

Multiple Input Multiple Output (MIMO) Process Optimization using Fuzzy GA Clustering

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Abstract—Due to the unique characteristics such as handling complex, nonlinear, and sometimes intangible dynamic systems, fuzzy systems are used in the modeling of Input- Output data of the process. The combination of fuzzy rule-based systems with genetic algorithms can lead to very useful descriptions of several optimization and search problems. In this paper, clustering strategy is implemented in the design of a Fuzzy Logic Controller (FLC) and for the determination of the optimal values of clustering parameters such as weighting exponent and the number of clusters; Genetic Algorithm (GA) is used. Water treatment process, a MIMO process, is chosen here as an application example and GA based Minimum Cluster Volume (MCV) algorithm is proposed which minimizes the sum of the volumes of the individual clusters based on the elimination of redundant rules in the fuzzy rule base thereby reducing the rule firing and computational time and improving optimization.

Index Terms— Fuzzy Logic Controller, Genetic Algorithm, Fuzzy GA Clustering, MIMO Process, Optimization

I. INTRODUCTION

Fuzzy logic controllers are capable to handle complex, nonlinear, and dynamic systems. The membership functions and fuzzy rules are derived and tuned by human experts in most of the fuzzy control applications. Tuning of FLC by human experts needs more computational time and experience and which may not be optimal.

In the design of the Fuzzy Logic controller, the rule base plays an important role, consists of a finite set of IFTHEN rules. If the inputs to the fuzzy controller are increased with membership functions for each input, then the number of rules increases exponentially. So the rule optimization technique is followed. Genetic Algorithm (GA) is used for optimizing the Fuzzy rule base. GA based Fuzzy clustering is mainly used to minimize the objective function used in GA whose parameters are the membership degrees and the parameters determining the localization as well as the shape of the clusters. In this paper, as a Multiple Inputs and Multiple Output (MIMO) process, Water Treatment Process is chosen as an application in which clustering techniques have followed and the clusters are determined where each cluster center belongs to one rule in fuzzy logic. If there are more rules in Fuzzy rule base, there is a drawback of more rule firing

and high computational time. To avoid that, it is proposed to eliminate rule redundancy through fuzzy clustering.

In comparison with the following clustering techniques such as

- Fuzzy C-means (FCM) Clustering Algorithm
- Subtractive Clustering Algorithm

Minimum Cluster Volume (MCV) Clustering Algorithm that minimizes the sum of the volumes of the individual clusters which is more versatile and can be used in a wider variety of applications. The most effective parameters of this clustering algorithm are: (i) weighting Exponent (m) which determines the degree of fuzziness; (ii) the number of clusters (c); and (iii) the norm matrix of the system (A). GA is used to determine the optimal values of these parameters. The fitness function is based on modified Fukuyama-Sugeno cluster validity index [5] that uses Mahalanobis distance measure.

II. CLUSTERING ANALYSIS

Clustering is an exploratory data analysis method and it is used in order to have certain groupings in the data set. Cluster analysis divides data into groups such as similar data objects belong to the same cluster and dissimilar data objects to different clusters. The resulting data partition improves data understanding and reveals its internal structure partitioned clustering algorithms divide up a data set into clusters where similar data objects are assigned to the same cluster whereas dissimilar data objects should belong to different clusters. The most common fuzzy clustering technique aims at minimizing an objective function whose parameters are the membership degrees and the parameters determining the localization as well as the shape of the clusters.

A. GA Based Fuzzy Clustering

GA based fuzzy clustering algorithm, also known as Minimum Cluster Volume (MCV) algorithm [1,2], is used to minimize the sum of the volumes of the individual clusters. The formation of the clusters has less effect on its performance.

In MCV algorithm, the objective function is obtained by summing the individual hypervolumes of the clusters:

$$J_{fv}(B,U;X) = \sum_{i=1}^c |C_{fi}|^{\frac{1}{2}} \quad (1)$$

where B is cluster center vector, U is fuzzy partition matrix, X is data set, c is cluster numbers, and $|C_{fi}|$ denotes the determinant of the covariance matrix C_{fi} of cluster i

The Mahalanobis Distance (MD_{st}) between x_t and c_s is defined as:

$$MD_{st} = (x_t - c_s)^T C_{fs}^{-1} (x_t - c_s) \quad (2)$$

for $t=1, \dots, p$ and $i = s$

and

$$D_{st} = \frac{|C_{fs}|^{\frac{1}{2}} (MD_{st} - p)}{\sum_{j=1}^n u_{sj}^m} \quad (3)$$

Fukuyama-Sugeno cluster validity index is expressed as

$$S(c) = \sum_{k=1}^n \sum_{i=1}^c (\mu_{ik})^m (\|x_k - v_i\|^2 - \|v_i - \bar{x}\|^2) \quad (4)$$

where n is number of data, c is number of clusters, x_k is k^{th} data, \bar{x} is average of data, v_i is vector expressing the center of the i^{th} cluster, $\|\cdot\|$ is any norm, μ_{ik} is the grade that k^{th} data belongs to i^{th} cluster, and m is degree of fuzziness.

The parameters of genetic algorithm used for optimization of the chosen process along with MCV algorithm [2,4] are listed in Table-1.

Table I Parameters of Genetic Algorithm for MCV Algorithm

Characteristic	Type and Value
Generation Number	100
Population size	50
Selection operator	Roulette Wheel
Crossover	Single point
Crossover rate	0.8
Mutation	Gaussian
Mutation Rate	0.008

III. APPLICATION EXAMPLE OF MULTIPLE OUTPUT SINGLE OUTPUT (MIMO) PROCESS: WATER TREATMENT PROCESS

In this process, the turbid river water enters the mixing tank where chemical products called ALUM and POLY are mixed in the water. Then the mixed water flows into a sedimentation tank where the turbid part of water is cohered with the aid of ALUM and POLY and settled to the bottom. After sedimentation which takes about 3-5 hours depending on the capacity of the tank, the treated

water finally flows into a filtration tank producing clean water. The variables concerned with the process are

- RW Turbidity of the original water (NTU)
- TW Turbidity of the treated water (NTU)
- PH PH
- AL Alkalinity (PPM)
- ALUM Amount of ALUM (PPM)
- POLY Amount of POLY (PPM)

Figure 1. shows the control process[3].

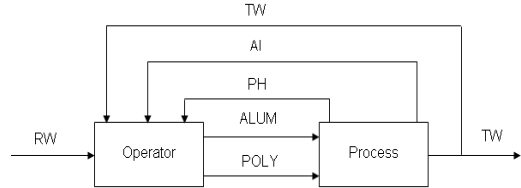


Figure 1. Control Process

Practically observed data from Veerapondi Water treatment plant, Tirupur, India, is illustrated in Table II.

Table II Practically Observed I-O data of Water Treatment Process

S.NO.	INPUT DATA				OUTPUT DATA	
	PH	TW	RW	AL	ALUM	POLY
1	7.25	0.72	3.2	75	21	0.16
2	7.22	0.78	3.15	70	21	0.21
8	7.28	0.67	3.23	78	26	0.18
...						
102	7.81	0.86	40	156	107	0.37
103	7.78	0.87	97.5	155	123	0.37
104	7.8	0.9	30.6	154	145	0.4

The main control problem of a human operator in this process is to determine the amount of ALUM and POLY, two outputs, to be added so that the turbidity of the treated water is kept below a certain level.

By using the observed I-O data of water treatment process shown in Table-II, different clustering methods are performed and number of cluster centers from them was also found. Figure 2. (a-c) represents the performances of different clustering algorithms.

The optimal values of m and c and cluster validity indexes of water treatment process is shown in Table III. For the determination of optimal values of m and c , GA is used and cluster validity indexes are also computed. According to the results, the cluster validity index has taken minimum value for cluster centers $c = 4$ and degree of fuzziness $m = 2.2158$. Thus, the optimal numbers of clusters of output variables are four. Consequently, the number of rules of the fuzzy system model is also four whereas the number of cluster centers obtained from K means clustering is 8 and FCM clustering is 6.

The comparison between observed output, statistical output and fuzzy GA output of water treatment process is shown in Figure 3. The statistical model of water treatment process is built using linear regression method, using MATLAB software 7.5.

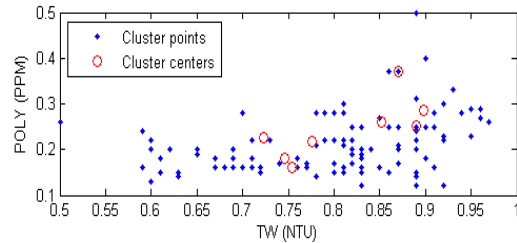
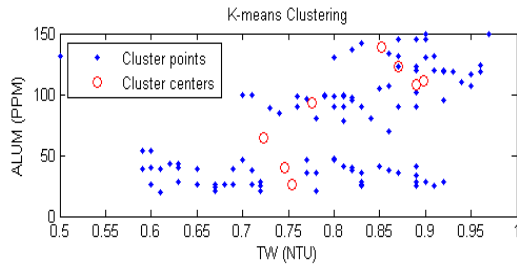


Figure 2(a). Performance of K-Means Clustering

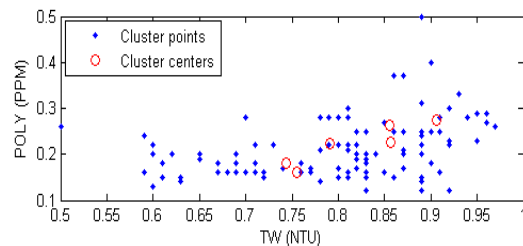
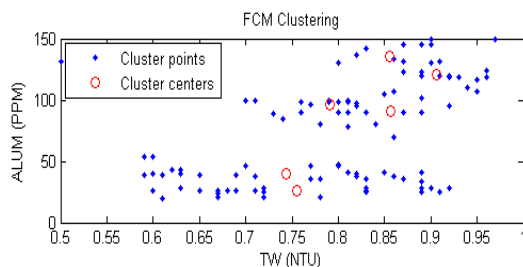


Figure 2(b). Performance of FCM Clustering

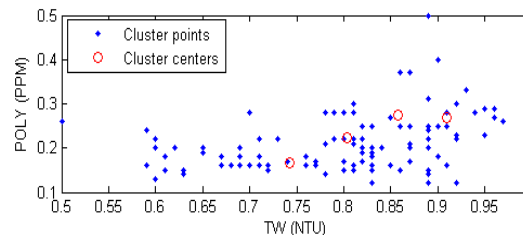
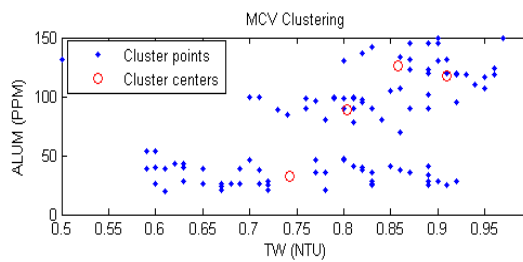


Figure 2(c). Performance of MCV Clustering

Table III Optimal Values of m and c and cluster validity indexes of Water Treatment Process

Range Of C	Range Of M	c	m	Cluster Validity Index
2-8	1-7	2	3.6705	4.1368E-3
2-8	1-7	3	3.1864	1.2752E-3
2-8	1-7	4	2.2158	2.8058E-4
2-8	1-7	5	5.9901	4.2975E-4
2-8	1-7	6	2.3605	3.6815E-4
2-8	1-7	7	3.2702	7.7433E-4
2-8	1-7	8	3.6705	6.9410E-4

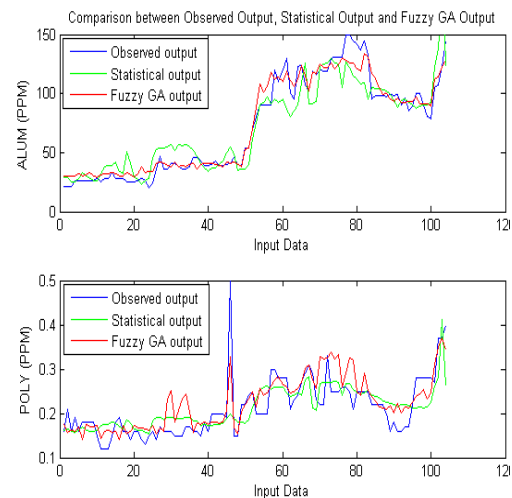


Figure 3. Comparison between Observed Output, Statistical Output and Fuzzy GA Output of Water Treatment Process

IV. CONCLUSION

The development of fuzzy modeling through different clustering concepts is discussed for the chosen MIMO process. The number of cluster centers is also determined for each clustering method. For the determination of the optimal values of clustering parameters such as weighting exponent and the number of clusters, GA is introduced. To overcome the drawback of rule redundancy, GA based Minimum Cluster Volume (MCV) algorithm is proposed and found that 50% of rule redundancy was eliminated.

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