Real-time implementation in JET of the SPAD disruption predictor using MARTe

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***Abstract*— One of the major problems in present tokamaks is the presence of disruptions. If disruptions are not mitigated, they can produce serious damage to the device. Therefore, disruption predictors are needed in order to apply the mitigation techniques in time. In this paper, the real-time implementation in JET of a new type of disruption predictor is presented. The new predictor, Single signal Predictor based on Anomaly Detection (SPAD), does not require past discharges for training purposes. The implementation is based on the Multi-threaded Application Real-Time executor (MARTe) framework. Analysis over all JET's ITER-like Wall campaigns (C28-C34) show that SPAD was able to predict 83.57% of the disruptions with enough time to apply mitigation techniques. The average anticipation time was 389 ms. In this paper the real-time implementation will be discussed, as well as the optimizations developed to make the algorithm suitable for real-time processing. Performance results and possible improvements will also be analyzed.**

***Index Terms*—disruption predictors, fusion experiments, plasma disruptions, real-time processing.**

I. Introduction

PLASMA disruptions are one of the major problems in present tokamaks. This phenomenon is currently unavoidable and it produces large thermal loads, strong electro-magnetic forces, and runaway electrons that can severely damage the machine components.

Several plasma disruption mitigation techniques have been developed and tested in current fusion devices, as massive gas injection [1, 2], killer pellet injection [3, 4] or Electron Synchrotron Resonance Heating injection [5, 6]. However, these techniques need to be triggered with enough time (>10ms in the JET case) prior to the disruption in order to be effective. This leads to the need of accurate and reliable disruptions predictors.

In this paper is presented the implementation of a real-time disruption predictor based on signal anomaly detection. The Single signal Predictor based on Anomaly Detection (SPAD) (formerly known as Predictor Based on Outlier Detection (PBOD)) [7-9] learns the normal behavior of a signal from the beginning of the discharge, and it triggers the disruption alarm when abnormal behavior is detected. The predictor has been developed using the Multi-threaded Application Real-Time executor (MARTe)[10] framework to be fully integrated into JET Real-Time Data Network (RTDN)[11]. SPAD presents good detection results, comparable with predictors based on machine learning but without the need of training process.

II. SPAD Implementation

As every MARTe application, SPAD is implementation is based on Generic Application Modules (GAMs), where each GAM can read and write signals to the Dynamic Data Buffer (DDB). Fig. 1 shows the SPAD architecture implemented according MARTe framework philosophy. First of all, the necessary signals are collected from JET's pulses database or from the RTDN network via Asynchronous Transfer Mode (ATM) interface. The former is used during development or testing use, and the latter is used during on-line pulse analysis. The signals used are Plasma Current and Locked Mode, sampled at 1 kS/s. Plasma Current is only used in the first GAM, Threshold GAM, which signals the pulse start to the rest of the GAMs when the current crosses a specific threshold. The Locked Mode will be processed in 32 ms windows sliding each 2 ms, which means that each 2 ms the two oldest samples are excluded from the window while two new samples are added. The packing into this processing windows is done by the SlidingWindowGAM, which also notifies when a new window is available. The Haar Wavelet Transform Approximation Coefficients of each window are obtained by the HaarAppCoef1DGAM. This coefficients are the input of the MahalanobisGAM. In this GAM is calculated the Mahalanobis distance of the current set of coefficients with the centroid of a cluster formed by all the previous set of Haar

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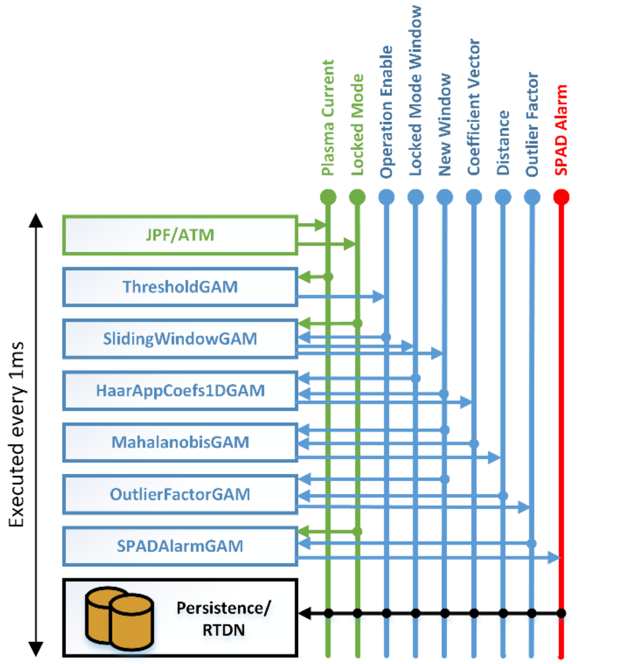

Fig. 1 Diagram of SPAD implementation in MARTe. GAMs are executed in order from top to bottom.

approximation coefficients. The distance is used to calculate the outlier factor in the OutlierFactorGAM according (1):

$$OutlierFactor = = \left|\frac{D_M(t_p) - mean(D_M(t \leq t_p))}{std(D_M(t \leq t_p))}\right| \quad (1)$$

Where $D_M(t_p)$ is the last distance calculated by the MahalanobisGAM and $D_M(t \leq t_p)$ refers to all the distances returned by the MahalanobisGAM since the pulse started. In the last step, the SPADAlarmGAM send the alarm signal to the RTDN when the outlier threshold surpasses a certain threshold at the same time that the Locked Mode signal reaches a maximum in the pulse history. All the GAMs are executed sequentially every 1ms.

III. Results

The presented implementation was tested in a computer with specifications similar to the final system but without a real-time operative system. In the test, the implementation was used to analyze all JET's ITER-like Wall campaigns. Fig. 2 shows the detection results compared with both APODIS and LMPT predictors. SPAD MARTe-based implementations shows the same results than the reference implementation in MatLAB, with 8.98% of false alarms, 10.60% of missed alarms, 3.18% of tardy detections, 83.57% of valid alarms, 2.65% of premature alarms and average anticipation time of 389 ms. The mean SPAD cycle execution time was under 5 us with a confidence level of 97 % (absolute mean plus three times the standard deviation). The maximum cycle execution time observed was 26.9280 us. Results obtained probe that the implementation complies with the time constraints imposed by the original algorithm specification.

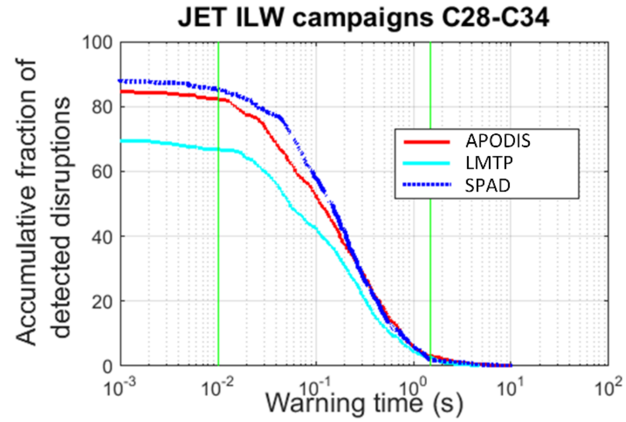

Fig. 2 Representation of the accumulative fraction of detect disruptions with regard to total disruptions during all JETs ILW campaigns.

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