The 2015 World Congress on
Advances in Structural Engineering and Mechanics (ASEM15)
Incheon, Korea, August 25-29, 2015

Repetitive control mechanism of disturbance rejection using basis function feedback with fuzzy regression approach

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ABSTRACT

Applying a repetitive control mechanism to eliminate disturbances in a mechanical control system has been an important subject of investigation. This paper presents a fuzzy theorem approach for the repetitive control law using basis functions feedback. The law adjusted the command given a feedback control system in order to eliminate tracking errors because of a periodic disturbance. This periodic error is reduced by linear basis functions and by a data classification system using fuzzy set theory. For each category of classified data, multiple regression analysis is applied to the linear model. With data which have been classified into 4 categories and when the data are stabilized, the tracking error of the obtained convergence value of $10^{-14.09}$ can be reached, illustrating that the proposed fuzzy regression approach is able to satisfactorily reduce the periodic error.

1. INTRODUCTION

For fuzzy control of structures and systems, stability analysis and systematic design have been certainly among the most important issues. Fuzzy control has been successfully applied to the control design of structures and systems. Liu *et al*. (1996) developed a fuzzy expert system and piecewise linear membership functions, whose expert system offered specific knowledge of various aspects about bearing monitoring, such as diagnostic methods, defect frequencies, feature selection, as well as fuzzy bearing classification.

To resolve the stabilization problem of fuzzy resonant and chaotic systems, Yau (2008) proposed a robust fuzzy sliding mode of control scheme for the synchronization of two chaotic nonlinear gyros subjected to uncertainties and external disturbances. Xu and Chen (2012) developed a linear matrix inequality based fuzzy approach of modeling and active vibration control of geometrically nonlinear flexible plates with piezoelectric materials as actuators and sensors. Shariatmadar and Razavi (2014)

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applied an active tuned mass damper for controlling the seismic response of an 11-story building, where a fuzzy logic controller (FLC) was used to handle the uncertain and nonlinear phenomena while particle swarm optimization was used for optimization of FLC parameters. Further, as data categorization has intrinsic property for reliability improvement, Lin *et al*. (2014) presented a factor-analysis based questionnaire classification method for improving the reliability of the evaluation of working conditions in Taiwanese and Chinese construction enterprises.

Based on the arguments above and the work of Lin *et al*. (2015) for disturbance cancellation using a hybrid regression and genetic algorithm, a repetitive control law has been newly developed in this study using a fuzzy regression approach with basis function feedback so as to reduce tracking errors of feedback controllers subject to periodic commands. First, the fuzzy regression algorithm is introduced into a repetitive feedback control system. Then, the efficiency of disturbance rejection using the fuzzy regression approach is demonstrated. Conclusions are thus drawn from the result analyses, addressing that more data classification acquires better accuracy and then turns to lower accuracy when the data classification number continues to increase.

2. FUZZY REGRESSION ALGORITHM

The model algorithm introduces fuzzy theorem into the regression algorithm. Fuzzy is aimed to measure the magnitudes of phenomena (Driankov 2013) while fuzzy clustering is used to arrange a similar data points into a same cluster (Gupta *et al*. 2015). For this purpose, phenomena have to be grouped and categorized so that distinct and discrete counting units can be defined. It is feasible to allocate all observations to mutually exclusive categories so that they are properly quantifiable. Category proliferation is avoided by normalizing input vectors at a preprocessing stage. A normalization procedure called complement coding leads to a symmetric theory in which the minimum operator and the maximum operator of fuzzy set theory play complementary roles (Carpenter *et al*. 1991).

On the one hand, fuzzy inference is a calculation process that obtains new fuzzy propositions as a conclusion under the condition of a given fuzzy proposition by the fuzzy logic method, also known as fuzzy logic inference (Xie *et al*. 2015). Fuzzy inference can be divided into fuzzification, fuzzy logic inference, and defuzzification. The fuzzy variety is the basis for establishing a fuzzy system, which analyzes problems using the complexity weight of use cases. On the other, fuzzy set theory permits the gradual assessment of the membership of elements in a set; this is described with the aid of a membership function valued in the real unit interval [0, 1] (Dubois and Prade 1988). Since the data are approximate and distribution, the Gaussian membership function is used to represent the degree of fuzzy. Using the Gaussian function as the membership function for the input and output variables, the mathematical description form of the Gaussian membership function can be expressed in Eq. (1):

$$\mu(T_y(i)) = \mathrm{e}^{-\frac{(T_y(i)-\mathrm{c})^2}{\sigma^2}} \tag{1}$$

where c is the center position of Gaussian membership function, σ is width of Gaussian membership function, and $T_y(i)$ is input signal. This study utilizes the center-of-gravity method to solve fuzzification, calculate the enclosed area of the width of the membership function and its membership function, as a clear value to the center of the fuzzy numbers. The formula is expressed in Eq. (2):

$$y_{output}(i) = \frac{\int_{T_{y(i)}} T_y(i) \cdot \mu(T_y(i)) dT_y}{\int_{T_{y(i)}} \mu(T_y(i)) dT_y} \quad (2)$$

The establishment of a classification model with fuzzy theory utilized the fuzzy theory of Matlab toolbox provided in this study. First, it is feasible to define the parameters of the Gaussian membership function using fuzzy membership functions of the input value. Second, applying Mamdani fuzzy inference rules and defuzzification (center-of-gravity method) to obtain classified assessed value. Following Eqs. (1) and (2), it is then possible to include the regression algorithm. In linear regression, the model specification is that the dependent variable, y_i is a linear combination of the parameters. To model *i* data points, there is one independent variable y_{output} and two parameters *a* and b_i, as expressed in Eq. (3):

$$y_i = a + b_1 y_{\text{output}}(1) + b_2 y_{\text{output}}(2) + b_3 y_{\text{output}}(3) + \cdots + b_i y_{\text{output}}(i) + \varepsilon_i \quad (3)$$

Following Eq. (3), it is convenient to introduce the fuzzy regression algorithm into a repetitive feedback control system so as to eliminate the tracking errors as is illustrated in Fig. 1.

Fig. 2 shows the consequences of a variety numbers of data classifications. It is observed that data classified into 4 categories acquires the most effective convergence value, yet its number of repetitions is a few more than that of other data classifications.

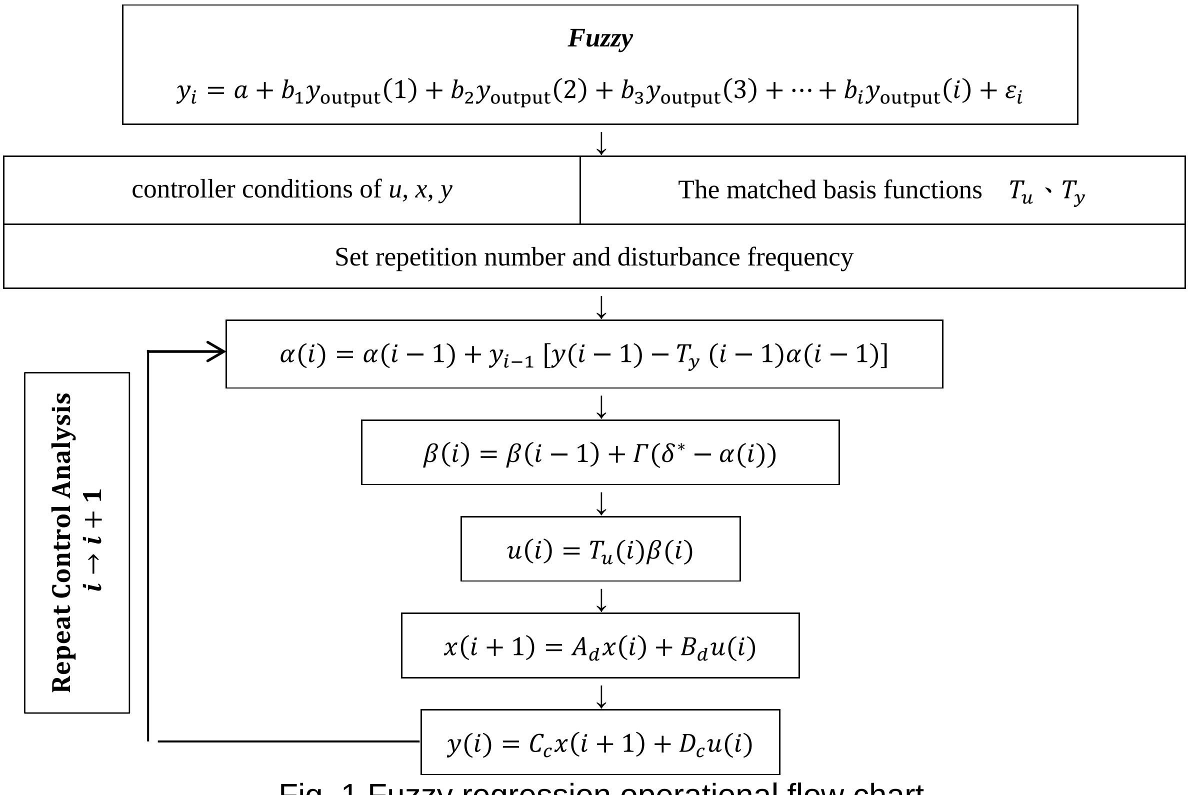

Fig. 1 Fuzzy regression operational flow chart

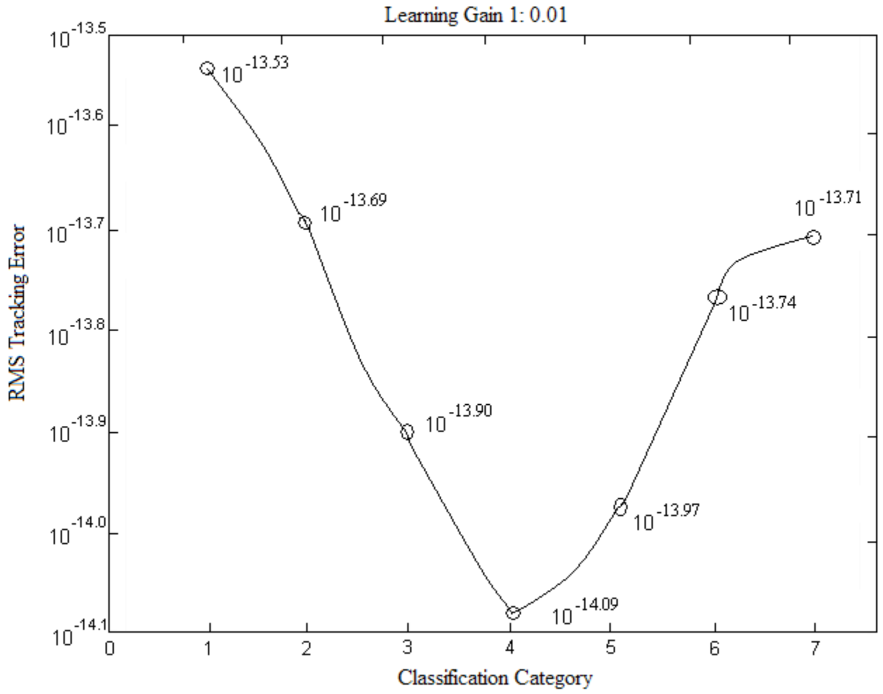

Fig. 2 RMS tracking error is shown for a single sine disturbance at 2 Hz with repetitive feedback control using only 2 Hz basis functions in fuzzy regression approach (Comparison of results with data classified into various categories)

3. CONCLUSIONS

Data categorization has intrinsic property for reliability improvement. The proposed fuzzy regression approach springs from the data preprocessing using the fuzzy inference rules. Although the convergence rate is slower, it provides better accuracy. By comparing the errors obtained from models built with data that have not been classified and those built with data which have been classified, it is found that the data classification system is able to successfully reduce tracking errors. More data classification acquires better accuracy, and then turns to lower accuracy when the data classification number continues to increase. When the data are stabilized, the optimal tracking error of the convergence value of $10^{-14.09}$ can be reached with data classified into 4 categories.

REFERENCES

Carpenter, G.A., Grossberg, S. and Rosen, D.B. (1991), "Fuzzy ART: fast stable learning and categorization of analog patterns by an adaptive resonance system", *Neural Networks*, **4**(6), 759-771.

Driankov, D. and Palm, R. (2013), *Advances in Fuzzy Control*, Physica-Verlag, Heidelberg, Germany.

Dubois, D. and Prade, H. (1988), *Fuzzy Sets and System*, Academic Press, NY, USA.

Gupta, D., Anand, R.S. and Tyagi, B. (2015), “A hybrid segmentation method based on Gaussian kernel fuzzy clustering and region based active contour model for ultrasound medical images”, *Biomedical Signal Processing and Control*, **16**, 98-112.

Lin, J.W. and Shen, P.F. (2014), “Factor-analysis based questionnaire categorization method for reliability improvement of evaluation of working conditions in construction enterprises”, *Structural Engineering and Mechanics*, .**51**(6), 973-988.

Lin, J.W., Shen, P.F. and Wen, H.P. (2015), “Repetitive control mechanism of disturbance cancellation using a hybrid regression and genetic algorithm”, *Mechanical Systems and Signal Processing*, **62-63**, 356-365.

Liu, T.I., Singonahalli, J.H. and Iyer, N.R.(1996), “Detection of roller bearing defects using expert system and fuzzy logic”, *Mechanical Systems and Signal Processing*, **10**(5), 595-614.

MathWorks (2014), MATLAB Users’ Guide, website: http://www.mathworks.com/help/matlab/.

Shariatmadar, H. and Razavi, H.M. (2014), “Seismic control response of structures using an ATMD with fuzzy logic controller and PSO method”, *Structural Engineering and Mechanics*, **51**(4), 547-564.

Xie, Y., Guo, J. and Shen, A. (2015), “Use case points method of software size measurement based on fuzzy inference”, *Proceedings of the 4th International Conference on Computer Engineering and Networks*, 11-18.

Xu, Y. and Chen, J. (2012), “Fuzzy control for geometrically nonlinear vibration of piezoelectric flexible plates”, *Structural Engineering and Mechanics*, **43**(2), 163-177.

Yau, H.T. (2008), “Chaos synchronization of two uncertain chaotic nonlinear gyros using fuzzy sliding mode control”, *Mechanical Systems and Signal Processing*, **22**(2), 408-418.