Towards Intelligent Video Understanding Applied to Plasma Facing Component Monitoring

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In this paper, we promote intelligent plasma facing component video monitoring for both real-time purposes (machine protection issues) and post event analysis purposes (plasma-wall interaction understanding). We propose a vision-based system able to automatically detect and classify into different pre-defined categories thermal phenomena such as localized hot spots or transient thermal events (e.g. electrical arcing) from infrared imaging data of PFCs. This original computer vision system is made intelligent by endowing it with high-level reasoning (i.e. integration of a priori knowledge of thermal event spatiotemporal properties to guide the recognition), self-adaptability to varying conditions (e.g. different thermal scenes and plasma scenarios), and learning capabilities (e.g. statistical modelling of event behaviour based on training samples).

1 Introduction

Infrared thermography has become a routine diagnostic in many magnetic fusion devices to monitor the heat loads on the Plasma Facing Components (PFCs) as heating antennas or divertor for both physics studies and machine protection. The good results of the developed systems obtained so far [1] motivate the use of imaging diagnostics for control, especially during long pulse tokamak operation (e.g. lasting several minutes). Moreover, in the future perspective of ITER, the development of a versatile, reliable and fully automatic system for the real-time monitoring of PFCs becomes essential. Indeed, the imaging system foreseen for thermal monitoring and protection of the vacuum chamber of ITER will be equipped with a network of 18 wide-angle infrared video cameras. This configuration is designed to cope with many different in-vessel components of the device (such as heating antennas and divertor) visible on a same image, and with a large amount of data produced at each pulse. In this context, the challenge is to automatically extract and process only useful information so as to reduce the volume of data stored. However, the understanding of the observed phenomena is not a trivial task and requires a high degree of expertise in both image/video processing and plasma-wall interaction (PWI) physics.

This paper is organized as follows. In section 2, we expose the challenges of video understanding in a tokamak environment. In section 3, we describe our proposed video understanding framework applied to PFC monitoring. Conclusion and outlook are presented in section 4.

2 Intelligent video surveillance applied to PFC monitoring

One of the goals of video surveillance is to interpret the individual behaviours of the objects present in a scene and their possible interactions or correlations with external parameters. In the field of PFC monitoring, the objects are not necessary moving objects but can be, for instance, local hot spots in an infrared image sequence. In the same way, external parameters correspond here to plasma parameters having an influence on the PFC heating (e.g. injected power level, plasma current, heating antenna positioning, etc.).

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One objective of PFC monitoring is to provide qualitative imaging as an essential diagnostic for machine protection functions (see [2]). Indeed, PFC protection can be fulfilled based on simple thermal events detection, such as "*the temperature of a detected hot spot is overrunning a predefined limit*". However, the reasoning process may quickly become complex: "*the time constant of a detected hot spot together with its spatial location, and correlated with the injected power level and the previous surface state of the component possibly describe the behaviour of a badly fixed layer of B_4C coating*". Since phenomena recognition requires a semantic, sometimes based on a complex analysis of what appears in the scene, it is a real challenge for video understanding. Analyzing and interpreting video events means recognizing spatiotemporal patterns and extracting from them, at a higher level, a description of the actions and interactions. To this end, an observed sequence of features has to be associated with a model sequence representing a specific phenomenon. The problem therefore consists of modeling typical events, by learning or by explicit description, and finding a comparison method that tolerates slight variations. These techniques trigger an alarm based on statistical discrepancy with the inferred model of the scene. These can also be based on a system of rules, such as triggering an alarm if an object characteristic (e.g. maximum pixel value, region size) falls within a set of predefined range values.

In the magnetic fusion community, the most advanced application of intelligent video monitoring is devoted to heat load control during plasma operation [1]. The image processing part of this system routinely used at Tore Supra relies on the infrared imaging of the four heating antennas. Each time the signal inside a predefined region of interest (ROI) overruns a fixed threshold, the heat power is modulated to prevent PFCs from overheating. Except from this protection task, the infrared image analysis is achieved by experts (e.g. between two plasma discharges) using ROI calculations. This post-event investigation concerns thermal events (TEs) caused by PWI as local RF sheath effect [3], impacts of fast particle losses [4] or due to the flaking of carbon deposit or B_4C coating. The task becomes rapidly intractable while the network of monitored views grows: currently 7 views in Tore Supra, 9 planned for JET (with its ITER-like wall), and up to 18 for ITER. In this context, intelligent video surveillance has many advantages:

- It relieves people in charge of PFC monitoring from useless redundant analysis by automatically recognizing well-known events.
- It reduces the bandwidth and archiving space needed by recording only data on relevant events.
- It enables a quick search of relevant events in the archived video footage.
- It makes it possible to identify objects in a scene and follow their time-evolution at different time scales (from frame to frame tracking to pulse to pulse tracking).

3 Proposed video understanding framework

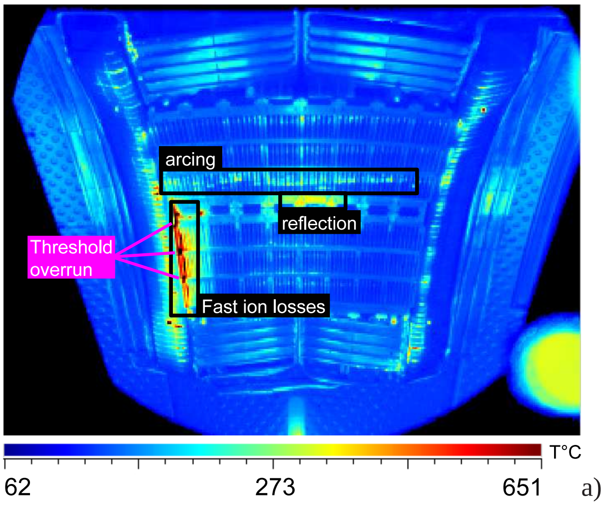
The video understanding framework we propose is based on two main tasks: hot spot detection and thermal event recognition. This machine vision framework (detection and interpretation) is made original by the use of generic components, each of them being specialized thanks to *a priori* knowledge of TE as described below.

3.1 Scene modeling

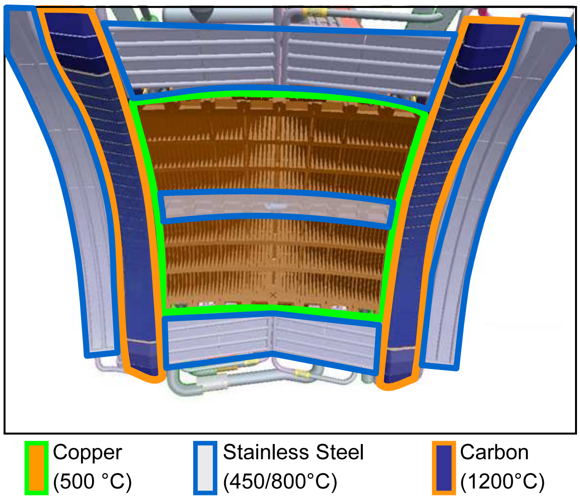
Scene modeling consist of representing the observed scene in terms of geometric and semantic attributes useful for the scene interpretation. In the present work, a 2D scene model is used from the projection of a 3D CAO model. Zones of interest corresponding to the different in-vessel components are then delineated (see figure 1(b)). For each zone, the user has the possibility to fill symbolic attributes (e.g. type of material) as well as numerical attributes (e.g. component emissivity factor and operational temperature limit) to be further used in the event recognition process. For instance, arcing event recognition is automatically instantiated for camera views labeled as '*heating antenna*' and in zones made of '*copper*', thanks to the *a priori* knowledge of this thermal event.

3.2 Hot spot detection

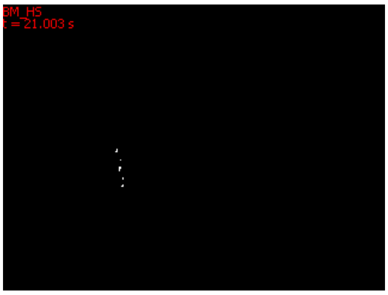
We pose the problem of hot spot detection as the problem of image segmentation, i.e. to the partitioning of an image into homogeneous regions thanks to some predefined homogeneity criteria. But image segmentation is an ill-posed problem since it does not exist a unique solution, depending on the (combination of) criteria used for the partitioning (e.g. intensity, motion, contours). Therefore, we have to design one algorithm per type of object to detect so as to achieve a *goal-oriented* detection. For instance, the detection of transient events such as electrical arcing relies on sudden changes detection, for which background modeling and subtraction techniques are well-adapted (see [5]). For hot spots with a slow temporal evolution, a criterion based on spatial coherency of neighbouring pixel levels is generally preferred. This approach, mostly based on image local contrast analysis, is independent of quantitative measurements as surface temperatures, ensuring a high degree of self-adaptability to varying conditions (e.g. different thermal scenes and plasma scenarios). Figure 1 presents the results of three different detection algorithms designed for three different purposes and applied on the same image sequence.



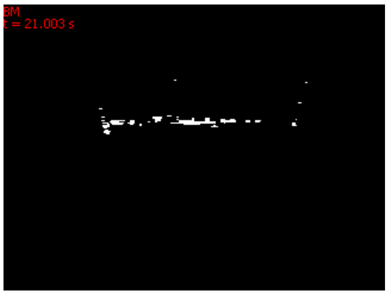
(a) Original infrared image where 4 different thermal events recognized by experts are indicated.



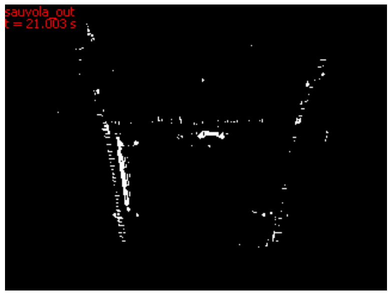
(b) Scene model of the heating antenna based on 3D CAO where zones corresponding to the different components are indicated with associated temperature thresholds used in (c).



(c) Thresholding method based on *a priori* knowledge of component temperature limits described in the scene model (b).



(d) Algorithm based on sudden change detection used for arcing event recognition.



(e) Adaptive thresholding based on local mean and variance used to detect hot spots of different temperature levels.

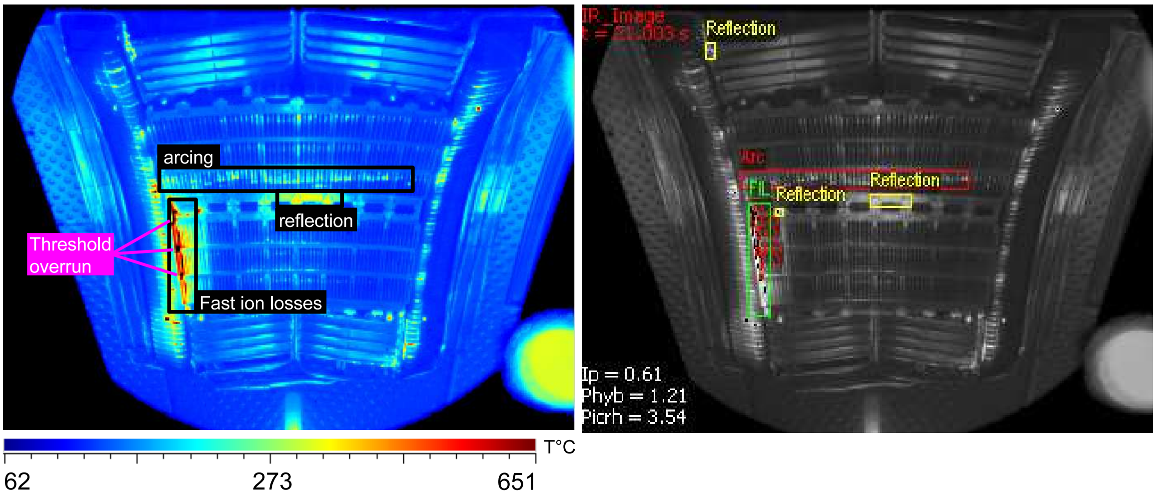
Fig. 1 Illustration of the segmentation techniques used as a first step for the recognition of different types of thermal events. (color online)

3.3 Thermal event recognition

Recognition aims at extracting semantic information from numerical data. In our approach, the recognition process relies on visual attributes of the TEs (e.g. pattern shape and location) and on plasma parameters ranges where events may occur. For instance the recognition process for arcing event occurring in the front of LHCD copper mouth is based on pattern matching from transient hot spot detection results and is triggered by the private power injection level. The arc pattern attributes (size, elongation, etc.) have been learned from statistics computed on representative training samples (see [5] for details). In a similar way, we model impacts of fast ion losses on LHCD as overheating regions located on copper mouth sides appearing during ICRH hydrogen minority heating scheme. Overheating regions are detected thanks to a local adaptive thresholding algorithm (see figure 1 (e)).

Detected blobs are then filtered to eliminate those not located in copper mouth sides. Finally, the remaining blobs (if any) are categorized into ‘fast ion losses’ class if two plasma parameter conditions are verified, as to know: ICRH power injection level is not null, and LHCD is not magnetically shadowed by ICRH (i.e. reasoning on antenna positions).

As seen in figure 2, the system is able to recognize four thermal events, based on hot spot detection results presented in figure 1, and with a high degree of confidence compared to a manual interpretation of the image. This multi-layered image interpretation is also made possible by parallel and synchronous processing of the different TE recognition requests.



(a) (b)

Fig. 2 Manual v/s automatic thermal event recognition where TO = Threshold Overrun and FIL = Fast Ion Losses. (color online)

4 Conclusion and Outlook

Video monitoring is a growing application in the field of PFC protection and PWI understanding. If quantitative measurements are required for heat flux calculations, qualitative analysis of images is essential in many operational uses as identification of thermal events. In this contribution, we have developed a framework for automatic thermal event recognition as a first step towards a real-time intelligent monitoring system. This original system is currently able to recognize simultaneously up to six different thermal events in infrared videos of Tore Supra. This framework is thus compatible with the qualitative performance level foreseen for the ITER VIS/IR diagnostic which will be involved in the crucial PFC protection function. Finally, such a system could be also used to generate event databases essential for better understanding of plasma-wall interactions.

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