Max-Planck-Institut für Plasmaphysik

Acceleration of Bayesian Model Based Data Analysis through Software/Hardware

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Motivation

- The improvement of the plasma control by an enhancement of the signal processing combining diverse diagnostics.
- Developing a real-time Bayesian model based data analysis for fusion experiments.
- Possibility of improvement of data integration and signal processing on smart systems or other platforms today in the way some diagnostics are integrated using Bayesian graphical models.
- Proof the possibilities of an acceleration of current model base data analysis.

Approach

The MINERVA project [1] sets a background and foundation for this type of research as a framework that formalizes the specification of diagnostic models, parametric dependencies and their relationship to physics model.

After creating a Bayesian model for the chosen diagnostic a profiling should be done to determine the possibilities of acceleration of the process.

An analysis and profiling of the designed model in an established framework is required in order to observe:

- Use of resources and optimization feasibility.
- Bottlenecks and parallelization points in order to take it to a faster solution with views towards real time.

The first approach would be a proof of principle with one free parameter to study the possibilities on a simple non-linear case.

Posterior to this a several free parameter approach can be done as well as the data fusion or correlation of models using data from different diagnostics. [2]

Conclusions

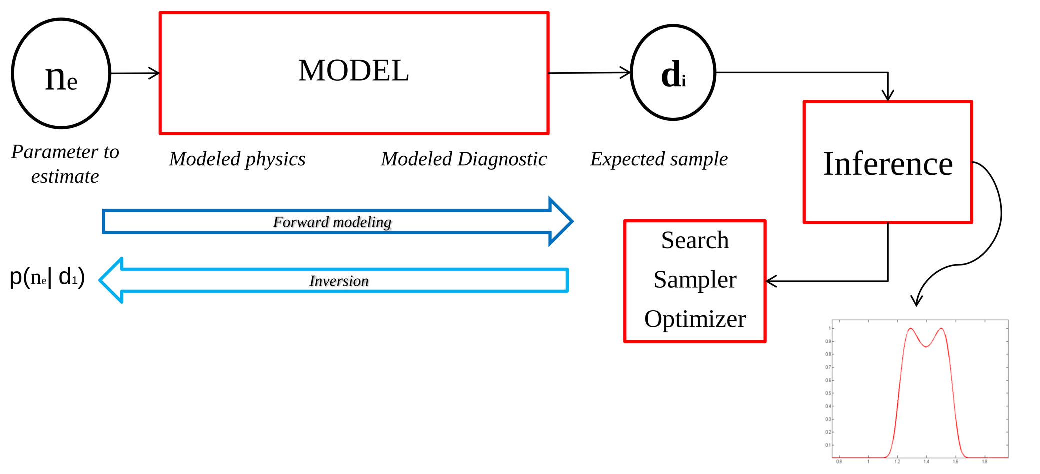
- Forward modelling, though it is tied closely to the system complexity and linearity of the diagnostic, represents a good opportunity for parallelization.
- Sequential Bayesian data analysis is a practical approach for a real-time processing application, reducing processing time for sequential data and pre-calculating required values.
- Inversion algorithms such as samplers and optimizers normally have an iterative approach that needs to be improved for the acceleration of this analysis.

[1] *J. Svensson et al. 'Integrating diagnostic data analysis for W7-AS using bayesian graphical models'. Review of Scientific Instruments, 75, 10:4219–4221, 2004. doi: 10.1063/1.1789611.*

[2] *J. Svensson and A. Werner. 'Large scale bayesian data analysis for nuclear fusion experiments'. In 'Proc. IEEE Workshop on Intelligent Signal Processing WISP', pages 1–6. 2007. doi: 10.1109/WISP.2007.4447579.*

Purpose

Parameter estimation improvement can be achieved by using a technique that eases the process of incorporating our knowledge, or lack of it, into our way of analyzing the data.



Bayesian analysis concepts have had a long tradition of theoretical exploration and a recent widespread deployment in post processing applications due to the advent of sufficient computation power.

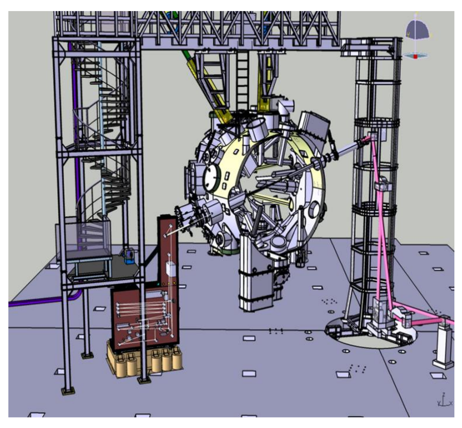
$$prob(H\,|\,D,I)=\frac{prob(D\,|\,H,I)*prob(H\,|\,I)}{prob(D\,|\,I)}$$

Current model based analysis requires high computational power and long processing times.

The next step is to look to the possibility of hardware/software implementations in situations necessitating real-time processing.

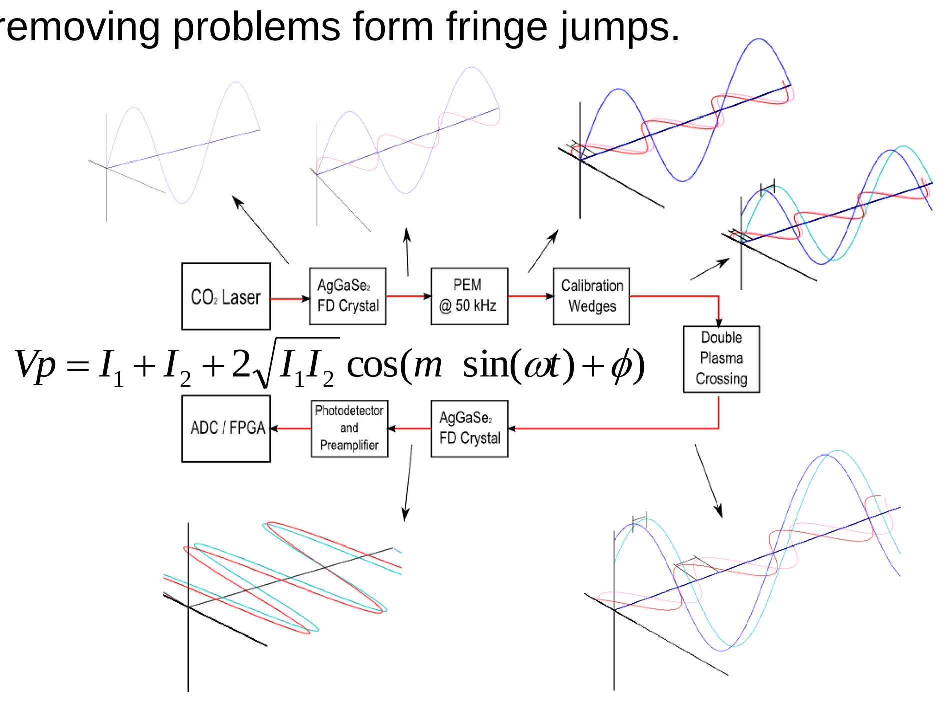
Testing Environment

A challenge and test environment appear in the possible use for an individual case for Wendelstein 7-X (W7-X) Dispersion Interferometer (DI) diagnostic, where a fast or even real time variant of this analysis is desired.



- It can be used to measure line integrated electron density.
- Currently performs data acquisition and processing with an FPGA.
- Non-linear model.

The DI has several advantages over 2-Color Interferometer like less sensitivity to vibrations of optical components due to a single beam path. The changes of the phase on the DI are only due to the plasma and not the vibrations, removing problems form fringe jumps.



Acceleration Possibilities

To reach a time resolution close enough to real-time the modification into a software/hardware concept for a faster processing is necessary.

A translation process is required to design and properly implement this analysis in a multicore system or an field programmable gate array (FPGA) for the acceleration of the forward modeling as well as solvers or optimizers.

Using the DI as well as a more complex example as test-benches will allow to determine the possibility of the general implementation on a software multicore design, an FPGA design or a combination of both.

The advantages of parallel processing, pipelining and versatility of the FPGA allows the signal processing niche to benefit from the possibility of having an alternative approach to current types of signal processing.

A modular FPGA design approach can be developed where generic operator, optimizer and sampler modules can be used on interchangeable Bayesian models.

Bayesian Inference on the DI

The DI is non-linear due to the ambiguity of the arccosine estimation. This system has two analytical solutions that are given by the phase difference value and a solution introduced by the modulation.

The initial stage is a one free parameter estimation (phase difference) using a normal distribution around the phase value.

$$Vp_i = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(m\ \sin(\omega t_i)+\varphi_i)$$

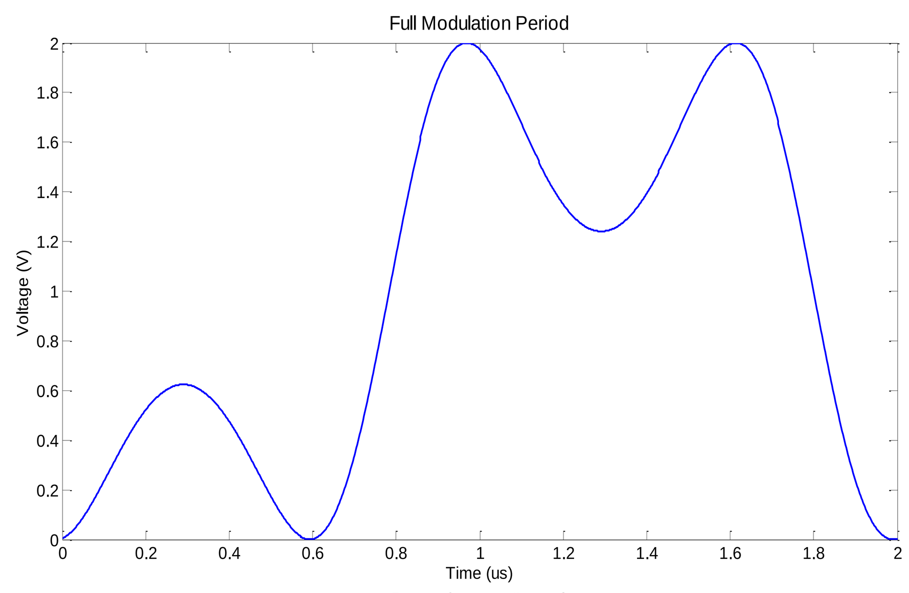
$$prob(\varphi\,|\,D_i,I)\propto prob(D_i\,|\,\varphi,I)\,prob(\varphi\,|\,I)$$

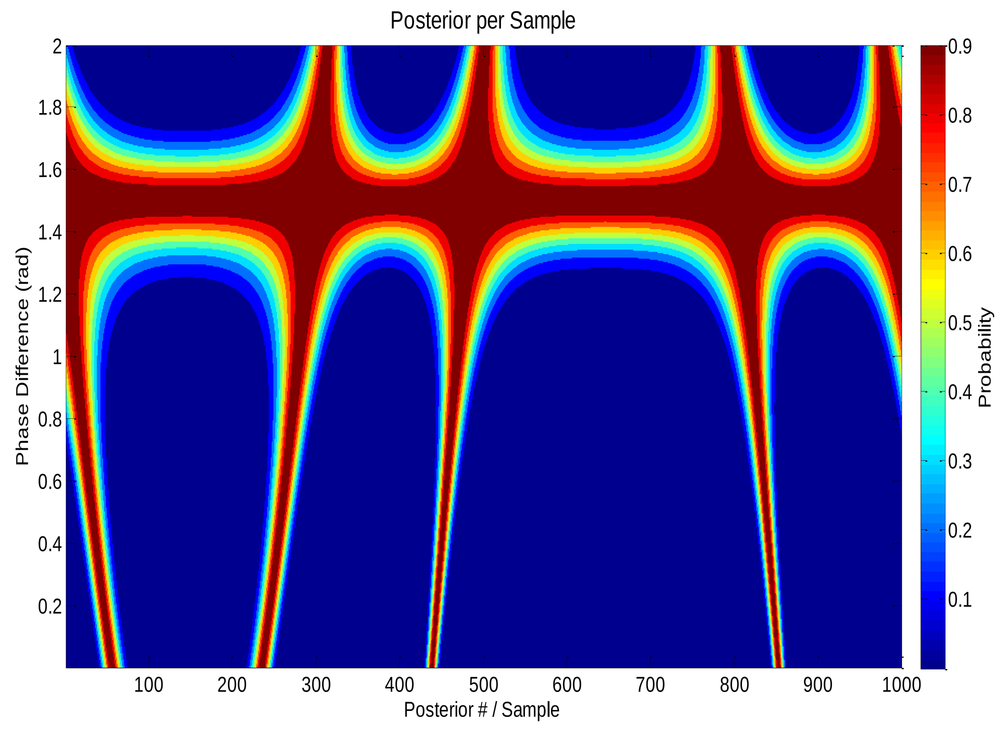
$$prob(\varphi\,|\,I)=\begin{cases}0 & \varphi<0\\ 1/2\pi & 0\le\varphi\le 2\pi\\ 0 & \varphi>2\pi\end{cases}$$

$$prob(\varphi\,|\,D_i,I)\propto\frac{1}{2\sqrt{\sigma}}\,e^{-\left(\frac{(Vp_e-D_i)^2}{2\sigma^2}\right)}\times 1/2$$

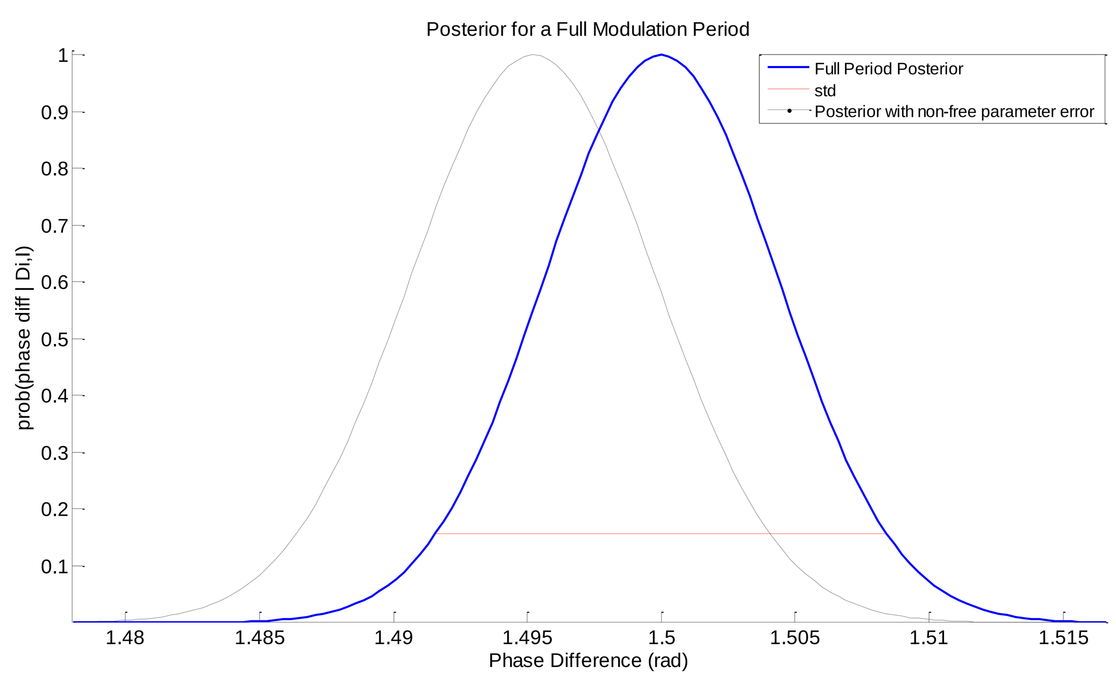
$$Max(prob(\varphi\,|\,D_i,I))\Rightarrow\varphi_e=\varphi_r\wedge\varphi_e=-\sin(\omega t)-\varphi_r$$

Given the chosen Bayesian model, the behavior can be better understood by analyzing the likelihood and posterior functions. Here it is possible to see how the posterior of each sample behaves during a the period of a full modulation with a fixed phase difference value of 1.5 radians.





Using a set of samples comprised in one full period, a full posterior of the analysis would be:



In this full posterior it is possible to see beyond the information that each sequential sample can give, and notice the effect on the posterior using a full period. Other tests currently being made are the insertion of estimation errors in the non free parameters to study the effect on the posterior.

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DPG-Frühjahrstagung