Prediction of radiative collapse by analyzing videos of plasma discharge with Convolutional Neural Network in LHD

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The termination of plasma discharges has been a critical issue for nuclear fusion research. In Tokamaks, the disruption causes severe damage to the vacuum vessel and the divertor. In helical devices, radiative collapse prevents sustaining high-density plasmas. In the previous research on the Large Helical Device (LHD), effective parameters to predict and avoid radiative collapse were identified using accumulated experimental data, sparse modeling, and machine learning methods. A plasma discharge experiment for avoiding radiative collapse succeeded using these parameters by controlling gas puffing and plasma heating [1]. This experiment shows the effectiveness of a data-driven approach in radiative collapse control.

The images of the radiative collapse are included in the videos of plasma discharge. The preliminary analysis of the videos suggested that they had some features to predict radiative collapse. A quantitative investigation of the radiative collapse by analyzing the videos has not yet been conducted in LHD. In this study, the analysis of the videos with a Convolutional Neural Network (CNN) is applied for the prediction of radiative collapse in LHD.

For monitoring the plasma discharges, about 16 cameras have been installed at the viewports on the vacuum vessel in LHD. The videos of about 180 thousand plasma discharges have been accumulated so far. Plasma discharges interrupted with the radiative collapse were extracted from the videos for analyzing the collapse using machine learning techniques. According to the reference [2], video frames were labeled by density exponent $x = (\dot{P}_{rad}/P_{rad})/(\dot{\bar{n}}_e/\bar{n}_e)$ for training a CNN model to discriminate between the stable state and the collapsed state in plasma discharge. Here, dot, P_{rad}, and $\bar{n}_e$ mean the time derivatives, the radiation power, and the line averaged electron density, respectively. When x exceeds 3, thermal instability is driven, and radiative collapse causes. The discriminating model was generated by an EfficientNet [3] which is a kind of CNN model using training datasets labeled by the above exponent. To visualize focus areas to discriminate stable or collapsed states, a Gradient-weighted Class Activation Mapping (Grad-CAM) [4] was used.

As a result, it proved that this model could discriminate between stable or collapsed states in plasma discharges with a probability of more than 95%. Figure 1 shows the combined images taken with all cameras for (a) a stable and (b) a collapsed state which were discriminated by this model. The heatmap, which shows the areas contributing to the discriminations (colored areas in the figures), was generated by the Grad-CAM. The plasma images observed from 3-O left and the 10-O right ports are identified as possible candidates for the region of interest to determine the plasma state. At present, a model to discriminate the transition state from a stable to a collapsed state is in preparation, which is for predicting radiative collapse. The prediction performance using this model will be presented.

References
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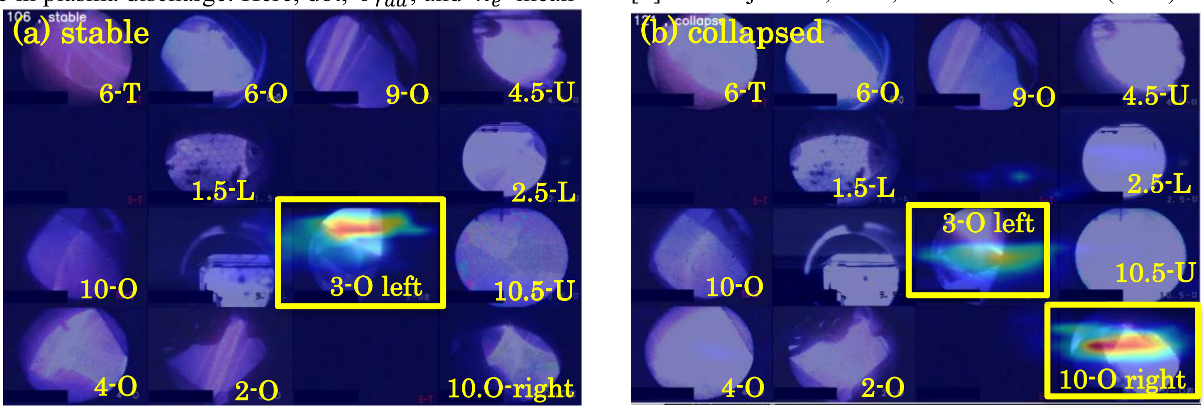

Figure 1. The combined images which were taken with all cameras installed in LHD. Labels like 6-T, 6-O, 9-O, etc. represent viewports where the cameras are installed. Figure 1 (a) and (b) show the combined images discriminated as a stable state and a collapsed state of the plasma discharge, respectively. The heatmap shows areas that contributed to discriminating between the stable and the collapsed states.