Applying Intelligent System Concepts to Automatic Beamline Alignment

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Abstract

Increasingly, automatic systems are required to have high dynamical performance and robust behaviour, yet they are expected to cope with more complex processes which are under development and highly non-linear dynamic. A very promising approach in dealing with this scenario is through Intelligent Systems (IS). IS incorporate the creative, abstract and adaptive attributes of a human while minimising the undesirable aspects such as unpredictability, inconsistency, fatigue, subjectivity and temporal instability.

Even if the Autonomous Systems area has always provided the demonstration platform of IS, the methodologies are applicable to a wider range of complex problems. Synchrotron Radiation facilities or Free Electron Lasers with their complex data acquisition, data analysis, diagnostic and control problems provide a challenging application area for Intelligent Systems.

The paper describes a framework for the conceptual development of IS for Experimental Physics. The proposed framework, based on emerging technologies such as Soft Computing (i.e. Fuzzy Logic, Neural Networks, Genetic Algorithms), Distributed Objects, Component Software, Java and WWW, has been tested on a pilot project: the automatic beamline alignment.

1 Introduction

Synchrotron or Free Electron Laser Facilities can be used for chemical, physical and biological experiments. Due to the characteristics of the experiments the light has to be collimated, monochromatized and focused on the sample under test; this is realized by a "beamline" made of several sets of highly sophisticated and expensive optic parts.

The success or performance of experiments is strongly affected by the alignment conditions i.e. all the optical components must be set to optimize some parameters such as flux or resolving power at the experimental station.

The manual alignment procedures currently used have some drawbacks: they are time consuming, they require well trained staff, they are boring for the optics experts and sometimes error prone, which could result in a sub-optimal use of the light beam and hence in a sub-optimal quality of the experimental data.

An automatic alignment system could contribute significantly to the reduction of these drawbacks and lead to an effective exploitation of extraordinary features of the new generation of light sources.

The development of such a system is really difficult. The propagation process of the light beam through the beamline has a complex structure, which can be different from experiment to experiment. Even the alignment purpose itself can differ from beamline to beamline: the main goal could be optimization of flux, resolving power or any combination of these or other parameters.

Many beamlines have not been designed with the automatic alignment problem in mind: we have to cope with intrinsic limitations of sensors and actuators.

Moreover, if the beamline is already operational, the time avalible to test an automatic alignment system is generally very limited.

The paper describes a framework for the conceptual development of automatic beamline alignment systems and an interrelated set of tools. The framework based on IS concepts was tested on two meaningful alignment problems.

2 Intelligent systems

Increasingly, automatic systems are required to have high dynamical performance and robust behaviour, yet they are expected to cope with more complex processes which are under development and high no-linear dynamic. A very promising approach in dealing with this scenario is through IS[3,5]. IS incorporate the creative, abstract and adaptive attributes of a human while minimising the undesirable aspects such as unpredictability, inconsistency, fatigue, subjectivity and temporal instability.

Research of intelligent systems assimilates and integrates concepts and methodologies from a range of disciplines: artificial intelligence, operational research, dynamic control theory and computer science.

Central to an IS design is the architecture which determines how complexity is managed, which modules are necessary for implementing the desired behaviour, as well as the command and control infrastructure. A very powerful system representation scheme, called Model Reference architecture, has been recently proposed to provide a convenient framework for the conceptual development of Intelligent Autonomous Systems (IAS). In this architecture, which combines the hierarchical and subsumption architectures, the system is decomposed vertically into various levels of abstraction and reasoning (i.e. servo, guidance, navigation, planning, etc.), and horizontally into sensor processing, world modelling and task decomposition.

Even if the Autonomous Systems area is the demonstration platform of IS, the methodologies are applicable to a wider range of complex problems. Synchrotron Radiation facilities or Free Electron Lasers with their complex data acquisition, data analysis, diagnostic and control problems provide a challenging application area for IS. Some preliminary tests[6] carried out at Elettra, pointed out that IS and "Soft Computing" techniques can be used to implement an automatic beamline alignment system.

The Model Reference architecture can be applied to the intelligent control of the beamline. Within this framework, at the servo abstraction level, the IS will provide the operator with functionalities such as the direct, possibly remote, control of the actuators and the graphical visualisation of the data acquired from the beamline instrumentation. At the guidance reasoning level the system will provide functionalities like obstacle avoidance, that it will avoid situations potentially dangerous for the beamline instrumentation. The automatic beamline alignment can be considered a navigation goal: moving the beamline to a situation where the light of desired quality reaches the experimental chamber. Now, as the first two levels are already present in a traditional beamline control system, the alignment system will be implemented on top of the installed beamline control.

3 A framework to develop automatic beamline alignment systems

We can represent a beamline as a pipeline of optical elements each with some degree of freedom. Sensors are placed along the beamline to measure specific beam parameters.

Goal of the alignment process is to determine the position of the optical elements which optimize the required beam parameters, such as flux and resolving power, at the experimental station.

Unfortunately, the complexity of the optical path results in a difficult determination of equations binding the quality of the synchrotron light spot on the sample to the position of the optical elements. In other terms, the beamline alignment is really a hard task; as a matter of fact it is a several hours work for a couple of well trained scientists. Considering the inherent complexity of the alignment we have adopted a "divide et conquere" approach to design our problem solving strategy which can be be desribed as follows:

- Split the alignment problem into small *sub-problems* involving, for example, only one optical element and the associated sensor;
- Implement for each sub-problem an *alignment module* using traditional or soft computing techniques;
- Combine the modules by using the stategic, behavioural knowledge of the optics expert.

The alignment modules should be designed as reusable components, possibly powered with learning capabilities; in this way they could be applied to different alignment problems. The selected strategy has important consequences on the framework and the interrelated tools which will be descibed in the following sub-sections.

3.1 The beamline simulator

A beamline simulator is necessary as an off-line development tool to reduce the amount of beam-time necessary to implement and test the alignment. Moreover, the simulator could be used on-line to overcome the limitations of the sensors installed on the beamline (i.e. it can be used as a reasoning aid and it can allow an easier decomposition of the alignment problem).

The simulator we are developing is based on object oriented ray tracing and provides an operational model of the beamline. Implemented in C++, the simulator was designed to be extensible, flexible, portable and easily integrable. New optical elements can be easily added to the already existing objects. The tool is dynamically configurable and can be embedded as a component of larger systems.

3.2 Yet Another software bus (YASB)

Another consequence of the selected strategy is the need of a very flexible system integration tool, a middlelware which allows a rapid solution of system integration problems. With this in mind we have designed YASB[8], an underlying control model to co-ordinate information exchanges and networking software to implement that model. The communication substrate transparently manages the complexities of inter program asynchronous interactions across networks of heterogeneous computers.

YASB has been designed to be portable across different platforms (Unix, LynxOS, MacOS, Win32). It can be integrated with commercial tools and in-home developed ones, using different programming languages (C, C++, Tcl/Tk, Java).

YASB co-ordination model is an extension of the basic client/server model designed to address interacting scenarios of decentralized, peer-to-peer collaborative computing where applications can be modelled as a set of interacting but independent agents. Agents are independent software machines, that is, active objects implemented in software, which are components of a computer system. Programming with agents thus involves constructing different specialized machines and then interconnecting them in order to achieve the required higher-level functionality. This is analogous to the way in which hardware designers combine standard components to construct specialized circuit boards. One of the benefits of the agent paradigm is that agents tend to be relatively self-contained, autonomous and hence reusable in different context. Communication between agents is based on a message-passing model.

4 Examples

The framework and the interrelated tools have been tested on two non trivial alignment problems which are descibed in the next sub-sections.

4.1 The vertical focussing mirror alignment module

The ELETTRA Spectromicroscopy beamline has been designed to perform photoemission experiments with high spatial resolution. The Vertical Focusing Mirror (VFM) alignment module determines the VFM position which centres the beam at the Entrance Slit (ES) balancing the photo-induced currents on the slit blades.

The architecture of the alignment system couples an artificial intelligence and a real-time sub-system as parallel, cooperating components. The Intelligent Alignment Agent was developed using FuzzyCLIPS[1]. FuzzyCLIPS can deal with exact, fuzzy[1], and combined reasoning, allowing fuzzy and normal terms to be freely mixed in the rules and facts of the knowledge based system. The expert system shell was integrated with the beamline control system (BCS) through YASB. The knowledge based system can thus control variables of the beamline equipment; moreover fuzzy inferences can be triggered by beamline equipment variable changes.

The alignment was implemented using a fuzzy logic algorithm. At each step blade currents are acquired through the BCS, normalized and fuzzified (i.e. transformed into a linguistic beam position).

The fuzzy inference then transforms this fuzzy input set into the output mirror movement fuzzy set which is then defuzzified, denormalized and transformed in the actual correction of the mirror position. The fuzzy algorithm is quite simple and easy to understand. As a matter of fact, it consists of the following five lignuistic rules:

IF BeamPosIS LowBig THEN MirrorMov IS NegBig;
IF BeamPos IS Low THEN MirrorMov IS Neg;
IF BeamPos IS Cented THEN MirrorMov IS Zero;
IF BeamPos IS High THEN MirroMov IS Pos;
IF BeamPos IS HighBig THEN MirrorMov IS PosBig.

The following graph describes the behaviour of the system during an alignment session.

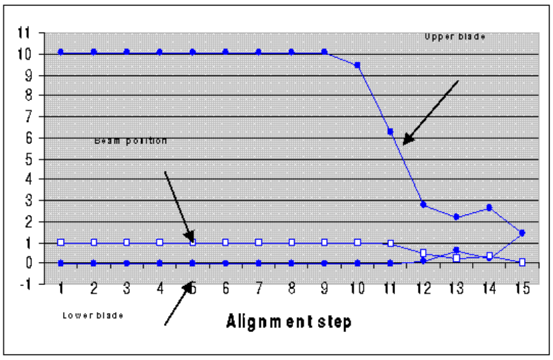

Fig.1: The behaviour of the VFM alignment module.

4.2 The toroidal mirror alignment module

The ESRF beamline BM 14, has been designed for MAD (Multi-Wavelength Anomalous Dispersion) phasing of protein crystals. The toroidal mirror is a very complex focussing element with six degrees of freedom potentially critical to the alignment. The Thoroidal Mirror alignment module has to optimise the spot shape and intensity assuming that the position of the X-ray beam is already optimised. The setup for automatic optimisation on BM14 consists of a small CCD camera controlled by a PC. The CCD is moved to view the sample during the alignment and removed during experiments.

[1] FuzzyCLIPS was developed by the Knowledge System Laboratory, National Research Council Canada.

The system presents an architecture similar to the preceding example. The alignment was implemented using a fuzzy logic algorithm. The Beamline Simulator has been used for the development of the linguistic rules. The following picture describes the results of an alignment session.

The two images on the left show the original beam while the two on the right show the result of the alignment process.

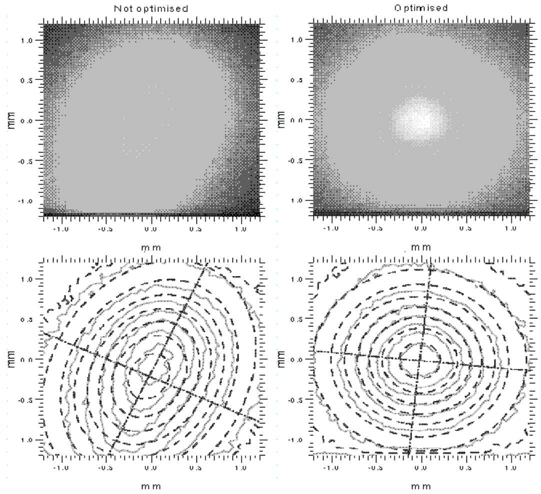

Fig.2:The behaviour of the toroidal mirror alignment

5 Conclusions

We have designed a framework for the conceptual development of Automatic Beamline Alignment systems based on Intelligent System concepts. We have already developed a set of tools which are part of the proposed framework. The framework has been tested to develop some simple but non trivial alignment sub-systems and the results are encouraging.

Further development work will concentrate on four main directions: the development of new reusable alignment modules; the introduction of maching learning techniques to overcome the knowledge elicitation problem and to reduce the dependency and sensibility of an alignment module to its environment; the extension and improvement of the suite of support tools; the implementation of alignment systems to solve more and more challenging alignment problems.

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