Machine learning approach to understand the causality between solitary perturbation and edge confinement collapse in the KSTAR tokamak

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Abstract

- Solitary perturbations (SPs) are detected within ~ 100 μs prior to the edge pedestal collapse in H-mode plasmas, which puts forward SP as a potential candidate for the edge pedestal collapse trigger.
- We have constructed an automatic SP identification model based on a convolutional deep neural network to enable a statistical study on the concurrence of SP and edge pedestal collapse.
- We applied the developed model to a large amount of data and confirmed that the complete collapse at the plasma boundary always involves the emergence of SP.

Solitary Perturbation (SP)

- SP, localized in the poloidal direction, appear mostly tens of μs before the onset of the edge pedestal collapse.
- SP persists a few tens of μs to hundreds of μs without a noticeable change in shape.
- SP is clearly distinguished from ELM by spatial structure, amplitude, and flow velocity.

Development of the SP identification model

- **Input data**
  - Raw data of toroidal Mirnov coils
  - Toroidal array of Mirnov coils on KSTAR: 19
  - Time: 400 (400 μs, 1 MHz sampling freq.)
- **Output data**
  - SP probability (1 = SP, 0 = no SP)
  - Time: 400 (400 μs, 1 MHz sampling freq.)

- **Network architecture**
  - 11 network layers:
    - 7 Convolution + 3 Max-pooling + 1 Linear
  - Padding:
    - Circular padding (coll dimension)
    - Zero padding (time dimension)
- **Training of the model**
  - Training dataset: 140 sequential data
  - 2015-2017 KSTAR discharges
  - 100 positive examples (w/ collapse and SP)
  - 20 negative examples (w/o collapse and SP)
  - 20 synthetic collapse examples (white noise × envelope of Mirnov signal)
  - Supervised learning:
    - Minimization of errors between network output and correct answer

Performance of the SP identification model

- **Test of the model**
  - Test dataset: 50 sequential data (2015-2017 KSTAR discharges)
    - 26 positive examples, 12 negative examples, 12 synthetic collapse examples
- **Three metrics to evaluate the model**
  - **Per-frame accuracy (AF):** The proportion of correct prediction of SP per frame
  - **Per-sequence accuracy (AS):** The proportion of correct prediction of SP per sequence
  - **Average precision (AP):** Mean precision over all possible threshold weighted by recall
- **Quantitative performance of the model**
  - Threshold for the SP presence in time frame: 0.5
  - Threshold for the SP presence in sequence (yₚ): 25
  - AF for a trivial model which predicts a non-SP for every temporal frame is 82.5%

Qualitative validation by visualization

- **Gradient based visualization technique**
  - Our Network is approximated by the 1st order Taylor expansion
  - The model predicts SPs by recognizing toroidally shifted SP patterns.

Statistical analysis of the pedestal collapse-SP co-occurrence

- **Statistical analysis data**
  - 2018 KSTAR discharges
    - 20540, 20660, 21087, 21207
- **Region Sequence**
  - 1 (Large collapse w/ SP) 176
  - 2 (Large collapse w/o SP) 0
  - 3 (no large collapse w/o SP) 18263
  - 4 (no large collapse w/ SP) 13

The complete edge pedestal collapse always involves the emergence of SP → Studying the effect of SP on the edge pedestal collapse is essential for successful operation of fusion devices

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