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FISLAB:
the Fuzzy Inference Tool-box
for
SCILAB

User's guide

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Contents

1 Scope and background

During a research in fuzzy logic (FL) tools for control engineering applications I discovered that some code was already developed and made available to the scientific community free of charge (web).

Often, during the first stages in the preparation of a project, engineers must prototype using the quickest, simplest and cheapest available solution. Nowadays, the free distributed software is reaching outstanding quality and it may start to present an alternative to expensive, hard to obtain, commercial packages.

Some fuzzy logic tool-boxes are available for commercial tools like MATLAB, Mathematica, Maple, etc. In most of the cases, these tool-boxes are freely distributed, but the software packages over which the tool-box runs are not. This represents a serious disadvantage to the fast prototype, newcomer, occasional developer or simply the student.

If a new free-of-charge fuzzy logic tool-box is developed this should be for an existing free-of-charge scientific software package. The goal is to provide the scientific community with an easy to use fuzzy logic tool-box for control engineering.

FISLAB runs over SCILAB. SCILAB is a scientific software package for numerical computations in a user-friendly environment. It is a MATLAB, MATRIXx alike software tool to solve problems of linear algebra, control engineering, signal processing, simulation, optimization, etc. SCILAB is developed by a prestigious French research institution called INRIA (Institute National de Recherche Informatique et en Automatique). **SCILAB is distributed freely** in source code format and as binary set. To know more about SCILAB, please refer to its web page at `http://www-rocq.inria.fr/scilab`).

2 What is FISLAB?

FISLAB is a fuzzy inference systems tool-box for SCILAB. FISLAB allows different arithmetic operators, fuzzification and defuzzification algorithm, implication relations, and different method of approximate reasoning such as Compositional Rule of Inference (CRI) and Approximate Analogical Reasoning Scheme based on Similarity Measure.

FISLAB is based on a MATLAB inference tool-box developed by Prof. Zadeh called FISMAT. For any queries about FISMAT, please enquire directly Prof.

Zadeh (Department of Electrical and Computer Engineering University of Queensland Qld., Australia, email: lotfia@s1.elec.uq.oz.au).

3 Requirements

To run FISLAB the following software is needed: SCILAB version 2.2 or above. The software has been tested in a PC running Linux, and in a SPARCStation 5 running SunOS.

4 Fuzzy logic in control engineering

4.1 What is fuzzy logic?

In what follows here I will try to give a mathematical explanation of the term fuzzy logic. This can serve as introduction to the new comer. More expert toolbox users could skip this part. This explanation tries to be simple, concise, and precise as much as I can.

Let's imagine the set U of all possible values of a particular variable x. This set U is called the Universe of Discourse of the variable x.

Let's consider a subset R of the previous universe U, such as $R \subset U$.

In a practical case U could be the set of all people in the planet. The subset R could be the subset of all rich man on Earth. Taking a particular element (man) H we want to know if H belongs to R or not. That is, we would like to know if H is a rich man or not.

Imagine that we would like to know what is the difference between a rich man an another man who is not rich. A good law could be the following: a person is rich if he/she has more than $100.000.000$ dollars in his/her bank account.

Under this classification a person with $99.999.999$ dollars could not be consider as rich.

But, for some persons the amount of $100.000.000$ dollars is the same as to have $99.999.999$ dollars.

This means that from a practical, human point of view everybody understands that to have $100.000.000$ dollars is the same as to have $99.999.999$ dollars.

To represent this type of knowledge it is necessary to develop a system which allow us to assign degrees of richness to the persons on the Earth. This system is called Fuzzy Set Theory. This theory establish a correspondence between the degree of membership and the element of the fuzzy set.

That is, in the case of the rich/poor person it will be possible to define the richness as a gradation in the interval $[0, 1]$ (to avoid normalizations). The degree of membership $= 0$ means a poor person while the degree of membership $= 1$ means a rich person. Any richness in between will mean partial money in the bank account.

Implicitly the following relationship is being established:

$$\mu_{rich}(x) = \begin{cases} 0 & \text{si } x < 50^3 \\ (x - 50^3)/(10^6 - 50^3) & \text{si } 50^3 \leq x \leq 10^6 \\ 1 & \text{si } x > 10^6 dollars. \end{cases} \tag{1}$$

In general the correspondence can be expressed as follows:

$$\mu(x) = \begin{cases} 0 & \text{si } x < \alpha \\ (x - \alpha)/(\beta - \alpha) & \text{si } \alpha \leq x \leq \beta \\ 1 & \text{si } x > \beta \end{cases} \tag{2}$$

Over the definitions of the fuzzy sets it is possible to define operations: *Union*, la *Intersection* y el *Complementary*.

Definition. Given a universe of discourse U and an element e of this universe, the UNION of two fuzzy sets A and B, such us $A, B \subset U$ is expressed as $A \cup B$ and is defined as

$$(A \cup B)(e) = max(A(e), B(e)) \text{ where } e \in U \tag{3}$$

where the result is another fuzzy set. This functions corresponds to the crisp operator OR.

Similarly it is possible to define for the intersection:

Definition. Given a universe of discourse U and an element e of this universe, the INTERSECTION of two fuzzy sets A and B, such us $A, B \subset U$ is expressed as $A \cap B$ and is defined as

$$(A \cap B)(e) = min(A(e), B(e)) \text{ where } e \in U \quad (4)$$

where the result is another fuzzy set. This functions corresponds to the crisp operator AND.

Finally for the complementary:

Definition. Given a universe of discourse U and an element e of this universe, the COMPLEMENTARY of a fuzzy sets A, such us $A \subset U$ is expressed as $\bar{A}$ and is defined as

$$\bar{A}(e) = 1 - A(e) \text{ donde } e \in U \quad (5)$$

where the result is another fuzzy set. This functions corresponds to the crisp operator NOT.

4.2 Inference Engines

With the previous definitions and mathematical expression little can be done.

A fuzzy logic controller is composed of a fuzzyfication subsystem, an inference engine, and a defuzzyfication subsystem. A fuzzy logic system represents an intelligent knowledge based controller which consists of a data base of rules and the definitions of the fuzzy sets. The plant state is normalized to be able to be fuzzificated into the appropriate fuzzy sets. The inference engine fires the rules using the membership functions over the fuzzy sets and produces a result that has to be defuzzificated. Finally the output is denormalized in order to be applicable to the control action required.

Let's image a fuzzy logic based control system. This system has a set of rules (premises) that will define the behaviors if the controller.

The process of calculating control actions over the fuzzy controller is called inference. The inference over a rule or set of rules realizes several operations in sequence.

① determination the degree of membership of a linguistic variable over a fuzzy set. This is done for each of the variable in the considered rule.

② resolution of all operations inside the rule considered. Computation of unions, intersections, etc.

③ evaluation of the result, using some of the proposed methods.

Each premise is a rule of the type:

$$An_1 \text{ operation } Ant_2 \longrightarrow C \quad (6)$$

where An are the antecedents and C is the consequent of the rule. *operation* is any of the previously explained operations.

Fuzzy logic has shown to be specially suitable in occasions when the plant is not static but changes with time (or differs slightly among very similar systems) or when the characteristics of the plant are not totally known or understood at the time when the controller was designed or when the control actions and goals were not precisely defined.

Fuzzy logic has been proven to be adequate to solve control problems not in the *best* way but just in a *suitable* way within the required limits and giving satisfactorily performance.

5 How FISLAB works

FISLAB is heavily based on FISMAT. The data structures are the same, the fuzzy inference system is the same and the fuzzyfication and defuzzyfication process are very similar. As we will see, the main differences are in the way FISLAB represents the output and results of the defuzzyfication process.

FISLAB is a fuzzy inference system composed of the following subsystems:

- a fuzzyfication subsystem,
- a knowledge data base,
- a fuzzy reasoning mechanism (sometimes known as a fuzzy logic controller),

- a defuzzyfication subsystem,

The tool-box user starts constructing the universes of discourse for the variables of the controller. Then the rules data base. Finally the user will fire the different inference engines provide in the tool.

6 Available scripts

The following scripts are available in this version of FISLAB:

6.1 bell_1

File: bell_1.sci

Description: It is a generalized bell-shaped membership function with three parameters a, b, c. Returns a matrix y with the same size as x; each element of y is a grade of membership.

This function implements the following formula:

$$y = e^{((-\frac{x-c}{a})^2)^b} \tag{7}$$

6.2 bell_2

File: bell_2.sci

Description: It is a generalized bell-shaped membership function with three parameters a, b, c. Returns a matrix y with the same size as X; each element of Y is a grade of membership.

This function implements the following formula:

$$y = \frac{1}{1 + ((\frac{x-c}{a})^2)^b} \tag{8}$$

This function is Copyright (c) 1993 by Jyh-Shing Roger Jang, U. C. Berkeley, jangeecs.berkeley.edu

6.3 cri

File: cri.sci

Description: This function is the famous Compositional Rule of Inference, based on a fuzzy relation matrix R and observation vector Ap. The function returns a decision vector Bp using the Zadeh's inference CRI.

6.4 fzfir

File: fzfir.sci

Description: The operation fuzzification has the effect of transforming a classical set or a crisp value Ao into a fuzzy set Ap. The fuzzifier developed in this function can handle five different types of membership functions for different crisp values Ao. The universe must be expressed an a ascending vector U.

6.5 initialize

File: initialize.sci

Description: This is not a function. This is a file in charge of the initialization of FISLAB function in SCILAB. In version 1.0 FISLAB is interpreted not compiled.

6.6 intersec

File: intersec.sci

Description: This function calculates the intersection of matrix of fuzzy values A and B over the same universe of discourse.

6.7 intrdemo

File: intrdemo.sci

Description: This is not a function. This file contains a demo file for the tool-box. This is the file which should be executed when firing the demo.

6.8 mfplot

File: mfplot.sci

Description: This is a function to plot the membership functions defined on a fuzzy matrix of fuzzy value A over universe U. This function plots the rules given for a rule base with maximum 4 inputs and one output. This function is very useful for display purposes.

6.9 moreless

File: moreless.sci

Description: This function operates as a quantifier on a matrix of fuzzy values A, and will return the membership function related to more or less A.

6.10 not

File: not.sci

Description: This function operates as a quantifier on matrix of fuzzy values A, and will return the membership function related to the function not of A.

6.11 rulebase

File: rulebase.sci

Description: This function allow to create a membership function definition for a production rules with maximum 4 inputs and one output. The inputs are U and V as universe of antecedent and consequent respectively. This routine allows the use of different shapes in the mathematical expression of the membership functions. The parameters governing the shape are N and M. When $N = 1$ the routine uses the exponential Gaussian function; when $N = 2$ the routine uses the Gaussian function; when $N = 3$ (M=3) the routine function uses the trapezoidal function; finally, when $N = 4$ (M=4) the routine function uses the sigmoid function. The parameters related to any types of membership functions are vectors the vector labeled as $a, b, c, ahat, bhat$, and $chat$. The length of these vectors defines the number of rules in the rule-base.

6.12 sigmoid

File: sigmoid.sci

Description: This function is the sigmoidal membership function with two parameters a and c. This function returns a matrix Y with the same size as X; each element of Y is a grade of membership. This function has as defaults values for a and c, 1 and 0 respectively.

6.13 trapeze

File: trapeze.sci

Description: This function implements the trapezoid as the membership function for a given matrix X. The function has as parameters a, b and c which are the slope, the flatness and the center of the trapezoid. This function has as defaults values for c and b, 0 and 1 respectively.

6.14 union

File: union.sci

Description: This function calculates the union of a matrix of fuzzy values A and B over the same universe of discourse. The matrices A and B are matrices of membership functions. The output of this function is the grade of membership function $A1$ and $A2$ over the same universe.

6.15 very

File: very.sci

Description: This function operates as a quantifier on matrix of fuzzy values A, and will returns the membership function related to very A.

7 More to come

This is the version 1.0 of the tool-box. There will be bugs, problems, missing documentation, etc. For any problems, drop me some lines. I will try to answer.

Here follow a preliminary list with functions to be implemented in the next release.

7.1 centre

File: centre.sci

Description: This function returns the center of matrix of fuzzy value B over universe V. The center C is a vector the same number on membership functions in B (the same number of row).

7.2 comple

File: comple.sci

Description: This function operates as a quantifier on matrix of fuzzy values A, and will returns the membership function related to the complement of A.

7.3 go_panel

File: go_panel.sci

Description: This function is a very useful manual tuning of different types of membership functions. This routine shows the effects of different quantifiers. The routine allows the operator to select a desired membership style and change its parameters on the fly. After closing the window, parameters a, b, c along X as universe and Y as grade of membership are available in the working space.

7.4 grademf

File: grademf.sci

Description: This function implements the *Grade of Membership Function*: Consider a matrix of fuzzy values A over universe of U. This function returns the grade of membership function corresponding to each fuzzy sets (Rows of matrix A) for observation non fuzzy/crisp value Ao.

7.5 integral

File: integral.sci

Description: This function returns the integral of matrix of fuzzy value B over universe V. The integral I is a vector the same number on membership functions in B (the same number of row).

7.6 reshape

File: reshape.sci

Description: Returns the m-by-n matrix y whose elements are taken column wise from x.

8 More Information Out There

This section contains a list of useful URLs. Those sites contain good information about fuzzy logic and control engineering related subjects.

➨ AI Repository files
file://ftp.cs.cmu.edu:/user/ai
➨ CMU Artificial Intelligence Repository
http://www.cs.cmu.edu:8001/Web/Groups/AI/html/repository.html
➨ What is Fuzzy Logic
file://ftp.essex.ac.uk/pub/robots
➨ FAQs
file://ftp.bath.ac.uk/info/faqs
➨ IEEE fuzzy 94
file://achilles.doc.ic.ac.uk/imported/pisa/
➨ Inference Engine Documentation
file://ftp.cfi.waseda.ac.jp/comp.archives/comp.ai.fuzzy

- Articles, bibliography
file://ftp.cfi.waseda.ac.jp/pub3/fj/fj.sources/lib
- Fuzzy-NN Bibliography
file://earth.csie.ntu.edu.tw/pub/doc/site/ftp.ira.uka.de/pub/bibliography/Ai
- Solomon (Artificial Intelligence Biblio)
file://solomon.technet.sg/pub/NUS/z7/csbiblio/Ai
- Quadralay Corporation
http://www.quadralay.com/www/Fuzzy/Fuzzy.html
- Fuzzy Repository
file://ntia.its.bldrdoc.gov

9 Review of Bibliography

This section gives a review of useful bibliography about FL and its applications. The order is more or less alphabetical.

The doctoral thesis by Abihana [1] is a pretty good booklet on how to design fuzzy controllers. Very well written but difficult for beginners, is the article by Baldwin [2]. The work of Berenji includes also neural networks [3] [4], and space applications [5]. The work of Braae bring attention on how to select the parameters of a fuzzy based controller [6]. Exceptional valued doctoral thesis of one of the FL applications in space science by Brown [7]. Buckley gives us the paradigm of the universal FL controllers in [8]. Real time FL control is brought by Chiu in [9]. FL for spacecraft control is analyzed by Daley in [10] and [11]. An obliged reference for all learners: a fantastic book written by Drianov in [12]. A classic of Dubois in [13]. Elkan writes **against** FL in [14]; this is a must-to-read reference. Complex systems are analyzed by Filev in [15]. Fung discusses fuzzy optimal controller in [16]. [17] gives us the simplified fuzzy ARTMAP by Kasuba. A good analysis of FL controllers is given by Kickert in [18]. The difficult multi variable fuzzy controller design is explained by King in [19]. Knapp writes about another space application of FL in his doctoral thesis [20]. Do not miss the already classic reference of Lee in [21]. Also, other classics by Mamdani in [22], [23], and [24]. McNeill give us a very good practical approach of FL in [25]. Another application: fuzzy navigation of a mobile robot by Song in [26]. And another, about a fuzzy logic automatic carrier landing system for a fighter airplane by Steinberg in [27]. The subject of fuzzy identification is well explained by Takagi in [28]. In [29] Tso explores the effective development of FL controller, and in [30] he talks about autonomous vehicles using FL. Yager has been written a good amount of articles about FL: some of them are [31], [32], [33], etc. And finally the job of Zadeh in [34], [35].

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