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Real-time ELM recognition algorithm based on deep learning

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ABSTRACT

- Based on the deep learning method, this research introduced a set of ELM real-time recognition algorithm on HL-2A
- The algorithm uses 5200 shots data (about 241,900 data slices) for learning
- A 22-layer convolutional neural network is obtained
- The system can recognize the ELMy H-mode and output the start/end time

BACKGROUND

Advantage of H-mode:

- Improve the confinement performance of the tokamak
- Universal physical mechanism

Characteristics of ELMy H-mode:

- Quasi-periodic discharge of impurities
  - More advantageous in long-term stable operation
- Quasi-periodic discharge of energy and particles
  - Erosion of target material

In order to achieve controlled nuclear fusion, it is necessary to develop an algorithm to recognize ELM in real time!

METHODS

The workflow of the ELM recognition algorithm is shown in Fig 1, which is mainly composed of the preparation of the training database, the neural network identification ELM, Smoothing the output of neural network.

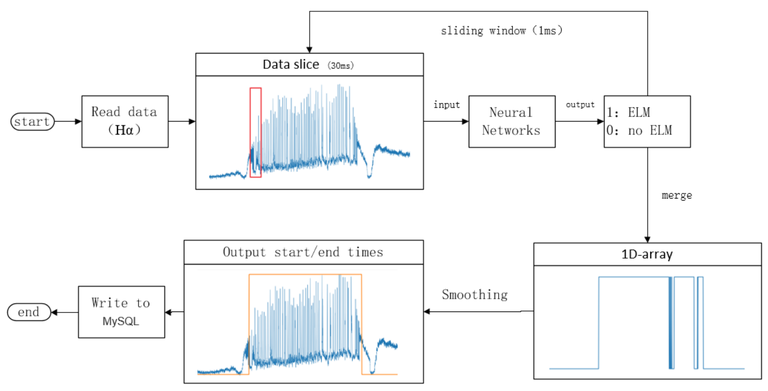

Fig1 ELM recognition algorithm work flow

Database preparation

- Using Hα signal and uniform resampling to 10 kHz
- Slicing original data, the length of each slice window is 30ms
- Only processing shots whose maximum value exceeds 0.4;
- The sliding step of the window during training is 10ms;
- The sliding step of the window during testing is 1ms;
- Normalizing the data in the slice window

Through the above rules, 241,900 pieces of data are obtained from the 20000-25200 shots on the HL-2A

Training neural network

The slice data is divided into a training set, validation set and test set in a ratio of 8:1:1 to train neural network. The training result is shown in Table 1.

Table1 test results for each data set

Data Set	Recognition success rate
Training set	99.4%
Validation set	98.8%
Test set	99.3%

Smoothing the output of neural network

Considering that the conversion of the L-H mode is a continuous process, ELMs of a few slice lengths do not appear. So the output of neural network is smoothed to obtain start/end time of the ELMy H-mode according to the following rule:

(1) It is considered as the start time when slices containing the ELM signal in the subsequent 20 slices is more than 16.

(2) It is considered as the end time when slices containing the ELM signal in the subsequent 20 slices is less than 10.

(3) It is regarded as one H-mode when the interval between two H-mode signals is less than 50ms.

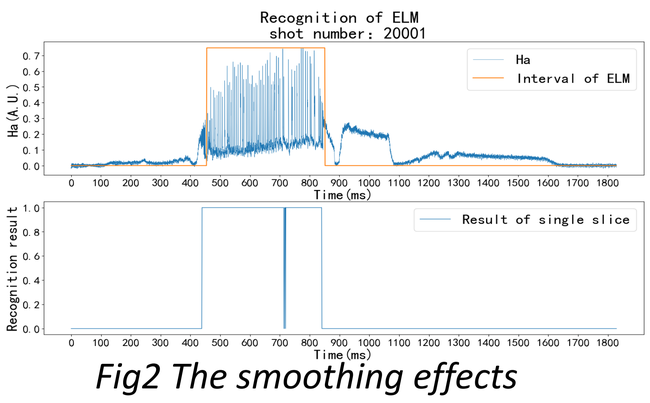

Fig2 The smoothing effects

OUTCOME

Neural Network structure

Based on the AlexNet network, after more than 70 network structure adjustments, a 22-layer neural network finally be obtained. (Fig 3) The network test results of training dataset, validation set and test set are 99.4%,98.8% and 99.3% respectively.

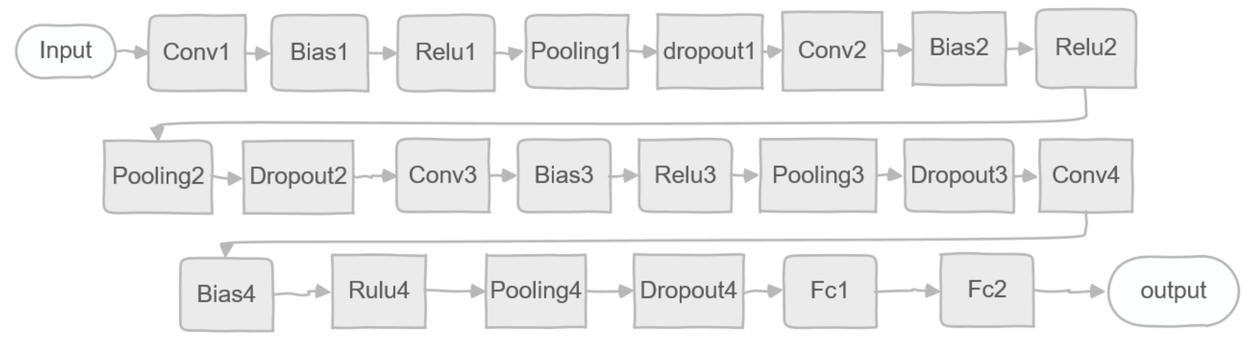

Fig3 The network structure

Recognition of historical data

All the data of the HL-2A since the implementation of stable H-mode discharge in 2009 were tested(Table 2):

- A total of 1665 shots of H-mode has been recognized, of which 35 shots are false recognized(False R), with the false positive rate (FPR) was 2.10%.
- In the actual 1634 shots of H-mode, the system missed to recognize(Miss R) 4 of them, with the false negative rate(FNR) was 0.24%.
- All the recognition error of the start/end times does not exceed 20ms in comparison with the actual ELM interval.

In addition to recognition of more standard ELM, the recognition algorithm has a good recognition effect for complex situations. (Fig 4)

The algorithm computing speed

This study builds a speed test platform which is based on the Linux operating system and built in C program language. It follows the data processing sequence in real-time control and uses a total of 14900 time slices for testing:(Fig 5)

- average recognition time is 0.46ms
- maximum recognition time is 0.75ms

The control period of HL-2A plasma control system (PCS) is 1ms. The results can meet the calculation speed requirements of real-time control.

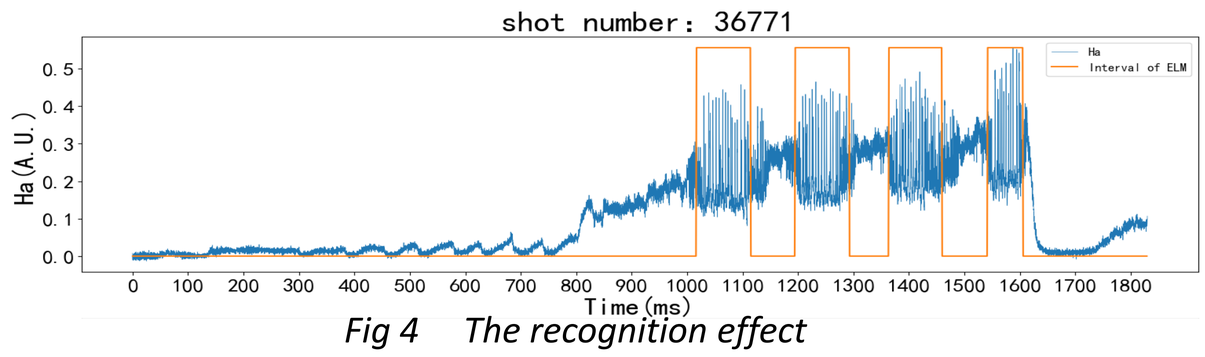

Fig 4 The recognition effect

Campaign	Shots	False R	FPR	Miss R	FNR
2018	(31983, 35915)	7/190	3.69%	0/183	0%
2017	(29893, 31982)	3/147	2.04%	1/145	0.69%
2016	(28052, 29892)	2/180	1.11%	0/178	0%
2015	(26579, 28051)	2/229	0.87%	0/227	0%
2014	(23074, 26578)	3/92	3.26%	0/89	0%
2013	(21326, 23073)	6/216	2.78%	0/210	0%
2012	(18219, 21325)	2/224	0.89%	2/224	0.89%
2011	(15118, 18218)	7/191	3.66%	1/185	0.54%
2010	(13434, 15117)	1/55	1.82%	0/54	0%
2009	(10595, 13433)	2/131	1.53%	0/129	0%
Total	(10595, 35915)	35/1665	2.10%	4/1634	0.24%

Table2 Recognition result

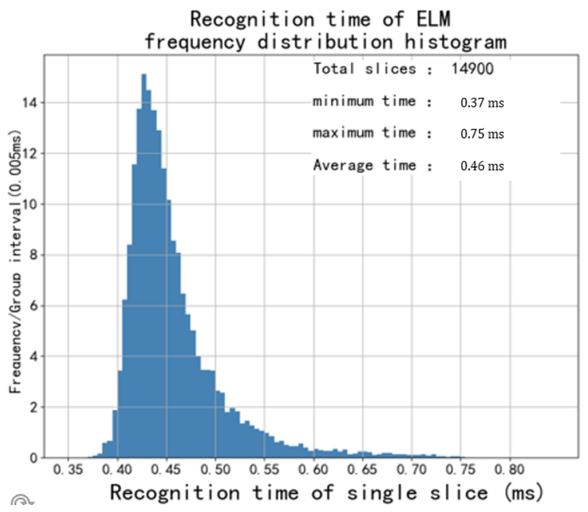

Fig 5 The recognition time of single slice

CONCLUSION

The ELM recognition algorithm meets the requirements of real-time control regardless of recognition accuracy or calculation speed. Moreover, since the data is normalized, the recognition algorithm can be applied to the ELM recognition of the HL-2M or other devices in the future. And this algorithm will use LSTM to implement smoothing process to improve portability.