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The Development of an Expert System to Tune a Beam Line

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Abstract

The experience of developing an Expert System to* aid in the tuning of the Ion Source Injection beam line at TRIUMF is described. The challenging and complex task of introducing Expert System technology into an established accelerator operation is outlined. Success in this environment depends strongly on the choice of project, the choice of experts, the choice of tools, and the methods used to represent the expertise. All these choices are discussed.

1 THE ACCELERATOR ENVIRONMENT

TRIUMF is a cyclotron which accelerates negatively-charged hydrogen ions to variable energies between 60 MeV and 520 MeV.

1.1 Ion Source Injection Beam Line

The Ion Source Injection System (ISIS) beam line accepts 300KV H- beam from the source and transports it a total of approximately 40 meters around two bends to the centre of the main accelerator. The beam is transported by electrostatic focusing and steering devices. There are four groups of diagnostic devices in the ISIS beam line: collimators, skimmers, non-intercepting monitors, and wire scanners. The skimmers precede and protect each quadrupole and help to centre the beam. In this project, the collimators were the principal devices used; the skimmers were used less because they do not tolerate very much current and because they are less sensitive. The non-intercepting monitors were used to calculate transmission. The wire scanners were not used because there is little operational experience with using

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them.

1.2 Manual ISIS Tune Procedure

After the desired source is selected mechanically and logically, the electrostatic elements of the ISIS beam line are restored to the values corresponding to the best known solution. The operator uses the currents on the beam stops and the spills on the skimmers and collimators to find the earliest significant spill. Next the operator determines whether the loss is caused by horizontal or vertical displacements, or if the beam is too large and hitting something. As a tuning contingency, the collimators are water-cooled and able to take the full ISIS beam. Close to a wire scanner, the operator uses the wire scanner to make the diagnosis. Elsewhere, he diddles (makes minor adjustments to) the setpoints of appropriate beam line or source devices. He uses the collimator and skimmer histogram patterns and the ISIS transmission, to minimize beam spill in the ISIS beam line.

2 THE OVERVIEW OF THE TASK

A six month pilot project was setup to determine the feasibility, problems, and benefits of using Expert System technology to solve a problem in the beam line tuning domain. Several questions arise when approaching a new technology. Some of the more obvious are:

1. Can it solve the problem?

2. Is it appropriate for the task?

3. How much does it cost in time, money, and stress on the existing system?

4. What are the limitations?

5. Is it a good choice for this problem in view of the above?

The project was staffed by one visiting scientist working full time with a review panel consisting of four (two technical and two managerial) TRIUMF employees. In addition, other TRIUMF technical people were called on to provide detailed information about specific parts of the beam line and the current tune procedures. For a detailed technical description of this project, see reference 1.

2.1 Characteristics Of Beam Line Control Problems

There are characteristics common to beam line control problems. In most cases, there are a large number of repeating interacting devices. Each device has several related devices. The effects of these devices are not always well understood. While there may be a mathematical model of the theoretical beam line used to design the beam line initially, often that model is not precise enough to accurately predict what a given change will do to the real beam. That is the case for ISIS. The biggest factors preventing the use of a model to predict the performance of ISIS are:

1. A portion of the line goes through a wall. That portion is unshielded from the effects of the main magnet (30 gauss or more).

2. Permanent magnets are placed on the beam line to compensate for the effects of the main magnet.

3. Due the the heavy weight of the accelerator, the floor below the ISIS beam line is sagging.

4. Moving large pieces of metal, such as the crane, have an unpredictable effect on the magnet fields around the ISIS line.

5. Each time the source is replaced, a slightly different set of initial beam conditions occur.

2.2 Implications Of Beam Line Characteristics On Expert System Tools

The type of problem to be solved places constraints on the selection of tools to be used[2]. For beam line control problems, the tool selected should provide for representing devices, representing interactions between devices,reasoning in the face of uncertainty, following an expert's recipe for approaching a tune, and reasoning based on observing effects.

3 CHOICES

To have a successful expert system project care must be taken to choose the right project, the right expert, the right tools, and the right approach to representing the expertise. The ISIS project will be described in terms of the choices forced on it by external factors or those made freely. These choices will then be compared to a perfect project to try to identify those factors that must be considered to increase the likelihood of successful application of Expert System techniques to beam line control problems.

3.1 Choice Of Problem

The ISIS tune problem was chosen because it is big enough to test the use of expert system techniques without being too big to handle. It is a real problem that has a real need for an automated solution. ISIS is a good choice because there is a limited amount of expertise available. There is a dramatic difference between the performance of the best tuner and the rest of the operators. The ISIS tune problem has a long life for the current TRIUMF accelerator will be the injector to the KAON factory.

3.2 Choice Of Development Team

Members of the project team should be trained in the technology to be used, knowledgeable about the application, have adequate time to spend on the tasks assigned, and dedicated to the success of the project. The domain expert is particularly important.

Fred Bach was available, and the acknowledged expert on the topic. He was interested, and cooperative. He has a long term familiarity with ISIS going back some 16 years. Fred was a cooperative expert who was willing to give up the secrets of his success. Sometimes this is difficult to achieve. Often a good candidate is one who wants or needs or is encouraged to move on to other tasks either for professional development or retirement. In those cases, the expert is not threatened by the apparent loss of some of his or her uniqueness. Fred felt that this project would make his job easier and hence he did not consider the expert system a threat.

3.3 Choice Of Development Machine

TRIUMF had at the start of this project about 25 VAX workstations available to use. All of the workstations were connected to a Local Area VAX Cluster (LAVC). In this environment, the workstations are normally disk-less and all the operating system, paging, windowing, and application data is obtained over the ETHERNET from/to the disk server on the boot node. At first, a VAX station 2000 and then later, a 3200 were used for ITA. Each initially had 8MB of memory.

Both workstations started disk-less, but, it quickly became clear that the demands on the boot node for windowing and paging were a serious bottleneck. A single low performance local disk was put on both the 2000 and the 3200. This improved performance. For example, window swapping no longer took several minutes; but, the improved performance was still subjectively slower than the author's previous experience using a 16MB micro-VAX II using two of the same low performance disks in a stand-alone system.

The LAVC environment was also considerably less reliable than similar hardware running outside a LAVC. The LAVC stations experienced repeated hang-ups when mouse or keyboard requests would be ignored. Another problem was the relatively frequent system crashes where the workstation's processor would halt or spontaneously re-boot. The unpredictability and unreliability of the LAVC was a serious problem for the development of ITA.

3.4 Choice Of Development Software

Two different Expert System shells were used and the features and limitations of each were compared informally. We started using NEXPERT, to evaluate the premise that an apparently simpler tool might be easier to learn, use, and integrate. KEE was later used as the full featured, high powered approach.

3.5 Choice Of Approach

The ISIS tune advisor (ITA) project took a slightly different approach than traditional Expert System applications [3]. In most expert systems, either one expert is used, or a group of experts combine their knowledge to form a composite expert. ITA uses three slightly different approaches. The first attack on a problem is to use the heuristics of the operational expert. If that succeeds, all is well. If the operational approach fails to solve the problem, a second attempt is made using a technique developed by a beam line physicist from a theoretical analysis of the problem. If that approach also fails, a technique is tried which mimics the actions of an operator when faced with a problem for which he has no previous experience. In this fallback, last-chance, approach the expert system searches for a solution using only very general heuristics based on relative physical location and performance feedback to limit the search for the right correctors. It is hoped that the combined power to solve tuning problems will be greater than concentrating on any one approach.

3.6 Choice Of Delivery Vehicle

While the project did not advance to the delivery phase, it is clear that features and performance that are adequate or suitable for development could be inappropriate for a production environment. This is true for both hardware and software. It is very likely that the best approach is to develop the expert system in a powerful high performance environment and when the concepts have been proven, port the knowledge gained in the development process to the best delivery vehicle available.

4 THE PERFECT PROJECT

This might be considered as an utopian description of the perfect project. However, it can be practically used to evaluate a proposed expert system project to determine the chances for success. While projects will succeed even if they differ from the ideals expressed here, the more deviation the more likely the project will not meet expectations. The knowledge gained from the work on ISIS and other accelerator control artificial intelligence projects worked on by the author is used here to describe the best of all possible projects.

4.1 The Perfect Problem

The perfect problem has a high payoff, available expertise, cooperative expert, and a relatively confined problem area (well circumscribed). Complexity caused by repetition is a problem that can be handled more easily by a program than by a person.

4.2 The Perfect Development Team

To create a knowledge based expert system successfully requires several things; the most important are the people that make up the project team. Ideally, the project team is made up of trained Knowledge Engineers (KE), programmers, an expert, and a managerial team that is knowledgeable in the technology. The team must have adequate time and support to build the system.

The development team must be open to technology, focused, concise, and insightful. The expert should have a stake in the out come. He should be able to share the praise or blame for the success or failure of the project. Not only must the expert be willing to spend the time on the project but the expert's managers must be committed to support he project. It has been said that you know that you have the right xpert when the manager is reluctant to give up that person's time.

.3 The Perfect Development Machine

It needs to have high performance, powerful environment, and be ntegrated with existing beam line control system machines (for access o real data). High performance implies large effective memory apacity, fast swapping device(s), high resolution display, and a fast ccurate pointing device. Large amounts of memory are particularly seful when using a LISP based tool on a traditional work station. ISP in that configuration takes a large amount of physical and virtual emory space. Though the single sample of a C based tool did not erform noticeably better in the LAVC environment. Whatever machine is hosen, it must also be robust. For these reasons the development achine must be dedicated to the task. It should be a stand-alone ystem in the sense that it is insensitive to outside forces. nterruptions affect development of expert systems even more seriously han similar interruptions to traditional programming for the following easons.

1. Large codes imply longer times to save

2. Quick response encourages experimentation

3. Neither shell used has journaling

4. Expert Systems require broader more complex thought processes

Because the codes are much larger (the initial prototype of ITA ontains almost 500K bytes) it takes a relatively long time to save. his coupled with the speed with which you can try another feature, ncourages the knowledge engineer to "try just one more thing before aving". The cost is often recreating what was lost due to a hang or a rash.

In traditional development with a text editor, a crash or hang ould not be as costly because usually the incremental additions to a rogram are smaller and most of a lost editor session can normally be ecovered from the journal file automatically generated. Neither xpert System shell used provides a journaling facility.

The breadth of knowledge contained in an expert system usually is ubstantially broader and more complex than in a traditional pplication program. Even there, an interruption can be costly in erms of time required to regain a train of thought. Interruptions are even more costly in expert system development because of the increased complexity.

4.4 The Perfect Development Software

Development software must be powerful, fast, flexible, easy to change, simple to document applications, easy to learn (good tutorial material with plenty of examples) and use. It must have good debugging tools, well documented features, multiple representations, and full support of external subroutines and interfaces to existing independent programs. Object-oriented programming tools provide many of the required features.

The thought processes required to develop an expert system are different than for a traditional program[4]. Expert system shells that look like or are patterned after traditional approaches, i.e., text editors or spread sheets, on the surface are very attractive for they look familiar to the typical traditional programmer. But, that familiarity can be costly for it makes it doubly difficult to change the traditional (procedural) thought patterns.

4.5 The Perfect Approach

This, of course, depends on the specific application. The development team must have a broad repertoire of tools and techniques to apply. Each application will be somewhat different thereby requiring a variety of approaches to solve.

4.6 The Perfect Delivery Environment

Both hardware and software should be inexpensive (so that many copies can be economically fielded), fast, robust, and requires minimal changes from development. It should match the existing environment so no new policies, procedures, or maintenance is needed.

5 CONCLUSIONS

AI technology can be profitably used in the solution to accelerator related problems, but, care must be taken in the choice of problem, expert, development and delivery vehicles[5]. AI techniques are appropriate because algorithms fail and the captured knowledge of the expert does lead to a solution. AI technology is costly in time to develop and in money for software, hardware, and people. It has not stressed the system yet but in operation it will put significant demands on the control system for data. The major limitations of AI technology are the limited number of people trained to do the work and the poor performance of the shells used in the VAX workstation LAVC environment. AI technology is none the less the best choice available.

There are several actions that can be taken to improve the chances for success of a production version of the prototype. Some suggestions for improvement include upgrade the workstation to a more powerful system, refine the approach used to include more, different or more powerful techniques, and port the application to a more powerful delivery environment.

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