Boundary Inspection in SOM Mapping of Plasma Disruption Scenarios at ASDEX Upgrade

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Abstract

The Self-Organizing Map is a computational method for the visualization and analysis of high-dimensional data. Self Organizing maps have been applied to ASDEX Upgrade database to define an ordered mapping of the high-dimensional plasma parameter space. In particular, a type of projection from a set of 7-dimensional parameters onto a regular, 2-dimensional grid has been performed. The reduction of 7-dimensional data into 2-dimensional data and the grouping of similar data items together, allows one the visualization of the plasma parameter space and the extraction of useful information on characteristic regions of the plasma operational space.

I Introduction

One of the most challenging problems in nuclear fusion research consists in the understanding of disruption events. The identification of characteristic regions in the operational space where the plasma undergoes a disruption is crucial for tokamak development. The approach proposed here is based on the classical Self-Organizing Map (SOM) data clustering technique [1]. In [2], a preliminary analysis of the information encoded in ASDEX Upgrade seven-dimensional database using the SOM has been presented. In this paper, the SOM is used as a common framework to identify the regions in the operational space with different "*risk of disruption*", and to present the extracted information on intelligible displays. Data for the study consisted of signals recorded at ASDEX Upgrade from July 2002 to April 2005, including 80 safe pulses and 149 disruptive ones in the pulse range 16200-19999. The large majority of disruptions occurred in this period are of the cooling edge type and typically preceded by the growth of tearing modes, degradation of the thermal confinement and enhanced plasma radiation. A very small percentage of them happens at large beta after a short precursor phase [3].

Seven plasma parameters have been selected during the current flat-top of the discharges: Safety factor at 95% of poloidal flux (q_{95}); Total input power (P_{tot}); Total Radiated Power/Total Input Power (P_{frac}); Internal inductivity (li); Poloidal Beta (β_{pol}); Electron density/Greenwald density ($ne_{Greenwald}$); Locked Mode signal (LM). They have been selected on the basis of previous results presented in the literature [3], and taking into account physical considerations and the availability of real-time data.

II. The Self Organising map

Let us consider an n-dimensional input space X and N samples $\mathbf{x}_i \in X$, which have to be partitioned in K clusters. The SOM defines a mapping from the n-dimensional input space X onto an array of neurons, usually 2D (corresponding to the clusters), preserving the topological properties of the input. This means that points close to each other in the inputs space are mapped into the same or neighbouring neurons in the output space [1]. The reduction of the dimensionality performed by the SOM allows one the visualization of high dimensional data, using a colouring scheme. The problem that data visualization attempts to solve is that humans simply cannot visualize high dimensional data as it is, so techniques are created to help us understanding this high dimensional data.

III. Analysis of the ASDEX operational space

In order to reduce the dimensionality of the data set, a preliminary clustering of the samples of each pulse is performed using SOM [3]. This procedure allows one to automatically select a limited and representative number of samples (55829 from 780969) for the subsequent operational space mapping. The 2D SOM (Fig. 1) consists of 49×29=1421 clusters. The number of clusters has been chosen by using some quality indices as measure of cluster validity [2]. Each colour is representative of a particular composition of the cluster, hence of the disruption risk. Table 1 schematically reports the cluster composition for each colour, where t_D is the disruption time and $t_{FAT-TOP}$ is the start time of the flat-top plasma current. In Fig. 1, black clusters contain samples from safe pulses together with samples very close to the disruption time. Therefore, the black region represents an uncertainty region where each cluster cannot be classified neither as safe nor as disruptive. In the same Fig.1, blue clusters identify regions with low risk of disruption, and green areas identify regions with high risk of disruption. The temporal sequence for each of the 229 pulses has been projected on the map in order to analyze their dynamical behaviour. This projection results in a trajectory on the map followed by the pulses during the time. In the majority of disruptive pulses, the trajectory starts in the safe blue region and passes trough green clusters only in the last 300ms of the discharge. In particular, in 90.6% of the cases, the pulses trajectories and enter in a dark green cluster or remain in a light green cluster for at least 5ms. Note that, only in 3.36% of the pulses the trajectories cross the green clusters more than 300 ms before the disruption, whereas in 0.67% of cases the trajectories cross dark green clusters only in the last 2ms. Moreover, some disruptive pulses (5.37%) remain in the safe blue region or stay in the light green clusters for less than 5ms. Furthermore, in 98.8% of safe pulses the trajectories remain in the blue safe region, or enter the light green regions remaining into them less than 5 ms, whereas only in the 1.2% of safe pulses the trajectories cross the dark green regions.

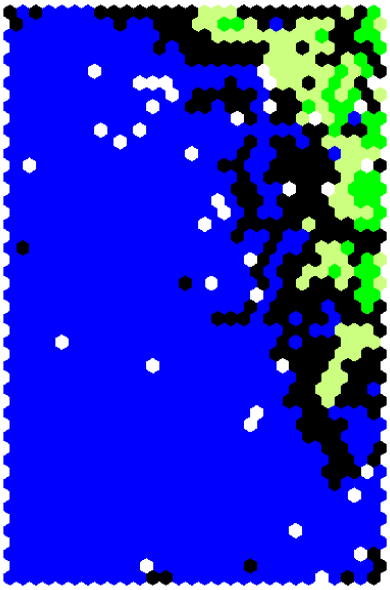
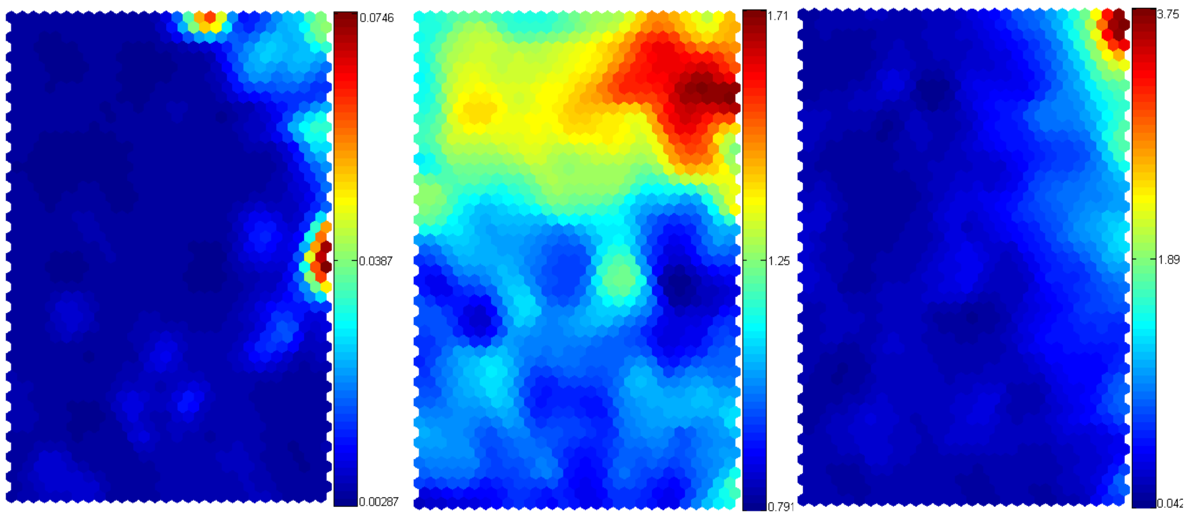


Table 1. Cluster colour coding

	Safe pulses	Disruptive pulses		
		$[t_{FAT\text{-}TOP};t_D\text{-}300]$ ms	$[t_D\text{-}300;t_D\text{-}45]$ ms	$[t_D\text{-}45;t_D]$ ms
Blue	X	X	-	-
Black	X	X	X	X
Light green	-	-	X	X
Dark green	-	-	-	X
White	-	-	-	-

Figure 1: SOM coloured on the basis of clusters type.

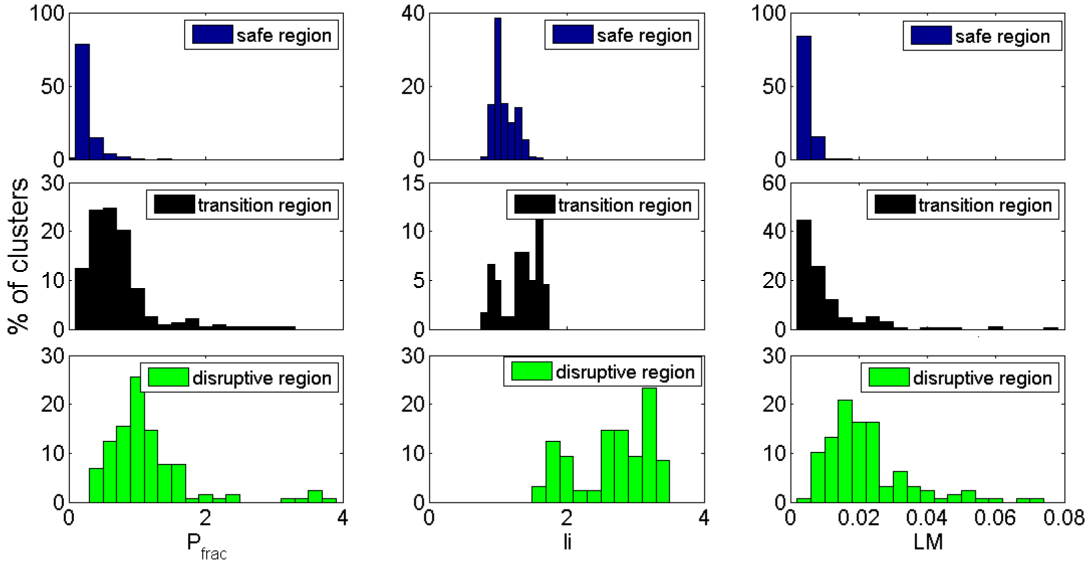
Another visualization technique, which enables to visually identify possible dependencies between variables, is the *Component plane representation* [4], which displays the values of each input variable on the 2D-map. The dependencies between variables can be seen as similar patterns (the colours corresponding to the values of the variables) in identical locations on the component planes. In Figure 2 (*a-c*) the component planes for *LM*, *li*, and P_{frac} are shown. Note that the values of *LM* have been processed in order to correct off-sets and/or drifts [5]. Figure 2 highlights that the combination of high values of *LM*, *li*, and P_{frac} characterizes the region with high risk of disruption.



(a) *(b)* *(c)*

Figure 2 Component plane representation for (*a*) *LM*, (*b*) *li*, and (*c*) P_{frac}.

The histogram of the values of P_{frac}, li, and LM in the cluster barycentres are reported in Fig. 3 for the blue, black, and green regions of Fig. 1. Note that, the distributions highlight the separability of the safe and disruptive regions. The blue histograms (see Fig. 3(*a*)-(*c*)) indeed present narrow ranges of values, which limitedly overlap the green wider histograms ranges. The black histograms values overlap both blue and green regions, confirming the intrinsic uncertain nature of the transition regions.



(a) *(b)* *(c)*

Figure 3 Histogram of the values of *(a)* P_{frac}, *(b)* li and *(c)* LM of the cluster barycentres.

IV. Conclusions

A 2D SOM is built in order to identify characteristic regions for the ASDEX Upgrade plasma scenario. The Component plane representation is also studied. The analysis clearly highlights the presence of a large safe region and a smaller disruptive region. Moreover, a transition region, where safe and disruptive plasma states coexist, is identified as a boundary between the safe and disruptive regions. As the risk of disruption is very low in the blue region, and it progressively grows when passing through black, light green and dark green regions respectively, an alarm could be activated if the trajectory remains in the green regions for a prefixed number of milliseconds. The choice of the criterion to activate the alarm is out of the scope of the present work, even if useful indications can be obtained by the present analysis.

V. References

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