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Artificial intelligence for infrared image processing and comprehensive untangling of internal thermal scene at WEST

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Artificial Intelligence (AI) and Machine Learning (ML) have imposed themselves as the standard toolkit for image processing. This happens also in experimental science, where the tools and methods of AI/ML (use case definition, annotated database creation, learning and inference) prove fruitful at solving science and technology challenges ill-addressed by conventional processes. At WEST, an tungsten medium size steady state tokamak preparing ITER operation, AI/ML is used to process images of the Infrared (IR) viewing diagnostic. Half of the vessel's internal components acting as thermal shields are monitored with 10 viewing lines for machine protection and science, resulting in typically 107 thermal images per experimental campaign. Two IA/ML processes developed at WEST for thermal event recognition and true surface temperature measurement are presented here.
First, a wall hot spot detection and classification process is operated. The automated detection aids the human experts, who monitor the internal components after each plasma experiment by viewing the IR movies toward identifying potential thermal issues. The detector operates as a phenomenological tool, based on previous knowledge. It uses the Faster-RCNN algorithm, to detect wall hot spots and write them in a SQL database for downstream automatic expertise. The tool runs after the plasma discharges, and performs well for customary hot spots such as divertor strike lines. The mean average precision (mAP@0.50) rates currently to 60%, a good performance by AI standards. It should improve with refinement of the event taxonomy and database size. The database size is a key challenge, especially for deep learning models requiring enough annotated images, typically > 105, with sufficient variety. Semi Supervised Learning (SSL) is investigated to exploit the large set of unlabelled images from previous experimental campaigns. A SSL test using a student-teacher architecture improves the mAP by 5% compared to the supervised process, a large gain by learning standards. Moreover, SSL proves effective for domain adaptation, toward adapting quickly the detection engine to a new experimental configuration, or later to another tokamak.
Switching to the quantitative processing of the IR experimental images, estimating real surface temperature from experimental images is another open challenge in reflective and hot radiative environment. This requires solving a multi-parametric inverse problem with unknown targets emissivity and spurious signal from multiple reflections. A promising resolution technique consists in using ML algorithms, trained from "artificial" (or simulated) images. Simulated images come from the synthetic diagnostic, also called "digital twin", able to model all phenomena involved in the chain measurement - from the plasma source (heat loads on in-vessel components) to camera, including photon-wall interaction. AI/ML inversion done from a large dataset of 1.6 105 simulated images gives the true components temperature with an accuracy of 5%, ignoring emissivity and filtering reflections. Beyond, it opens the possibility of physical model injection into AI/ML image processes, such as the actual component geometry, and also possible science model such as power deposition laws. By explicitly accounting physical models into AI/ML processes, it is aimed at reconciliating the AI/ML techniques with traditional model-based physical science, and promoting trustworthy AI.

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