Data Mining and Soft Computing

Session 6.

Genetic Fuzzy Systems II

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Summary

1. Introduction to Data Mining and Knowledge Discovery
2. Data Preparation
3. Introduction to Prediction, Classification, Clustering and Association
4. Introduction to Soft Computing. Focusing our attention in Fuzzy Logic and Evolutionary Computation
5. Soft Computing Techniques in Data Mining: Fuzzy Data Mining and Knowledge Extraction based on Evolutionary Learning
7. Some Advanced Topics: Classification with Imbalanced Data Sets, Subgroup Discovery, Data Complexity

Outline

✓ Brief Introduction to Genetic Fuzzy Systems

✓ Tuning Methods: Basic and Advanced Approaches

✓ Genetic Fuzzy Systems Application to HVAC Problems

✓ Concluding Remarks
GENETIC FUZZY SYSTEMS: APPLICATION TO HVAC PROBLEM

Heating Ventilating and Air Conditioning Systems: Problem

GENESYS

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Fuzzy Logic Controllers for Energy Efficiency Consumption in Buildings

Heating Ventilating and Air Conditioning Systems: Problem

- Energy consumption in buildings is the 40% of the total and more than a half is for indoor climate conditions
- The use of specific technologies can save up to a 20% of the energy consumption
- The use of appropriate automatic control strategies could result in energy savings ranging 15-85 %
- Moreover, in current systems, several criteria are considered and optimized independently without a global strategy
Fuzzy Logic Controllers for Energy Efficiency Consumption in Buildings

Generic Structure of an Office Building HVAC System

- It maintain a good thermal quality in summer and winter
- It dilutes and removes emissions from people, equipment and activities and supplies clean air
Fuzzy Logic Controllers for Energy Efficiency Consumption in Buildings

Initial Data Base

17 Variables
Fuzzy Logic Controllers for Energy Efficiency Consumption in Buildings

Initial fuzzy sets

V1: PMV
V2: PMV_t-1
V3: Thermal preference
V4: Tout-Tin
V5: Required heat
V6: CO2
V7: dCO2/dt
V8: Air quality preference
V9: Integral of PMV
V10: Integral of energy consumption
V11: Thermal/Energy priority
V12: Ventilation/Energy priority
V13: Valve old position
V14: Valve new position
V15: Fan coll speed
V16: Old extract fan speed
V17: New extract fan speed
Fuzzy Logic Controllers for Energy Efficiency Consumption in Buildings

Initial Rule Base and FLC Structure

172 Rules

Module 1a1: Thermal Demands
Module 1a2: Thermal Preference
Module 1b: Air Quality Demands
Module 2: Energy Priorities
Module 3a: Required HVAC System Status
Module 3b: Required Ventilation System Status
Fuzzy Logic Controllers for Energy Efficiency Consumption in Buildings

Layer 1: System Demands
- Module 1a₁: Thermal Demands
- Module 1a₂: Thermal Preference
- Module 1b: Air Quality Demands

Layer 2: Priorities
- V3: Thermal preference
- V4: Tout-Tln
- V9: Integral of PMV
- V10: Integral of energy consumption

Layer 3: Control Decisions
- V6: CO₂
- V7: dCO₂/dt
- V8: Air quality preference
- V12: Ventilation/Energy priority
- V13: Valve old position
- V14: Valve new position
- V15: Fan coil speed
- V16: Old extract Fan Speed
- V17: New extract fan speed
Fuzzy Logic Controllers for Energy Efficiency Consumption in Buildings

Representation of the Test Cells

- Volume: 30 or 60 m³
- Full control of temperature range (-15/45°C).
- Full control of relative humidity (10/90%).
- Maximum heating/cooling power: 48 kW.
- Fully configurable test cells.
- Equipped with various sensors for indoor climate evaluation: air flow velocity, relative humidity, CO₂ concentration, etc.

Two adjacent twin cells were available

A calibrated and validated model of this site was developed to evaluate each FLC
Fuzzy Logic Controllers for Energy Efficiency Consumption in Buildings

- **Goal:** multi-criteria optimization of an expert FLC for an HVAC system: reduction of the energy consumption but maintaining the required indoor comfort levels

  \[ O_1 \text{ Upper thermal comfort limit}^3: \text{if } PMV > 0.5, O_1 = O_1 + (PMV - 0.5). \]

  \[ O_2 \text{ Lower thermal comfort limit: if } PMV < -0.5, O_2 = O_2 + (-PMV - 0.5). \]

  \[ O_3 \text{ IAQ requirement: if CO}_2\text{ conc. > 800 ppm, } O_3 = O_3 + (CO_2 - 800). \]

  \[ O_4 \text{ Energy consumption: } O_4 = O_4 + \text{ Power at time } t. \]

  \[ O_5 \text{ System stability: } C_5 = C_5 + \text{ System change from time } t \text{ to } (t - 1). \]

- **INITIAL RESULTS**

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Improving the FLC Performance

The main objective was the reduction of the energy consumption (10%), improving the stability of the controller, maintaining the required indoor comfort levels.

- Genetic tuning of the Data Base
  - Local modification of the membership function definition points
GFS Models for Fuzzy Control of HVAC Systems: Genetic Tuning

Objectives (to be minimized)

\( O_1 \) Upper thermal comfort limit \(^3\): \( if \ PMV > 0.5, O_1 = O_1 + (PMV - 0.5) \).

\( O_2 \) Lower thermal comfort limit: \( if \ PMV < -0.5, O_2 = O_2 + (-PMV - 0.5) \).

\( O_3 \) IAQ requirement: \( if \ CO_2 \ conc. > 800ppm, O_3 = O_3 + (CO_2 - 800) \).

\( O_4 \) Energy consumption: \( O_4 = O_4 + \) Power at time \( t \).

\( O_5 \) System stability: \( C_5 = C_5 + \) System change from time \( t \) to \( (t - 1) \).

- Expert knowledge as objective weights:

\[
\begin{align*}
    w_1^o &= w_2^o = 0.0041511; \quad w_3^o = 0.0000022833 \\
    w_4^o &= 0.0000017832; \quad w_5^o = 0.000761667
\end{align*}
\]
GFS Models for Fuzzy Control of HVAC Systems: Genetic Tuning

Problem Restrictions

- Different-Criteria-Based Evaluation

- Multiple Criteria Algorithms:
  - Multi-objective approach
  - Aggregation approach

\[ F(x) = w_1 \cdot f_1(x) + \ldots + w_n \cdot f_n(x) \]

\[ \sum w_i = 1, \quad 0 \leq w_i \leq 1, \quad i = \{1, \ldots, n\} \]

Since trusted weights exist:
- The problem solving is easier
- Quicker algorithms can be designed
GFS Models for Fuzzy Control of HVAC Systems: Genetic Tuning

Problem Restrictions

- The controller accuracy is assessed by means of simulations which approximately take 3-4 minutes.

Efficient tuning methodologies:

- Local adjustment of each tuned parameter
- Steady-State Genetic Algorithms: quick convergence
  
  2000 evaluations $\Rightarrow$ 1 run takes approximately 4 days

- Considering a small population (31 individuals)
A real coded steady-state genetic algorithm for local tuning of the membership function definition points.

- Two individuals are selected to be crossed and four descendents are obtained.
- The two best offspring are included in the population replacing the two worst individuals if they are better adapted than the latter.
- A restarting approach is considered if the population converges.
GFS Models for Fuzzy Control of HVAC Systems: Genetic Tuning

Data Base Tuning: Algorithm (1)

- **Coding Scheme** (with $n$ variables and $L$ labels):

  $$C_i = \left( a_1^i, b_1^i, c_1^i, \ldots, a_{L_i}^i, b_{L_i}^i, c_{L_i}^i \right), \quad i = 1, \ldots, n$$

  $$C = C_1 C_2 \ldots C_n$$
Data Base Tuning: Algorithm (2)

Genetic operators:

- The max-min-arithmetical crossover. From parents $C'$ and $C''$, four offspring are obtained:

  $C'' = (c_1, \ldots, c_k, \ldots, c_H)$
  $C''' = (c'_1, \ldots, c'_k, \ldots, c'_H)$

  $C'_1 = aC'' + (1-a)C''$
  $C'_2 = aC'' + (1-a)C''$
  $C'_3$ with $c'_3 = \min\{c_k, c'_k\}$
  $C'_4$ with $c'_4 = \max\{c_k, c'_k\}$

- Michalewicz’s non-uniform mutation.
### GFS Models for Fuzzy Control of HVAC Systems: Genetic Tuning

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GFS Models for Fuzzy Control of HVAC Systems: Genetic Tuning

Tuned Data Base
GFS Models for Fuzzy Control of HVAC Systems:

- Initial fuzzy sets
- Tuned fuzzy sets

- V1: PMV
- V2: PMV t-1
- V3: Thermal preference

- V4: Tout-TIn
- V5: Required heat

- V6: CO2
- V7: dCO2/dt
- V8: Air quality preference

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GFS Models for Fuzzy Control of HVAC Systems: Genetic Tuning

Tuning Evolution Chart

- Fitness
- PMVsup/inf/CO2
- Energy
- Stability

Improvement (%)

Generation

(0.81,131) (11.46,250) (-12.13,402) (-15.86,131)
(-19.44,250) (-17.79,402) (-19.66,500)
(-1.88,500)
GENETIC RULE WEIGHT DERIVATION AND RULE SELECTION

OBJECTIVE OF GETTING:

- a subset of rules presenting good cooperation
- the weights associated to rules

IF \( X_1 \) is \( A_1 \) and ... and \( X_n \) is \( A_n \) \( \text{T} \)HEN \( Y \) is \( B \) with \([w]\),
\[ w \in [0,1] \]

We use a steady-state genetic algorithm with a double coding scheme.
Weight Learning: Algorithm

- A double coding scheme \((C = C_1 + C_2)\):

  - \(C_1\): The coding scheme generates binary-coded strings of length \(m\) (number of single rules in the previously derived rule set):
  
  - \(C_2\): The coding scheme generates real-coded strings of length \(m\)

  Each gene represents the weight used in the corresponding rule

  \[
  C_1^{11} \cdots \cdots C_1^{m} \quad C_2^1 \quad C_2^2 \cdots \cdots C_2^{m-1} \quad C_2^{m}
  \]

  - Two points crossover
  - Flip a gene at random
  - BLX-alpha + Arithmetical crossover
  - Random mutation
GFS Models for Fuzzy Control of HVAC Systems: Genetic Rules Selection with Weights

### Obtained Results

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GFS Models for Fuzzy Control of HVAC Systems: Genetic Rules Selection with Weights

Weighted Rule Base
GFS Models for Fuzzy Control of HVAC Systems:

- V1: PMV
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Layer 1: System Demands
- Module 1a₁: Thermal Demands
- Module 1a₂: Thermal Preference
- Module 1b: Air Quality Demands

Layer 2: Priorities

Layer 3: Control Decisions
- Module 2: Energy Priorities
- Module 3a: Required HVAC System Status
- Module 3b: Required Ventilation System Status

#R = 102
GFS Models for Fuzzy Control of HVAC Systems: Genetic Lateral Tuning and Rules Selection

New coding schemes: 2- and 3-tuples:


- **2-tuples**: label id. $i$ and a displacement parameter $\alpha_i \in [-0.5, 0.5]$

- New rule structure:
  
  IF $X_1$ IS $(S^1_i, \alpha_1)$ AND ... AND $X_n$ IS $(S^n_i, \alpha_n)$ THEN $Y$ IS $(S^y_i, \alpha_y)$
# GFS Models for Fuzzy Control of HVAC Systems: Genetic Lateral Tuning and Rules Selection

## Genetic Lateral Tuning

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### GFS Models for Fuzzy Control of HVAC Systems: Genetic Lateral Tuning and Rule Selection

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*Table Note:* The highlighted rows indicate the models with the lowest energy consumption and highest stability.
GFS Models for Fuzzy Control of HVAC Systems: Genetic Lateral Tuning and Rules Selection

Tuned Data Base (GL-S₁):
GFS Models for Fuzzy Control of HVAC Systems: Genetic Lateral Tuning and Rules Selection

Selected Rule Base (GL-S1):
GFS Models for Fuzzy Control of HVAC Systems: Genetic Lateral Tuning and Rules Selection

⇒ The combination of lateral tuning (global and local) and rules selection allow us to eliminate redundant rules, tuning the parameters, and getting a high behaviour reducing the energy consumption and with good stability.

⇒ ¿What is the reason of the good behavior?

The SBRDs tuning for an HVAC system is a large scale problem with 17 variables and a lot of parameters, and the use of 1 parameter per label allows us to reduce the search space, allowing to get a better optimal local than using 3 parameters per label.
GFS Models for Fuzzy Control of HVAC Systems

Bibliography


Outline

✓ Brief Introduction to Genetic Fuzzy Systems
✓ Tuning Methods: Basic and Advanced Approaches
✓ Genetic Fuzzy Systems Application to HVAC Problems
✓ GFSs: Current Trends and Prospects
✓ Concluding Remarks
Currents Trends and Prospects

- Multiobjective genetic learning of FRBSs: interpretability-precision trade-off.
- GA-based techniques for mining fuzzy association rules and novel data mining approaches.
- Learning genetic models based on low quality data (noise data and vague data).
- Genetic learning of fuzzy partitions and context adaptation.
- Genetic adaptation of inference engine components.
- Revisiting the Michigan-style GFSs.
Multiobjective genetic learning of FRBSs: interpretability-precision trade-off.

Fig. Non-dominated fuzzy systems
Currents Trends and Prospects

- GA-based techniques for mining fuzzy association rules and novel data mining approaches.
- Genetic learning of fuzzy partitions and context adaptation.

Currents Trends and Prospects

- GA-based techniques for mining fuzzy association rules and novel data mining approaches.
- Genetic learning of fuzzy partitions and context adaptation.

Fig. 1. Scheme for discovering both useful fuzzy association rules and suitable MFs.

Currents Trends and Prospects

- GA-based techniques for mining fuzzy association rules and novel data mining approaches.
- Genetic learning of fuzzy partitions and context adaptation.

Census

Fig. 9. Relationship between large 1-itemsets and minimum support.

Currents Trends and Prospects


Fig. 10. MFs with/without lateral displacements (black/grey) and displacements of the MFs obtained by t terms.

Classic Fuzzy Association Rule:
If number of children is Low and hours head worked last week is Low then head’s personal income is Low
Factor of confidence 0.87

Rule with 2-Tuples Fuzzy Linguistic Representation:
If number of children is (Low, −0.16) and hours head worked last week is (Low, −0.06) then head’s personal income is (Low, 0.1)
Factor of confidence 0.99
Currents Trends and Prospects

Fig. 15. Relationship between the number of fuzzy association rules and the confidence threshold along with different minimum supports.

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- Learning genetic models based on low quality data (noise data and vague data).
- Genetic adaptation of inference engine components.
- Revisiting the Michigan-style GFSs.
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- **Interpretability quality:** associated to the meaning of the labels and the size of the rule base

**Interpretability considerations: semantic criteria**

- **Semantics:** the study of meanings

  - **Distinguishability:** Each linguistic label has semantic meaning
  - **Number of elements:** Compatible with human capabilities
  - **Coverage:** Any element belongs to at least one fuzzy set
  - **Normalization:** At least one element has unitary membership
  - **Complementarity:** For each element, the sum of memberships is one
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- **Interpretability quality**: associated to the meaning of the labels and the size of the rule base

**Interpretability considerations: syntactic criteria**

- **Completeness**: for any input, at least one rule must fire
- **Rule-base simplicity**: Set of rules as small as possible
- **Rule readability**: small number of conditions in rule antecedents
- **Consistency**: rules firing simultaneously must have similar consequents
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- **Interpretability quality:** associated to the meaning of the labels and the size of the rule base

Strategies to satisfy interpretability criteria:

- Linguistic labels shared by all rules
- Normal, orthogonal membership functions
- Don’t care conditions
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- **Interpretability quality:**

What is the most interpretable rule base?
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- New data mining tasks: frequent and interesting pattern mining, mining data streams, etc
- Dealing with high dimensional data sets
Outline

✓ Brief Introduction to Genetic Fuzzy Systems

✓ Tuning Methods: Basic and Advanced Approaches

✓ Genetic Fuzzy Systems Application to HVAC Problems

✓ GFSs: Current Trends and Prospects

✓ Concluding Remarks
The hybridization between fuzzy systems and GAs in GFSs became an important research area during the last decade. GAs allow us to represent different kinds of structures, such as weights, features together with rule parameters, etc., allowing us to code multiple models of knowledge representation. This provides a wide variety of approaches where it is necessary to design specific genetic components for evolving a specific representation.

Nowadays, it is a mature research area, where researchers need to reflect in order to advance towards strengths and distinctive features of the GFSs, providing useful advances in the fuzzy systems theory.