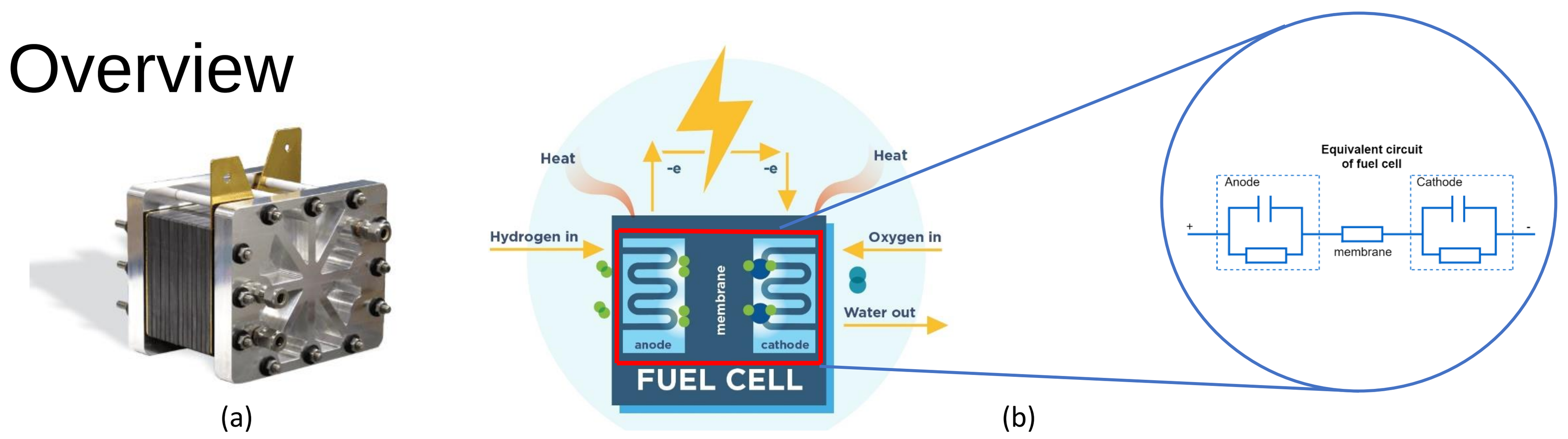
Prediction of high frequency resistance in polymer electrolyte membrane fuel cells

Tong Lin, Leiming Hu, Willetta Wisely
Xin Gu, Jun Cai, Shawn Litster
Levent Burak Kara

Overview



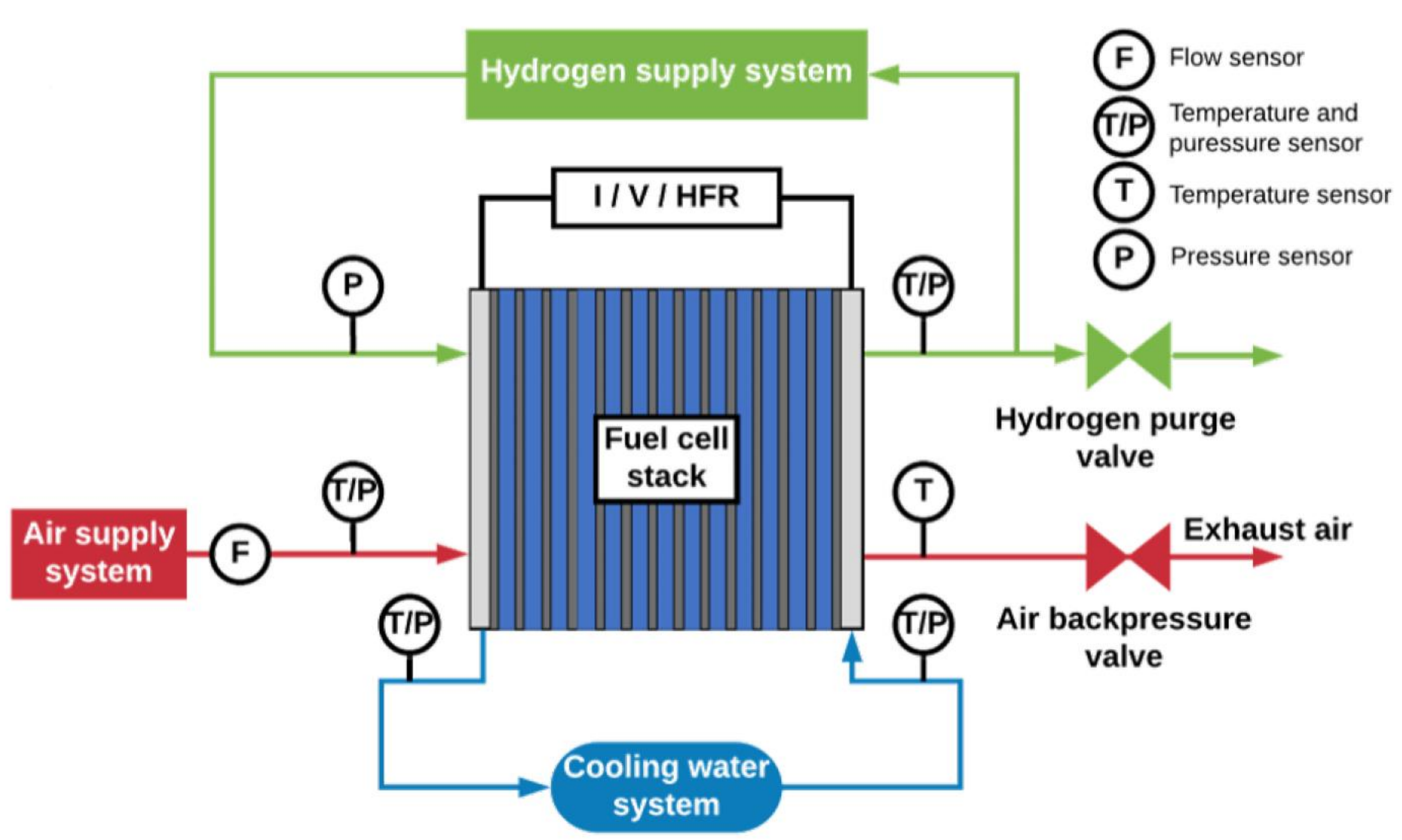
(a) A hydrogen fuel cell stack [1]. (b) Illustration of HFR modelling in a fuel cell [2].

High-frequency resistance (HFR) is an impedance of the fuel cell under high frequency perturbation source. It is a critical quantity strongly related to a fuel cell system's performance. As such, an accurate and timely prediction of HFR is useful for understanding the system's operating status and the corresponding control strategy optimization. On a real car, It is beneficial to estimate the fuel cell system's HFR from the measurable operating conditions without resorting to costly HFR measurement devices. Our research investigates HFR estimation in a complex and real fuel cell system in a lab environment. It is an initial stage to prove the potential usage of a data-driven method for online HFR prediction on real driving environment. We demonstrate that,

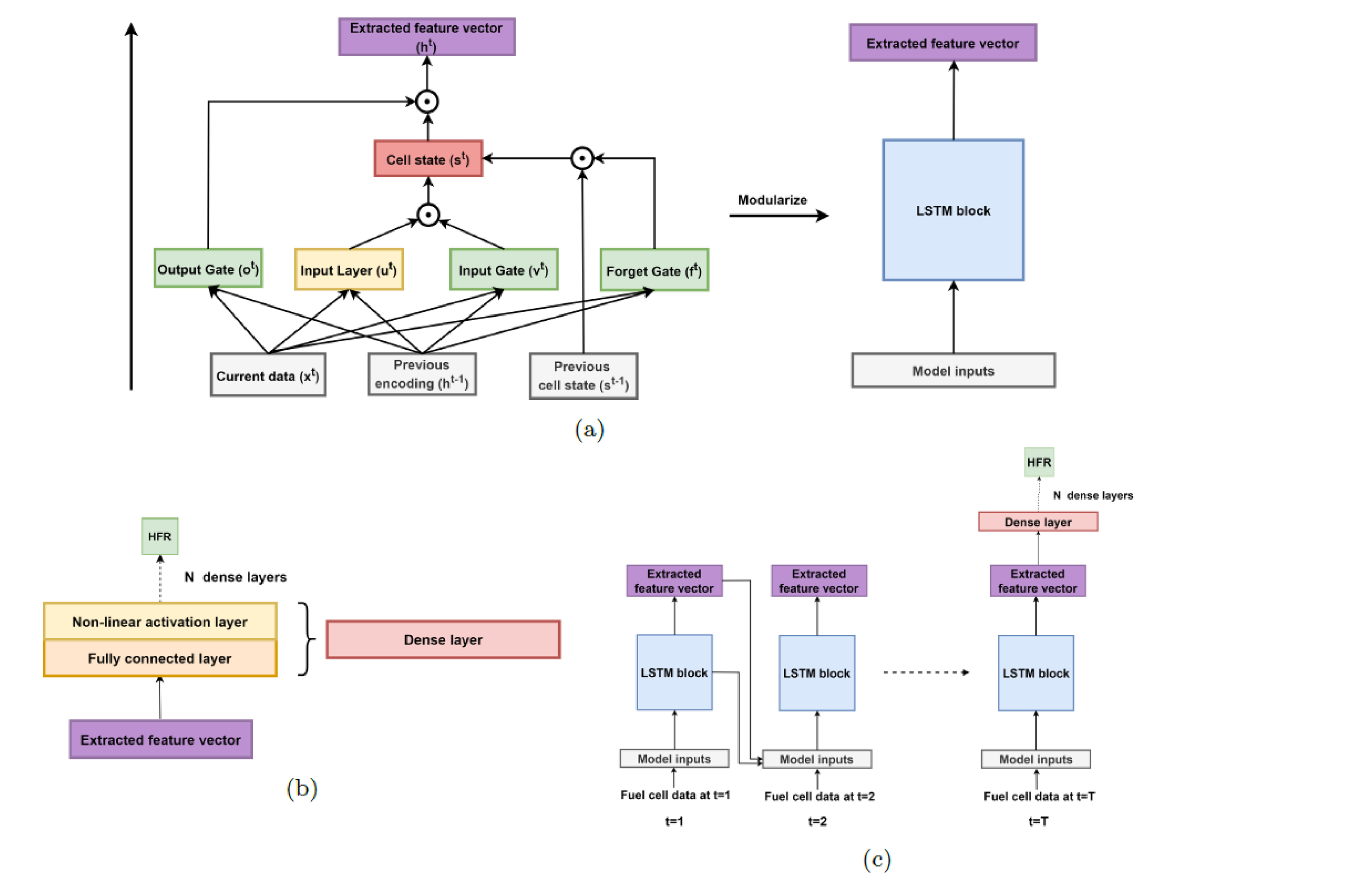
- a data-driven model can be used to achieve high accuracy of online HFR prediction for an industry level fuel cell stacks.
- the model can be computationally light and thus, practical to use.

Experiment setup

The experiment data was collected from a commercially available multi-stack fuel cell system (PROMER P390 Fuel Cell System, Shanghai Hydrogen Propulsion Technology (SHPT), Shanghai, China). Current is the main external power source of the fuel cell. The collected data are fuel cell voltage and current, air flow rate, cooling water temperature and pressure, air supply system's temperature, hydrogen supply system's pressure and temperature and fuel cell's HFR.



HFR prediction model



(a) One time slice of LSTM model and its simplified module. (b) Multiple layer perceptron model. (c) LSTM-MLP model.

The long short-term memory (LSTM) model concatenated by a multiple layer perceptron (MLP) model is used for HFR estimation. The model inputs are all the collected data except HFR in an interval of 20 seconds. The collected HFR at the 20th second is used as the ground truth for the model.

Results

Three current trends are conduced in the experiments. The trends are the constant current (type I), the upramp current (type II), and the cyclic current (type III). Several test datasets are generated under the three trends. We compared LSTM model with several other frequently used regression models. LSTM shows the best performance under all the current conditions.

	RMSE		
	Current type I	Current type II	Current type III
LSTM-MLP	3.77	4.70	3.51
L-SVR	6.34	5.47	5.58
GK-SVR	4.09	7.48	4.89
ANN	4.76	8.79	4.69

* LSTM-MLP is our model
* L-SVR is the support vector regression with linear kernel
* GK-SVR is the support vector regression with gaussian kernel
* ANN is the feedforward neural network.

We test the model speed and accuracy by tunning LSTM's encoding dimension on all test datasets. This is critical for the practicality of the model design because the model will be deployed on a micro-controller on a real car. We test typical setup of the encoding dimension from 16 to 512. We find that a large shrinkage of the encoding dimension doesn't decrease the error significantly while it is helpful to increase the model speed. However, we do observe that GK-SVR is still faster than a LSTM-MLP model of 16 encoding dimension although its error is also much higher. Thus, which algorithm setup to choose is still a decision to be made depending on the requirement of the specific application environment.

LSTM-MLP encoding dimension comparison							GK-SVR
Encoding dimension	16	32	64	128	256	512	
RMSE	4.61	4.47	4.52	5.49	3.86	4.06	5.41
Speed (sec)	0.82	0.81	0.84	1.02	1.08	1.13	0.67

Conclusion

This work presents a deep learning method for predicting HFR in fuel cells. Our LSTM- and MLP- based model, can take the previous and current information of the sensor data for a real-time prediction of HFR in operational, deep-stack fuel cells. The following conclusions are drawn:

- The presented model achieves high prediction accuracy under varied current patterns.
- The model can achieve runtime performance with high accuracy by reducing the model size

The model is designed for computationally efficient real-time predictions. Once the model is trained off-line, it can be executed very fast on board. The speed can be further increased by reducing the model size while the accuracy only slightly decreases. Considering the high prediction accuracy and runtime performance, the model may prove promising for fuel cell vehicles, which usually control their fuel cell system using embedded controllers.

References

1. The image is taken from Fuel Cell Store website.
2. Part of the image is taken from Fuel Cell & Hydrogen Energy Association website.

Acknowledgements

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