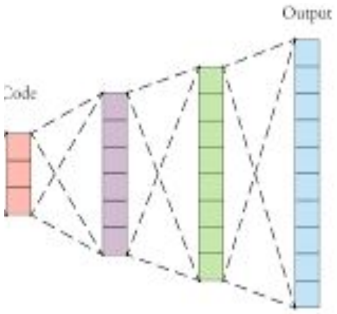
Pseudo-inverse

Linear kernel

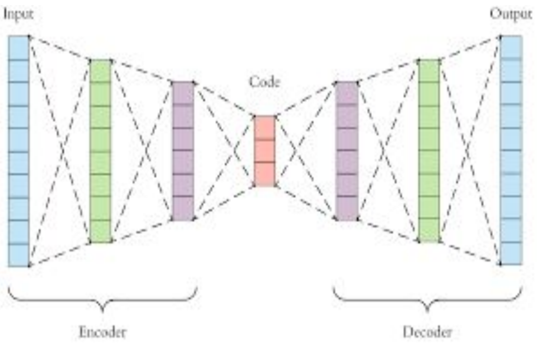
Gaussian kernel

Logarithmic kernel

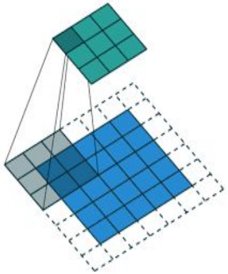
Kernel Regression



Simple Neural Networks



Autoencoder

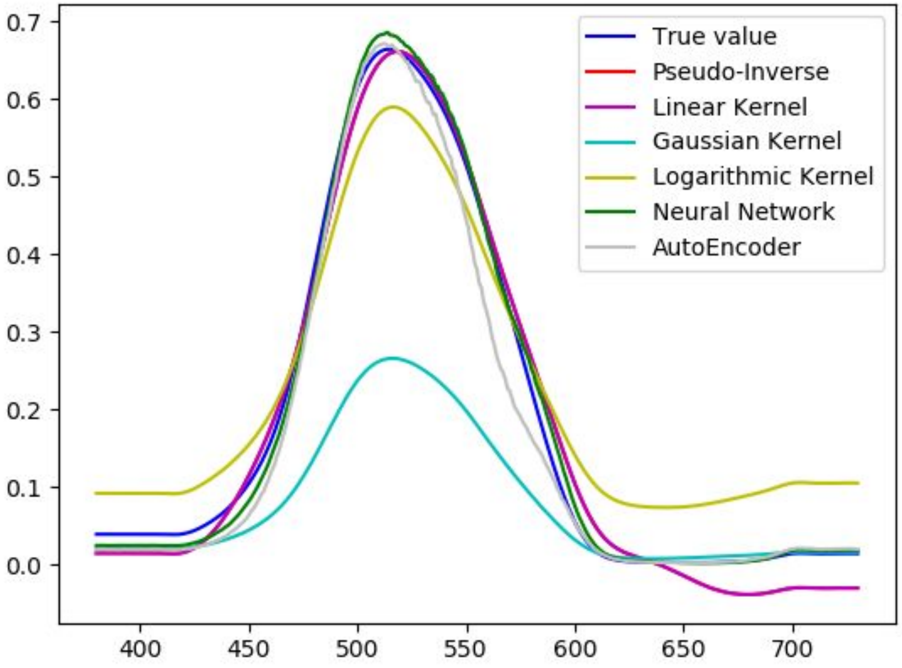


CNNs

NN-based methods

NNs for robust spectra reconstruction

Experimental Results



Noise: $N(\mu, \sigma^2)$

Noise	σ=50
pseudo-inverse	3.47E-06
linear kernel	3.47E-06
gaussian kernel	0.004006324995
logarithmic kernel	3.51E-05
NN	**3.38E-06**
Autoencoder	5.86E-06

Table 3: Average RMSE of reconstructions using different estimation method

Experimental Results

Conclusion:

- Neural Network method can achieve the best results on spectra reconstruction, especially when the noise exists in the camera system. NN is a robust method.

Final Conclusion

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- Neural Network method can learn the model from the data itself.
- NN is useful when the model is unknown or the model is complicated.

Thank you!

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