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A Review on Cuckoo Search Algorithm for Fuzzy Rule Base Generation

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Abstract: Fuzzy Classifiers are an powerful class of fuzzy systems. Evolving fuzzy classifiers from numerical data has assumed lot of remarks in the recent past. This paper proposes a method of evolving fuzzy classifiers using a three-step technique. In the first step, a modified Fuzzy C–Means Clustering technique is applied to generate membership functions. In the next step, rule base are generated using cuckoo search algorithm. The third step was used to reduce the size of the generated rule base. By this method rule explosion issue was successfully tackled. The proposed method was applied using MATLAB. The approach was tested on a very well-known multi-dimensional classification data sets i.e. Iris Data. The performance of the proposed method was very encouraging. Further the algorithm is implemented on a Mamdani type control model for a battery charger data set. This integrated approach was able to evolve model quickly.

Keywords: Rule Base, Fuzzy C, CSA.

I. INTRODUCTION

The theory of fuzzy sets and fuzzy logic was introduced by Lotfi A. Zadeh through his seminal paper in 1965 [1]. Both these, fuzzy set theory and fuzzy logic is a powerful method for dealing with imprecision and nonlinearity in an efficient way [2], [3]. As the need of fuzzy set theory is concerned, there are numerous situations in which classical set theory of 0 and 1 is not sufficient to describe human reasoning. Thus, for such situations we need a more appropriate theory that can also define membership grades in between 0 and 1 thereby providing better results in terms of human reasoning. Fuzzy set theory helps in solving this problem.

Fuzzy set theory leads to the development of fuzzy logic-based systems. These systems are capable of making a decision on the basis of intelligence or knowledge provided to the system through rule bases. As a proper combination of input is given to the system, system on the basis of knowledge embedded into it in the form of rules makes a decision and processes those inputs. As the intelligence of these systems depends upon rule base, these systems are also called as Fuzzy Rule Based Systems. These systems have been successfully applied to a huge range of problems from different areas presenting uncertainty in different ways. These FRBS„s can be categorized as data driven systems and knowledge-based systems. There are two ways of providing knowledge to the systems. In first type of systems called data driven systems to automatically generate the rule base, a number of classical approaches like Hong and Lee„s Algorithm [9], Wang and Mendel Algorithm [4], Online Learning Algorithm [13], Multiphase Clustering Approach [14] and soft computing techniques like Artificial Neural Networks Genetic Algorithm Swarm Intelligence based techniques, Ant Colony Optimization, Particle Swarm Optimization, Biogeography based Optimization, Big Bang – Big Crunch Optimization technique are available in the literature.

In knowledge driven modeling, the rule base is provided by an expert who has the complete knowledge of the domain while in second type of models called data driven models, this rule base is generated from available numerical data.

This paper is based on an integrated approach that makes use of a modified Fuzzy C–Means Clustering approach (FCM) and Cuckoo Search Algorithms. The approach was implemented in MATLAB for fuzzy classification problems of Iris data, and Battery Charger data (control problem). A system was evolved using set of training examples and systems performance was then evaluated using test data set for the given system. The system performances were evaluated in terms of Average Classification Rate (for classification problems) and Mean Square Error (for control problem).

The paper is arranged in a following way: Section I contains introduction of paper. Section II introduces Fuzzy Logic Based Systems. Section III discusses the proposed integrated approach and CS method for rule base generation. In section IV the result analysis along with the comparative study for above mentioned standard data sets are shown and section V includes conclusions.

II. RELATED WORK

It is a proven fact now that fuzzy logic is a powerful problem-solving methodology with wide range of applications in industrial control, consumer electronics, management, medicine, expert systems and information technology. It provides a simple way to draw definite conclusions from vague, ambiguous or imprecise and incomplete information. It is a natural way of making a decision and is very close to the way the human beings think and make decisions even under highly uncertain environments.

P. Sandhu suggested that the automatic generation of fuzzy rule base from given numerical data using an ad-hoc classical approach named as Wang and Mendel Algorithm for Mamdani type systems is discussed. The rule base in a fuzzy logic system is composed of linguistic rules (IF-THEN statements) and is responsible for providing the necessary intelligence to the system.
The paper discusses two standard data sets; one is battery charger which is a control problem and iris data set which is a classification problem.
S. Kumar said that nature-inspired methodologies are currently among the most powerful algorithms for optimization problems. This paper presents a recent nature-inspired algorithm named Firefly Algorithm (FA) for automatically evolving a fuzzy model from numerical data. FA is a meta-heuristic inspired by the flashing behavior of fireflies. The rate and the rhythmic flash, and the amount of time form part of the signal system to attract other fireflies. The paper discusses fuzzy modeling for zero-order Takagi-Sugeno-Kang (TSK) type fuzzy systems. Simulations on two well-known problems, one battery charger that is a fuzzy control problem and another Iris data classification problem are conducted to verify the performance of above approach. The results indicate that the FA is a very promising optimizing algorithm for evolving fuzzy logic-based Systems as compared to some of the existing approaches.
P. Narulas addresses that fuzzy rule-based systems are a class of knowledge based systems. The intelligence of a fuzzy logic based system lies in its rule base. Two approaches can be found in the literature which are used for rule base generation. In the knowledge driven fuzzy models, the requisite rule base is provided by domain experts and knowledge engineers. In the data driven models, the rule base is generated from the available numerical data. As, the domain experts are difficult to find and the requisite knowledge extraction from the experts itself is a difficult task, the data driven modeling assumes significance. Fuzzy systems are used to model highly complex and highly nonlinear systems and under the circumstances, the rule base extraction problem becomes NP hard problem. When the problem is very complex, application of classical methods turns out to be very expensive computationally. One has to apply soft computing based methodology to extract a rule base from data. Neural networks, genetic algorithms, ant colony optimization and particle swarm optimization are some of the approaches, which can be found in the literature. In this paper, they present Biogeography Based Optimization (BBO) for the rule base generation of Mamdani type fuzzy logic based systems. Biogeography is the study of the geographical distribution of biological organisms. It is a burgeoning nature inspired technique to find the optimal solution of the problem. In BBO, habitats represent the problem solutions, and species migration represents the sharing of features between solutions according to the fitness of the habitats. The results indicate that the BBO is a very promising optimizing algorithm for evolving fuzzy logic based systems.
Shyi-Ming Chen discuss that fuzzy classification systems are important applications of the fuzzy set theory. Fuzzy classification systems can deal with perceptual uncertainties in classification problems. In recent years, many methods have been proposed to deal with fuzzy classification problems. In this paper, we present a new method to deal with the Iris data classification problem based on the concept of fuzzy compatibility relations for finding the cluster centers of training instances. The proposed method can get a higher average classification accuracy rate to deal with the Iris data classification problem than the existing methods.
Ahmed S. Tawfik revealed that cuckoo search is a nature-inspired metaheuristic algorithm, based on the brood parasitism of some cuckoo species, along with Lévy flights random walks. In this paper, a modified version is proposed, where the new solutions generated from the exploration and exploitation phases are combined, evaluated and ranked together, rather than separately in the original algorithm, in addition to imposing a bound by best solutions mechanism to help improve convergence rate and performance. The proposed algorithm was tested on a set of ten standard benchmark functions, and applied to a real-world problem of algorithmic trading systems optimization in the financial markets. Experimental analysis demonstrated improved performance in almost all benchmark functions and the problem under study.

III. FUZZY MODEL

A zero-order TSK fuzzy system. It is clear from the figure that such system consists of 4 major modules i.e. fuzzifier, rule composition module (fuzzy t-norm/s-norm), implication module (multipliers in this case), and defuzzification module.

In data driven modeling we first cluster the input data for all the input variables. The number of clusters represents membership functions for each input variables. Various techniques have been suggested in literature to partition universes of discourse of input and output variables. We use modified FCM [7] to partition the given data. The next step is to extract rule base from data.
In zero-order TSK model a rule is of the following form [1]:
R_k: If x_1 is A_{k1} and x_2 is A_{k2} and … and x_n is A_{kn}
Then y is R_kC, k = 1, 2, …,R

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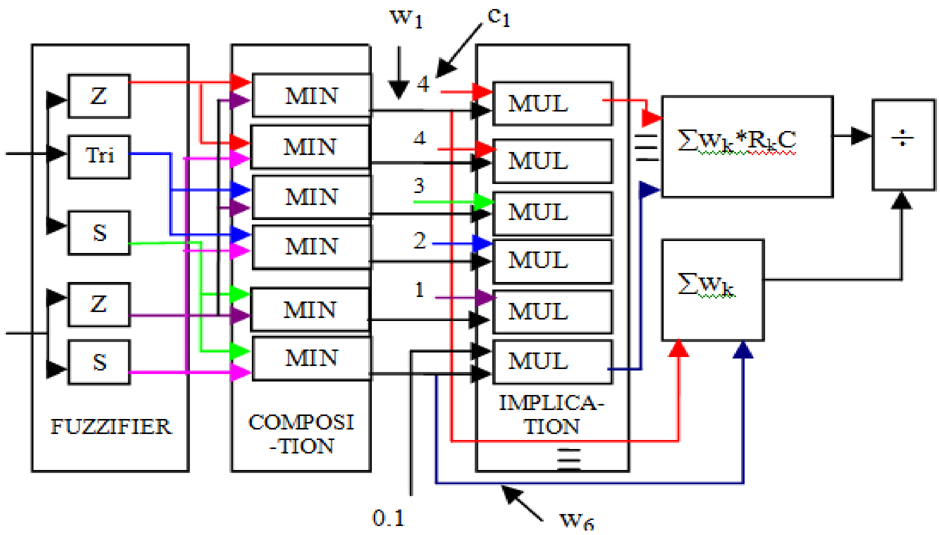

Figure 1: A zero-order TSK fuzzy system

Where R_kC are the consequent of k[th] rule. $x_1, x_2, \ldots, x_n$ and y are input and output variables respectively and $A_{k1}, \ldots, A_{kn}$ are linguistic labels, each one of them having associated a fuzzy set defining its meaning.
The maximum number of fuzzy rules can be computed as follows:

$$R = \prod_{i=1}^{n} m_i$$

where m_i represents the number of membership functions for i[th] input variable and n is the number of input variables. But these R rules are due to combinations of membership functions of input variables and these are incomplete as we could have knowledge only about antecedent part and consequents are yet unknown.
The total output of the zero-order TSK model (Sugeno model) [2] is computed by

$$\text{Computed output } (O_C) = \frac{\sum_{k=1}^{R} w_k (R_k C)}{\sum_{k=1}^{R} w_k}$$

where w_k is the matching degree (i.e., the firing strength) of the k[th] rule. Therefore, the degree the input $x_1 = a_1$, $x_2 = a_2$, …, $x_n = a_n$ matches k[th] rule is computed using the min operator:

$$w_k = \min\left(\mu_{A_{k1}}(a_1), \mu_{A_{k2}}(a_2), \ldots, \mu_{A_{kn}}(a_n)\right)$$

In our problem we are using min operator as composition operator or we can use product operator instead of min. Because for any set of inputs, w_k are easily computed by fuzzifier and rule composing modules, the right hand side of output expression can be evaluated if we could choose the proper values for R_kC. Our problem is to find the optimal values of R_kC such that the difference between the computed output and the actual output as given in input data set is minimal.
Let the error be defined as follows:
Error = Actual output (as given in training data set) – Computed output
For each training example we compute error . For the complete data set mean square error (MSE) is computed. This MSE is used as the fitness function to evaluate the quality of fuzzy model.
With this pre-amble the whole problem of rule base generation boils down to minimization problem as stated below:
Minimize objective function (MSE)

$$MSE = \frac{1}{N}\sum_{k=1}^{N}\left[O_A - O_C\right]^2$$

Subject to the constraint that
$R_kC \in$ {specified set of consequents};
where,
O_A= Actual output as given in data set
O_C= Computed output of model
R_kC = Consequent of k[th] rule.

Any minimization technique may not be applicable if the problem is very complex. Soft computing based optimization algorithms have the capability to find the optimal or near optimal solution in a given complex search space within a reasonable time.

IV. CONCLUSION

This research paper is based upon the automatic rule base generation from numerical data for sugeno type data driven systems using an integrated approach with the following objectives. The literature survey reveals that a large number of classical computing and nature–inspired approaches have been developed for the automatic rule base generation in Fuzzy system. In real life we come across designing of engineering systems which are very complex and highly nonlinear. In order to reduce design cycle time there will always be a need for a fast and better modelling approach which provides tractable, robust and low cost solution to engineering system modelling. In this research work the objective is to develop new methodologies and techniques for:

a) To generate membership functions from given numerical data using Fuzzy C–means clustering approach.
b) To generate rule base automatically from given numerical data using Cuckoo search algorithm.
c) To find optimal number of rules for generated rule base.
d) To evolve a complete optimal fuzzy system from a given data set.
e) To evaluate the performance of the evolved optimized fuzzy system in terms of mean square error.

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