FUZZY LOGIC CONTROL OF A PARTICLE ACCELERATOR

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Abstract

The ion beams produced in a particle accelerator have to be characterized and monitored using parameters specific to the instruments involved and information from practical (hands-on) operation of these instruments and of the accelerator as a whole. The control is critical considering the multitude of equipment and tasks involved. It is a nonlinear, non-standard process that is difficult to model. This paper presents the progress made in implementing fuzzy logic theory and controls in the operation of the 1.7 MV Tandem particle accelerator at the Michigan Ion Beam Laboratory.

INTRODUCTION

Since its inception in the 1960's [1], Fuzzy Logic (FL) has evolved from a pure theoretical science to a widely accepted theory. It was followed [2 - 4] by work on Fuzzy Logic Controls (FLC) that signalled the beginning of the design and implementation of many new products. Some of these applications based on FLC are already around us, in automatic train controls [5], nuclear reactor controls [6] and many others [7-8]. What makes these controllers stand apart from other controllers is the fact that they are very appealing when the systems are unusually complex, when the information needed to run the systems is not precise and when the input variables can have more than one value or maybe a range of valid values that work for a given situation. The goal of this paper is to present a specific application of FLC in the control of the 1.7 MV Tandem particle accelerator. This instrument is located in the Michigan Ion Beam Laboratory (MIBL) at the University of Michigan in Ann Arbor Michigan (Figure 1). As seen from Figure 1, aside from the accelerator, the lab includes also a 400 kV NEC ion implanter.

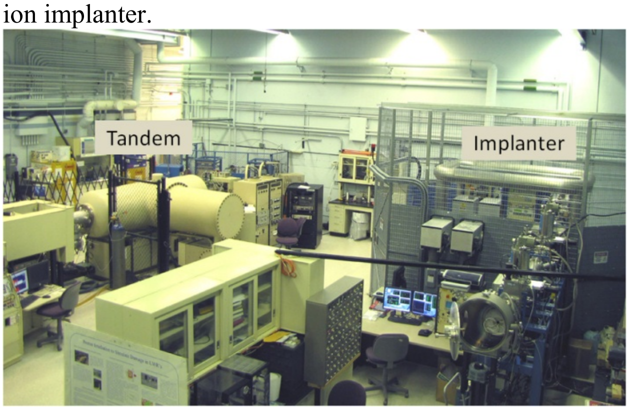

Figure 1: Michigan Ion Beam Laboratory.

The particle accelerator consists of thousands of parts and components, many power supplies and a large number of auxiliary equipment. Ensuring a centralized monitoring and control centre is not an easy task. In practice, there are a few important issues that have to be accounted for when upgrades or changes are considered in the way the components interconnect:

1. The operator of the system has to be constantly aware of all of the parameters, as problems at the end station could be caused by any of the many indicators and control units that are more or less likely to influence a certain outcome in the experimental setup.
2. As with all the instruments, in time, some of the components become obsolete. When an upgrade is planned, the first components that will have to be replaced are the ones that are hard to find or are about to become obsolete
3. It is hard to anticipate future needs, so designing an upgrade that "boxes in" a certain component by not allowing future changes or developments is something that needs to be avoided at any cost. The present work provides a possible approach to controlling as many parts of the accelerator as possible through the use of fuzzy logic (FL) on a Labview platform in MIBL.

FUZZY LOGIC AND FUZZY LOGIC CONTROLLERS

FLC may not be as widespread used in industrial controllers as the Proportional-Integral-Derivative (PID) controllers are, but the purpose and range of use is slightly different. FL is basically a variation of the set theory (ST) [1]. In ST a variable is either in a set or outside of it (Boolean way of thinking); in FL there is a certain probability associated with the membership of a variable to a set. FL is much closer to human thinking and natural language than the traditional logical systems are. In programming a FLC, actual sentences are being used, and in this way, the inexact and very approximate nature of the world around us can be more realistically captured. The basic steps of implementing FL are (figure 2): (a) receive the input values: measurements are taken of all relevant variables, and eventually A/D conversion occurs; (b) fuzzification: the measurements are converted into fuzzy sets to express their uncertainty; (c) applying the rules: fuzzified measurements are used by the inference engine (set of rules) to evaluate the control decisions and (d) defuzzification or generating an output: the outcome is converted into crisp (precise) values best representative of the fuzzy set, and a D/A conversion occurs in this step. There is nothing "fuzzy" about the values at the output of a FLC: they are firm, précised and fixed values that are sent to the instruments that are being controlled.

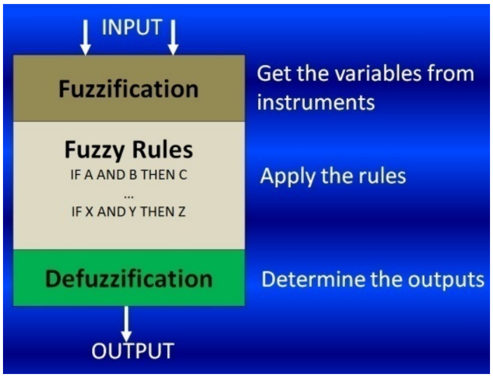

Figure 2: FLC process.

There are many good books and articles written on the subject [9-11] and it is not the purpose of the current paper to discuss in detail the FL concept. We only concentrated on a specific application of FL, more precisely the use of this concept to simulate human control in operating and setting the right operating conditions for a particle accelerator to generate a focused ion beam at the low energy end. In short, the FLC will take the input, match it with linguistic variables and determine the conversion to an appropriate output. Labview can apply one of three accepted defuzzification methods: a) Center of Gravity (CoG), b) Center-of-Maximum (CoM) and c) Mean-of-Maximum (MoM). These methods are explained in detail in literature [9-11]. Each of these methods may give a slightly different output, and is a safe practice to try them all if possible, for a given system. All the parameters can be modified and adjusted according to the outcome.

THE HARDWARE AND THE SOFTWARE

The hardware that needs to be interfaced consists mainly of power supplies with remote interfaces (Glassman, Lambda and Sorensen), turbo pump monitoring devices and the experimental unit devices. Most of these instruments can be controlled with a 0-10V, 0-5V, 0–100 mV or 4-20 mA signals. The status or set values of the interlocks or other parameters can be determined or set by digital modules. The values returned from the instruments and needed in the control loops come also in a variety of forms, either as analog or digital signals. The computer interface consists of a computer that communicates with the instruments either through a PCI card, USB ports or through RS232 ports and a network of devices (Ioplexer by DuTech) that can accommodate a mixture of up to 16 analog or digital input and output modules. The software of choice is Labview (National Instruments) due to the fact that most of the computers in the laboratory control the instrumentation through this code.

EXPERIMENTAL SETUP

The system intended to be controlled is very large. It consists of a few major blocks: (1) the source; (2) the tandem controls; (3) low energy (LE) beam focus; (4) high energy (HE) beam focus, (5) the end (experimental) station and (6) auxiliary systems. Ideally we would like the FLC to be able to interface and control/communicate with all the modules. However, such an endeavour is too complicated at this point and very large computing power would be needed, which it is not available at MIBL at this time. However, smaller steps would be feasible to implement and then link at a later time.

FLC models represent the human operator more closely than other controllers, maybe not the complete expert but certainly a novice one. A good working FLC that could be implemented in the beam focusing process could save a lot of time and could correct easily small fluctuation in the input variables. The power supplies (PS) that need to be controlled and tuned considering the current reading in the LE Faraday cup, are: the LE magnet (LEM), Gridded Lens (GL) and Y-Steerer (YS). To focus the beam at the HE end, in addition to setting the above power supplies and monitoring the current reading from the HE Faraday cup, we have to consider the Quadrupole PS (Qx and Qy), Injector Steerer PS (Sx and Sy), HE Magnet PS (HEM) and Tube Lens PS (TL). In the first step we concentrated on generating the set of rules needed to focus the beam at the LE end. For the FL concepts introduced above, an example will be given for one of the power supplies: The Y-Steerer (YS), whose values vary from -1kV to + 1kV. For now, we assume that the beam focusing depends only on this one variable. The operating values for the YS are known empirically for a given energy and particle to be around a certain value, let's say 100 V and a current reading in the LE Faraday cup of about 100 μA (FC = 100) . Then a fuzzy set defined for the YS input could be {Far Lower, Mid Lower, Slightly Under, Close Enough Under, Close Enough Above, Slightly Over, Mid Over, Far Over}. As we work on a Labview platform, we are limited to a maximum of 9 variables but other processors might allow a larger number of variables. Next we have to define the range of these variables or a step, and in this case, 5 V (something in this range would be fine). If this value doesn't work it can be adjusted accordingly with the outcome. Then, the set of rules for the actions on this power supply have to be defined in accordance with the expected setting and the target current value that is the value received from the LE Faraday cup. If we take into account two power supplies (YS and GL), then the set of rules would significantly increase in complexity, but be still manageable. These rules can actually be drafted if a log of the beam condition and the decisions of multiple operators is being kept and evaluated.

RESULTS

Newer versions of Labview Control Toolkit have available a “Fuzzy System Designer” that makes the project easy to initiate. In our case we first designed the systems with one input and one output, then we moved to two and finally to three inputs and three outputs that would be controlled independently in response to the reading from the LE FC. The hard part was to decide on the set of rules that basically define the FLC that would take the inputs, fuzzify them, determine their membership, defuzzify them and determine a response or more according to the defuzzification method. Screen shots from this process are displayed in figure 3 (a,b and c). Using this approach we were able to simulate a human operator, probably at the level of novice. Once the operating values were determined, the hardest part was to actively respond to small fluctuation without over-reacting. The programing was very intense and a lot of feedback and adjustments were needed. In order to design a more complicated FLC the idea of a simpler FLC can be used and built upon by adding additional variables. Every new function must be tested by itself and in conjunction with the others. It may be well worth the time invested to write code that would actually simulate the power supplies’ responses and see where the responses from the FLC take the output.

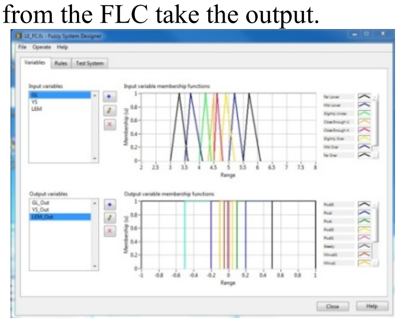

Figure 3a: Defining all variables.

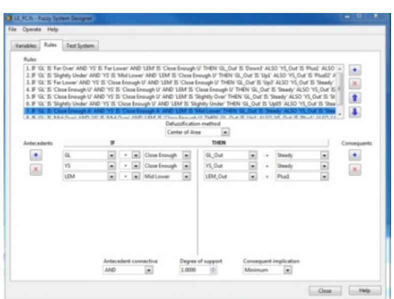

Figure 3b: Defining the rules.

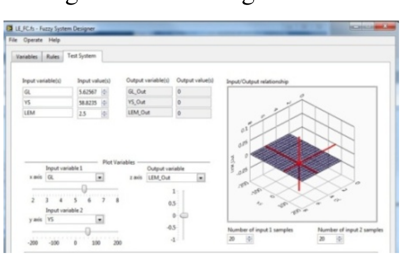

Figure 3c: Testing the rules.

SUMMARY

Controlling the output of individual power supplies to generate a steady beam current in the Faraday cup could be accomplished with FLC on a Labview platform. Allowing the FLC to first control one power supply, then two power supplies and ultimately three to achieve this task can be accomplished using a relatively complicated set of rules. With the experience gained from this level of control, it is actually feasible to move to the next level and try to accomplish the control of beam current in the high energy FC ultimately on the experimental stage. In general the fuzzy rules are derived from the human operator experience (sometimes multiple operators). The rules may be subject to personal choices, so it makes sense to check them all for redundancy and to minimize the possibility of contradictory actions. Although the FLC might offer an approximate correct solution and/or value for an output or multiple outputs, it is also possible that there will be a long “oscillating” time around this value. Practice and experience are be important factors in modifying input values to minimize this effect and to adjust membership functions to produce a reliable FLC.

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