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Neural Networks and Expert Systems To Solve The Problems Of Large Amounts Of Experimental Data At JET

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ABSTRACT

A data acquisition system has been designed and constructed that demonstrates the use of a real-time expert system for event triggering. The design for an upgraded system, currently under development, is described and demonstrates real time data evaluation using neural networks, and post-experiment event classification and tagging by a compound system of expert system neural networks.

Introduction

JET is the world's largest fusion research project, jointly funded by fourteen European countries. In a high vacuum vessel, isotopes of Hydrogen are injected and ionised to form a plasma, electric currents are induced, heating the plasma and additional radio frequency heating is applied until the temperature reaches approximately 90M°C. At this temperature nuclei collide with sufficient force to enable them to fuse forming Alpha particles and highly energetic neutrons.

The entire cycle of fuelling the vessel, heating the plasma and cooling down again is termed a 'shot'. A typical shot in JET lasts approximately 30 seconds, during which many diagnostics study every aspect of plasma behaviour. Many events in the plasma occur over very short periods of time (10μS), so high speed diagnostics are required. However, the relatively long duration of the experiment means that traditionally they must limit their data acquisition around events of interest in order to minimise the total amount of data taken.

At JET this has been done by triggering data acquisition at pre-defined times, such as when additional plasma heating was active, or in response to some external signal such as the injection of a fuel pellet. The Soft X-ray diagnostic requires a more sophisticated system than this however due to the nature of the phenomena being observed: motion of the plasma due to magneto-hydrodynamics (MHD). MHD effects usually involve high speed motions of the plasma, with little or no precursor, that happen many times during the shot and sometimes result in the end of plasma confinement, an event called a disruption.

This article describes the system that has been developed to solve the problem of recording these events, which demonstrates a practical implementation of real time expert systems, and the new, more complex system that is proposed for the next phase of the JET project. The system will involve Neural Network pre-processing of the data, event tagging and, in association with an expert system, event classification to aid data analysis.

The Current System

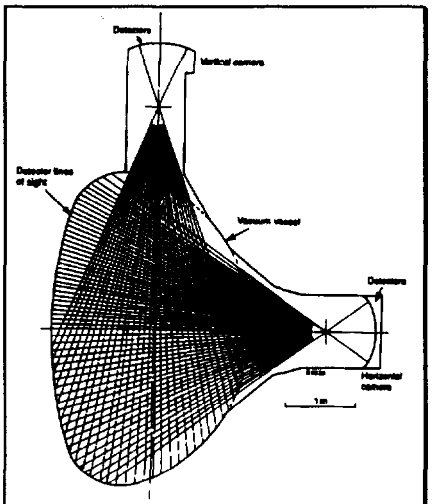

Figure 1
Soft X-ray cameras on JET

The soft X-ray cameras measure emissivity of the plasma along a hundred lines of sight, split between two cameras (figure 1). The emissivity of the plasma is highest in the centre of the vessel and decreases rapidly towards the walls. As the plasma moves about due to MHD effects the signals measured by each channel change. Specific motions of the plasma express themselves by characteristic changes in these signal levels.

Over time, the level of emissivity observed in a channel can increase or decrease linearly, can oscillate, or indeed follow some combination. These characteristic patterns were taken as the basis for rules defining plasma events.

High speed digital signal processors (DSP), Event Monitors, look in parallel for each of these behaviours, and classify them according to their speed, size and frequency. One may then describe the time evolution of interesting events in terms of these changes, and this definition may be of arbitrary complexity.

The rules defining events are interpreted by the Event Processor. During a shot this processor receives notification from the Event Monitors about plasma activity, classified as described above, and attempts to infer the presence of events based upon these rules. This fitting does not require an exact match between data and rule and is able to 'ignore' the high levels of noise present in the signals. When the rule is considered satisfied, data acquisition is triggered.

This system is running at JET[1], and has resulted in a greatly enhanced quality of data. New phenomena were seen, such as the spontaneous 'snake' (figure 2), and many phenomena previously seen have been recorded in far greater numbers, enabling better conclusions to be drawn from the observations. The system has proved flexible and has reduced the staffing requirement for the system during weekend and late night operations.

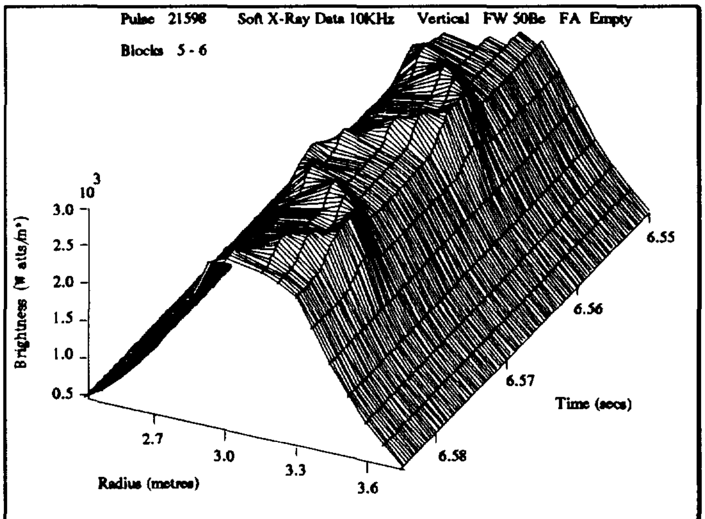

Figure 2 - A 'Snake' in the Soft X-ray Emission

The system has demonstrated the applicability of real time processing to data acquisition at JET and its reliability and performance.

The Future System

The JET machine is shut down from mid February 1992 to late 1993 for a major upgrade. During this time the Soft X-ray diagnostic is to be replaced by a new system capable of taking much greater quantities of data, and at higher speeds. This means that a new data acquisition must be designed with data reduction a primary aim.

The new system will have approximately 300 channels, each capable of taking data at up to 400Ksamples/second during an experiment lasting 30 seconds, i.e. a potential 7.2Gbytes of data per shot. There can be five shots per hour, which would result in a major data storage problem. It would obviously be impossible for the physicist to manually interpret this data, and to search for phenomena of interest. The data acquisition system currently being designed will solve these problems in two stages:

Stage 1 - Real Time Data Reduction

Plasma activity varies greatly during a shot, for most of the time the emissivity varies only slowly (0.1-1ms), but this is interspersed with short periods of very high speed events (<20μs) which occur without warning. Clearly, recording slowly changing signals at high speed wastes storage space, but as high speed events must be recorded without loss it is proposed that a high speed real-time trigger system will determine the level of activity and trigger data acquisition at a suitable rate. Data acquisition is no longer only performed around events of interest, but constantly at the rate that is most suitable for current plasma conditions.

A significant reduction of data is achieved by this method. During times of low plasma activity the system will only be recording at 2.5KHz compared to the maximum achievable rate of 400KHz This represents a 160:1 compression rate with no loss of physically significant information.

Clearly, a method must be found to determine when plasma activity justifies a higher (or lower) data acquisition rate. It is not a simple problem as the signals have a large dynamic range and contain a high degree of variation.

The data will be band filtered to split it into distinct frequency ranges, corresponding to the regions between the Nyquist frequency for each sampling rate (figure 3). The power of the signal present in each region gives an indication of the level of activity in that frequency band. These power signals can then be used by a decision making system to determine if there is sufficient activity to justify acquisition at this rate.

It is proposed that neural networks be used as they provide a method for encoding a decision making algorithm that can only be specified by example. A network will be used for each acquisition rate, and each will take as input the power signals for all frequency bands. Each network will be trained to 'vote' on the suitability of its sampling rate for those inputs. These votes are then interrogated using a fuzzy logic gate to determine the winner. Sampling will then be performed at the relevant rate.

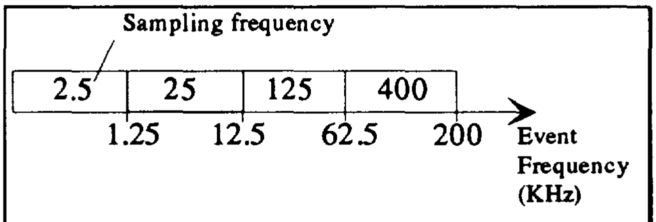

Figure 3 - Most appropriate sampling frequency for plasma activity rates

Stage 2 - Post Shot Data Interpretation

Even after this first stage of reduction there can be up to 600Mbytes of data taken in a shot. The data is collected by a network of Transputers that provide convenient and low cost memory, and provide a very large amount of processing power that will allow fast data analysis to be performed immediately after a shot, enabling results to be rapidly available.

A major requirement at this stage is to aid the physicist by finding and classifying the events in a shot; these may be well-known phenomena for which it would be possible to produce a detection algorithm, or they may be very poorly defined changes in plasma behaviour for which no algorithm exists. Classification of noisy data is a further application for neural networks.

To reduce the overhead of network training, indeed to make the problem solvable, it is necessary to utilise all the knowledge one has about that data being classified. Knowledge about constraints on the data is very important in reducing network complexity. For example, the three hundred channels in this system are not independent. They observe a confined plasma from several view points, but it is the same plasma, so a general growth in emissivity will be reflected in all channels, and a movement of the emission maximum will be reflected by a signal drop in all channels that have lines of sight through the old position, with an increase in those looking at the new location.

By studying these relationships, and using experience gained from the theory of tomographic inversion[2], it is possible to calculate the degrees of freedom of the plasma emissivity as observed by the cameras. This is governed by the number of cameras (detectors are collected into groups with their lines of sight fanning out from a single point), their radial and angular position around the plasma and the number of lines of sight each has.

A separate network will therefore be used for each camera, the emissivity of each line of sight being loosely constrained by its neighbours but otherwise independent. These will be trained to classify the profile being observed, a curve with a distorted bell-like shape. This parameterised data from each camera will then be used by a further network that, in conjunction with a short history, will classify the current plasma activity.

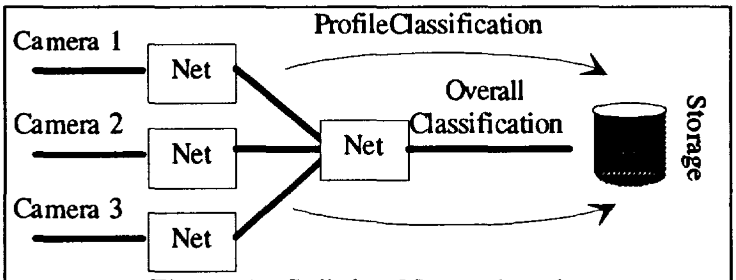

Figure 4 - Splitting Network tasks

It is envisaged that an expert system will monitor the outputs of these networks, acting as a supervisor, spotting errors and unfamiliar events. Important, and well-defined events could be explicitly defined, and inputs from other plasma diagnostics may be incorporated in order to make classification more accurate.

Conventional data analysis will also be performed, utilising the large processing power and parallelism available. The results, along with a summary of the shot produced by the expert system, will then be available via displays. All results will be written to a database allowing enquiries to be made based on many search criteria.

Conclusions

The current data acquisition system has demonstrated that real time data interpretation is reliable and useful at JET. With the acquired experience it has been possible to propose a more complex system utilising AI systems. The design for the data acquisition system demonstrates the importance of categorising problems into areas, and using the most appropriate technique for each. In particular, Neural Networks are most effective when the task they are to be trained for is well defined and small. It is better to use several small networks each configured and trained to solve part of a problem than one large net.

References

1. A.W. Edwards, K. Blackler, R.D. Gill, E. van der Goot, J. Holm, *Review of Scientific Inst.* **61**(10), 3306(K), also JET report JET-P(90)19.
2. R.S. Granetz, P Smeulders, *Nucl. Fusion* **28**(1988) 457.

ANNEX

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