Advanced Fuzzy Logic Tools for Industrial Control Applications - A Survey

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Abstract - The application of fuzzy logic is an effective alternative for any problem where logical inferences can be derived on the basis of causal relationships. Among the developed intelligent control techniques, fuzzy logic control provides a direct methodology to encode the operator's heuristic knowledge into the control strategy and is therefore a natural choice for nonlinear control action. With the growing wide use of fuzzy logic control, many fuzzy logic software and hardware products have been developed. This paper is intended to present a quick review on the advanced software and hardware tool available for fuzzy logic based embedded controller implementing an intelligent control technique, fuzzy logic, for Industrial control applications. These applications for example, be liquid level control, flow control, or pressure control.

Keywords - Fuzzy logic, Families of fuzzy software tools, Embedded system.

I. INTRODUCTION

Classical techniques, such as proportional-integral (PI) or proportional-integral-derivative (PID) control, are widely used in process or manufacturing industries on account of their simple structure, their ease of implementation, and the wide understanding of their tuning techniques by trained operators.

When the system is nonlinear though, the PID control action is slower, sometimes ineffective, and does not provide good results in conditions of parameter perturbations and system disturbances. Also, use of PID techniques must be preceded by derivation of the system model, while intelligent control techniques can be used without obtaining the model of the system under consideration. In such situations, operator heuristics become significant and indeed essential to obtain good control action. In industry today, all processes require automatic control with good performance over a wide operating range, in addition to simple controller design and implementation [1]. This motivates the implementation of intelligent control techniques, which can directly implement the operator heuristics in the control action, thereby providing faster and more accurate results. The popularity of the fuzzy logic is due to its simplicity and effectiveness in solving control problems [2].

There is a noticeable trend in the development of FLC algorithms. There are a number of software products available that would allow the user to design a fuzzy controller from a high or algorithm level, and sometimes interactively with a special graphics user interface(GUI). The user could start from a fuzzy logic algorithmic level to design the controller. Consequently, these tools would usually generate C codes, which can to be modified to fit into a target platform. This further simplifies the implementation of FLC using a general-purpose platform [3].

II. FUZZY LOGIC SOFTWARE DEVELOPMENT TOOLS AND IT'S APPLICATIONS

Table No.1 shows Fuzzy Logic Freeware Software Tools and Table No.2 shows Fuzzy Logic Commercial Software Tools.

2.1 Development software preprocessor for fuzzy logic

The Byte Craft Fuzz-C ™ Fuzzy Logic Preprocessor makes it easy to add fuzzy logic control to your programs [4]. The Byte Craft Fuzz-C translates a source file of mixed fuzzy logic statements and C statements to a file of pure C source code. The resulting C source file can be compiled by your favorite C compiler to quickly integrate fuzzy logic with supporting C functions. This stand-alone preprocessor provides a practical, unified solution for applications that require fuzzy logic control systems.

The Byte Craft Fuzz-C is a flexible system that allows all data types supported by your C compiler. Standard defuzzification methods are included in source form, and new methods can easily be added. Fuzzy functions and C functions are completely integrated and can easily call each other.

2.2 A Fuzzy Logic Freeware Software Tools

2.2.1 The FuzzyCOPE family of software

FuzzyCOPE 1 was released in 1995, and contained some basic data manipulation tools, a MLP simulator, and a Kohonen SOM simulator. FuzzyCOPE 2 was released in 1996, and added a fuzzy neural network (FuNN) simulator. The results of this effort were released in 1998. It provides for the creation, training and validation of connectionist structures to be used in the development of intelligent control systems. It's functionality may be accessed interactively (through a GUI), from the DOS prompt (through several command line tools), and from provided Dynamic Link Libraries. The current release version of FuzzyCOPE is version three. The modules in version three include: Multilayer Perceptrons, Kohonen Self Organising Maps, Fuzzy Neural Networks, data manipulation and transformation functions (data shuffling, normalisation, denormalisation) [5].

Table 1. A Fuzzy Logic Freeware Software Tools

No.	Software Tool	Developer	Special Feature	Platform
1	Fuzzy COPE	Michael Watts Department of Information Science University of Otago New Zealand	a free software environment for teaching, research and intelligent system development	MS Windows 95/98 (Win32).
2	Fuzzy Logic Inference Engine	Institute of Robotics (IfR), Swiss Federal Institute of Technology Zurich (ETH).	It performs simple fuzzy inferences from supplied fuzzy rules. A nice piece of software for class exercises.	Macintosh
3	SCILAB	SCILAB Enterprise	Fuzzy logic simulation and code generation	GNU/ Linux, Mac OS X and Windows XP/Vista/ 7/8
4	Fuzzy CLIPS	National Research Council of Canada	An enhanced version of CLIPS which supports development of fuzzy expert systems.	PC, Macintosh and Unix
5	NEFCLASS	Leader in BT's Intelligent Systems Research Centre, United Kindom	A DOS tool used to develop, test, and train neuro- fuzzy systems.	MS-DOS
6	Fuzzy Software provided by the University of New Mexico	students of Prof. Timothy J. Ross	Included are academic fuzzy logic programs and a fuzzy calculator	DOS (pkunzip required for decompression).

2.2.2 FLIE (Fuzzy Logic Inference Engine)

FLIE (Fuzzy Logic Inference Engine) has been developed at and used by the Institute of Robotics (IfR), Swiss Federal Institute of Technology Zurich (ETH). It is written entirely in MacMETH a dialect of Modula-2 for Macintosh computers also developed at the ETH. MacMETH is distributed free of charge by anonymous ftp from neptune.ethz.ch directory macmeth. All source code is included.

CFLIE is a C version of FLIE written by Ahmet Sekercioglu, Swinburne University of Technology, Australia. FUN (Fuzzy Using Neural networks) implements some learning strategies for fuzzy rule based systems.

2.2.3 SCILAB

SCILAB is free and open source software package developed at INRIA (France), for numerical computation providing a powerful computing environment for engineering and scientific applications [6]. It was introduced as an Open source alternative to MATLAB [7]. It is also a vector based program. It has constantly undergone vital changes ever since its inception in 1994. The first version of SCILAB was launched in 1994 and since then it has been constantly updated and is available for download via the Internet.

SCILAB is released as open source under the CeCILL license (GPL compatible), and is available for download free of charge. SCILAB includes hundreds of mathematical functions. It a high level programming language allowing access to advanced data structures, 2-D and 3-D graphical functions. A large number of functionalities is included in SCILAB: control, simulation, optimization, signal processing, Application development.

2.2.4 FuzzyCLIPS

FuzzyCLIPS is a fuzzy logic extension of the CLIPS (C Language Integrated Production System) expert system shell from NASA. It was developed by the Integrated Reasoning Group of the Institute for Information Technology of the National Research Council of Canada and has been widely distributed for a number of years. It enhances CLIPS by providing a fuzzy reasoning capability that is fully integrated with CLIPS facts and inference engine allowing one to represent and manipulate fuzzy facts and rules. FuzzyCLIPS can deal with exact, fuzzy (or inexact), and combined reasoning, allowing fuzzy and normal terms to be freely mixed in the rules and facts of an expert system. The system uses two basic inexact concepts, fuzziness and uncertainty. It has provided a useful environment for developing fuzzy applications but it does require significant effort to update and maintain as new versions of CLIPS are released [8].

2.2.5 NEFCLASS - Neuro-Fuzzy Classification

NEFCLASS is short for NEuro-Fuzz CLASSification and it is used for data analysis by neuro-fuzzy models [9]. It can learn fuzzy rules and fuzzy sets by supervised learning. NEFCLASS has the following features:

- It represents a fuzzy classification system.
- It can learn fuzzy classification rules incrementally.
- It learns fuzzy sets by using simple heuristics.
- The learning algorithm does not afflict the semantics of the underlying fuzzy classifier. The system is always interpretable in terms of fuzzy classification rules.
- It is freely available for scientific and personal use.

2.3 **A Fuzzy Logic Commercial Software Tools Table No.2. A Fuzzy Logic Commercial Software Tools.**

No.	Software Tool	Developer	Special Feature	Platform
1	Fuzzy Logic Toolbox for MATLAB	MathWorks, Natick, Massachusetts, U.S.A.	Fuzzy logic simulation	MS Windows, UNIX, and Macintosh. MATLAB required
2	PID and Fuzzy Logic Toolkit for NI LabVIEW	National Instruments Corporation, Austin, TX.	Fuzzy logic simulation and code generation for Embedded System	Windows, OS X, Linux
3	fuzzyTECH	Inform Software, Aachen, Germany	Fuzzy logic simulation and code generation	Front-end: MS-Windows, back-end: multiple
4	FIDE	Aptronix, Inc., Palo Alto, CA	Fuzzy logic simulation and code generation	Windows
5	FLDE	Syndesis Ltd, Iofondos 7 Athens, Greece.	Fuzzy logic simulation and code generation	MS Windows
6	Fuzzy Logic Inferencing Toolkit (FLINT)	Logic Programming Associates	FLINT providing tools for the construction of fuzzy expert systems and decision support applications.	MS Windows, DOS, and Mac

2.3.1 MATLAB

MATLAB have a Fuzzy Logic Toolbox™ software that is

a collection of functions built on the MATLAB® technical computing environment [10]. It provides tools for you to create and edit fuzzy inference systems within the framework of MATLAB. You can also integrate your fuzzy systems into simulations with Simulink® software. You can even build stand-alone C programs that call on fuzzy systems you build with MATLAB. This toolbox relies heavily on graphical user interface (GUI) tools to help you accomplish your work, although you can work entirely from the command line if you prefer. The toolbox provides three categories of tools: Command line functions Graphical interactive tools Simulink blocks and examples. The toolbox lets you model complex system behaviors using simple logic rules, and then implements these rules in a fuzzy inference system. You can use it as a stand-alone fuzzy inference engine. Alternatively, you can use fuzzy inference blocks in Simulink and simulate the fuzzy systems within a comprehensive model of the entire dynamic system.

Key Features of MATLAB as follow:

Fuzzy Logic Design app for building fuzzy inference systems and viewing and analyzing results.

Membership functions for creating fuzzy inference systems and support for AND, OR, and NOT logic in user-defined rules.

1. Standard Mamdani and Sugeno-type fuzzy inference systems.

2. Automated membership function shaping through neuroadaptive and fuzzy clustering learning techniques.

3. Ability to embed a fuzzy inference system in a Simulink model.

4. Ability to generate embeddable C code or stand-alone executable fuzzy inference engines.

2.3.2 NI LabVIEW

The NI LabVIEW PID and Fuzzy Logic Toolkit is an add-on to the LabVIEW graphical development environment that can be used to add sophisticated control algorithms to our LabVIEW programs. By combining this toolkit with NI data acquisition, FPGA-based, and other I/O hardware, we can create complete automated control applications. The LabVIEW PID and Fuzzy Logic Toolkit help to deploy deterministic proportional integral derivative (PID) control algorithms to stand-alone embedded hardware targets. The implement single- or multi-channel PID control algorithms in hardware on NI FPGA-based hardware devices can be possible by using LabVIEW FPGA Module along with PID and Fuzzy Logic Toolkit [11].

Key features of NI LabVIEW PID and Fuzzy Logic Toolkit have following:

1. Integrate P, PI, PD, and PID control algorithms into LabVIEW applications.

2. Use the Fuzzy System Designer and Fuzzy Logic VIs to design, adapt, and control fuzzy systems.

3. Auto tune gains online and offline based on different algorithms to improve control performance.

4. Take advantage of advanced features including gain scheduling and integral antiwindup.

2.3.3 FuzzyTECH

For FuzzyTECH is a leading family of software development tools for fuzzy logic and neural-fuzzy systems [12]. The software supports both English and German languages. Moreover, the documentation is available in the English, German, and Mandarin Chinese languages. FuzzyTECH families of particular interest here include:

- FuzzyTECH Editions for General Target Hardware including fuzzyTECH Professional and fuzzyTECH online editions.

- FuzzyTECH MCU-HC05/08 Edition: Supports all microcontrollers of the 68HC05 and 68HC08 families from Motorola.

- FuzzyTECH MCU-HC11/12 Edition: Supports all microcontrollers of the 68HC11xx and 68HC12xx families from Motorola. Utilizes the special fuzzy logic instruction set of the HC12. RTRCD functionality included.

- FuzzyTECH MCU-MP Edition: Supports all microcontroller families of Microchip Technologies Inc. (PIC16C5X, PIC16CXX, and PIC17CXX).

- FuzzyTECH MCU-51 Edition: Supports all microcontrollers of the 8051 and 80251 families. Special libraries for 80517 included. RTRCD functionality included.

- FuzzyTECH MCU-96 Edition: Supports all microcontrollers of the MCS®-96 family from Intel (8096, 80C196, ...). RTRCD functionality included.

- FuzzyTECH MCU-166 Edition: Supports all microcontrollers of the C16x family from Siemens. RTRCD functionality included.

- FuzzyTECH MCU-320 Edition: Supports all digital signal processors (DSP) of the TMS-320 C2x/3x/4x and 5x families from Texas Instruments.

2.3.4 FIDE

Fuzzy Inference Development Environment (FIDE) is a development environment for fuzzy logic systems from Aptronix, Inc., Santa Clara, USA [13]. The software can automatically generate fuzzy algorithms in Java, ANSI C, MATLAB M-file, and assembly code for a variety of microcontrollers. Chips supported include: Motorola: 68HC05, 6805, 68HC08, 68HC11, 68HC12, 68HC33x, Intel 80C196 and 80C296 architectures, Siemens:

Free demos of FIDE and example files are available for downloading. The demo allows the creation and simulation of fuzzy logic models and it helps to learn about the fuzzy inference process. The demo is useful for educational purposes and as a preview of the full version. The compiler and code generator are disabled in the production environment of demo version.

2.3.5 FLDE

Fuzzy Logic Development Environment (FLDE) is a tool specifically for embedded systems with two features. The first is portable ANSI C code generation which is a self-contained, strictly deterministic, re-entrant subset of C that supports all standard C data types, allowing the code to be targeted to wide range of microcontrollers. The second is a debugging facility which allows embeddable source-level debugging of compiled fuzzy logic and features tracing, break-points, watch, and profiling of all fuzzy logic entities. Embedded fuzzy logic programs which may be integrated with other C user code can thus be debugged at the fuzzy logic level.

2.3.6 FLINT (Fuzzy Logic Inferencing Toolkit)

Traditional expert systems work on the basis that everything is either true or false, and that any rule whose conditions are satisfiable is useable, i.e. its conclusion(s) are true. This is rather simplistic and can lead to quite brittle expert systems. FLINT provides support for where the domain knowledge is not so clearcut.

FLINT, a powerful sub-system which augments the decision-making power of both Prolog and Flex [14]. FLINT provides a comprehensive and versatile set of facilities for programmers who wish to incorporate uncertainty within their expert systems and decision support applications.

FLINT supports three treatments of uncertainty, namely: Fuzzy logic, Bayesian updating and Certainty factors. Flint does this by augmenting the normal backward-chaining rules of Prolog and, where Flex is present, by extending the KSL of Flex.

LPA's software solutions have been put to many applications throughout industry and research.:

- Environmental Modelling
- Fungus Identification
- Fire Training
- Management Consultancy
- Shift Allocation
- Image Recognition

III. EMBEDDED FUZZY CONTROLLER

In paper [15] for A Design Laboratory Testbed for Embedded Fuzzy Control for pressure control application based on Sugeno fuzzy model, Matlab software is used. Matlab has an additional capability of easily interfacing several types of data acquisition (DAQ) cards, which could then be used to complete the control loop between the plant and the controller. All the DAQ cards used in the design are manufactured by M/S Advantech.

The paper [16], presents an embedded fuzzy controller to regulate the pressure in a pilot air tank system. The control regulate pressure in a pilot pressure control plant using fuzzy algorithm is formulated using direct mamdani fuzzy sets, which control algorithm been discussed.

The paper [17] deals with one of frequently encountered tasks in process industry - water level control. Proportional Integral Derivative (PID) control is often used for this purpose. Since control parameters of PID controller are fixed and tank system is inherently nonlinear, PID controller should not be used on wider level range. The fuzzy controller is implemented based on mathematical model of tank and using MATLAB. The controller is implemented on Friendly ARM - embedded computer. Arduino board is used as an acquisition board for collecting sensor data from tank system Festo Didactic DD 3100 and as a PWM signal generator for water pump control.

The paper [18] presents a new robust Fuzzy logic controller that extends the concepts of advanced process control in new directions by performing servo-tracking and disturbance rejection simultaneously. An attempt has been made to analyze the efficiency of an intelligent fuzzy controller (IFLC) on Continuous Stirred Tank Reactor (CSTR) Level loop. Analysis of the effects studied through computer simulation using Matlab/Simulink toolbox. Here the conventional PID controller parameters are designed based on Ziegler-Nicholas method and its servo & regulatory responses are compared with Fuzzy logic controller based on mamdani model. The real time implementation of the process is designed and implemented in LabVIEW using Data Acquisition Module.

In paper [19], the Water Level Control by fuzzy and neural network control algorithms were ported to a stand-alone VRP MTSC32 micro-controller. The main board of micro-controller is based on Texas Instruments' TMS320C32 DSP with a CAN bus communication port that facilitates the communication with a PC for monitoring online parameters. The control algorithms were developed with C language, complied with TI Compiler and run from the microcontroller

IV. CONCLUSION

In the present article we have made an attempt to address the system design software and hardware especially for creation of the fuzzy logic system. The researchers, academician should develop in-depth knowledge of the system domain for amalgamation with software support. The MATLAB have powerful simulation and rich in GUI and easy to use with fast development process, but its main disadvantage is that its high cost. NI LabVIEW supports lots of feature for real time hardware testing and embedded system design but it's also have high pricing. SCILAB is another tool similar to MATLAB available free of cost, but there is lack of product help as compared to MATLAB. LabVIEW, FUZZYTECH, FLDE can able to generate the embedded code for fuzzy logic. However, SCILAB is very attractive tool for academician and individual developers.

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