PAPER 215 – DEVELOPMENT OF A FUZZY LOGIC BASED OFFLINE HANDWRITTEN CHARACTER RECOGNITION SYSTEM

A.R. Ajayi[1*], A.T. Ajiboye[1], O.A. Yusuf[l], O.F. Adebayo[1], E.T. Olawole[1]

[1]Department of Computer Engineering, University of Ilorin, Ilorin, Nigeria.
[*]Email: ajayi.ra@unilorin.edu.ng

ABSTRACT
Offline character recognition is a technique that allows computers to read letters, numbers, and other symbols and convert them into digital form that can be used by computers. Existing fuzzy logic based recognition systems have employed transition data and other features to recognize alphabets. In this study, geometrical features of the alphabet character contour, based on the basic line types that form the character skeletons are used. The selected features are the number of vertical lines (VL), the number of left diagonal lines (LD), number of intersection points (IP) and the sum of pixel (SOP) values. The fuzzy logic model takes these inputs and outputs numbers corresponding to the recognized alphabets. The fuzzy system actual outputs have been compared with the reference outputs; the maximum error observed was 0.45 which is considerably minimal. The mean absolute percentage error (MAPE) value obtained for the model was 1.72%. The MSE and RMSE are 0.03 and 0.16 respectively.

KEYWORDS: Fuzzy logic, Handwritten, Recognition, Geometric

1 INTRODUCTION

Character recognition is a technique that allows computers to read letters, numbers, and other symbols and convert them into digital form that can be used by computers. Machine recognition of handwritten characters has gained much attention over the decades, this is due to its application in various automation processes such as digital character conversion, meaning translation, content based image retrieval, keyword spotting, signboard translation, Text-to-Speech Conversion, Scene Image Analysis, intelligent paper marking, Reading postal addresses and signature verification (Hamdan, 2021; Manisha et al., 2016; Shen et al., 2023).

Character recognition can be classified into two categories: offline recognition and online recognition. Offline character recognition system accepts images of machine printed and handwritten characters as input and gives as output the recognized characters in machine editable text. The online handwritten recognition system receives dynamic signals from electronic devices such as digital pen, digital stylus like devices (Pugazhenthi & Vallarasi, 2015), smartphone and tablet, and gives the recognized characters in machine editable format as output (Manisha et al., 2016). Although deep learning techniques have proved to be highly efficient in recognition systems, but it comes with high computational cost (Wang et al., 2021). It is therefore, expedient to employ methods that can achieve efficient result at a very low computational cost. This study will recognize offline handwritten English Alphabets based on the geometrical properties of handwritten images using a fuzzy logic model. The objectives of this study are to: recognize offline handwritten alphabets using fuzzy logic; compare the actual results with the system's fuzzy logic outputs and evaluate the performance of the developed fuzzy logic model.

2 THEORETICAL ANALYSIS

Fuzzy logic is a soft computing approach based on the degree of truth of membership rather than the classical true or false approach (Alhassan & Hagras, 2020). The fuzzy logic system consists of the fuzzifier, the fuzzy inference engine, the rules base system, and the defuzzifier as shown in Figure 1 (Mohammed & Hagras, 2020). The fuzzifier takes the crisp inputs and converts them to fuzzy sets using fuzzy linguistic variables, fuzzy linguistic terms, and membership functions. The fuzzified inputs and the fuzzy rule base serves as input to the fuzzy inference engine where inferences are made based on a set of rules and produce an output. The resulting fuzzy output is then mapped to a crisp output using the membership functions by the defuzzifier.

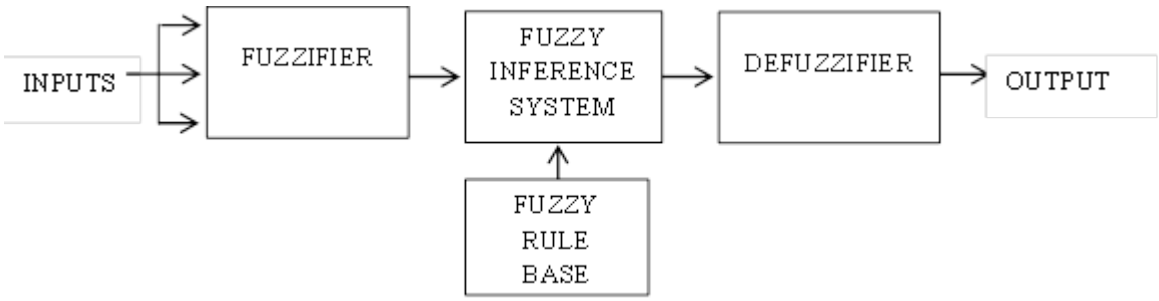

Figure 1: Block Diagram of a Fuzzy Logic System

3 METHODOLOGY

This section describes the stages of the developed fuzzy logic based character recognition system.

3.1 Data Samples

A feature extraction technique based on character geometry for character recognition was reported by (Dileep & Ramesh, 2012). In the study, a feature vector was formed from each zone of uppercase offline handwritten alphabets. The feature vector has a length of 8. Four of these features with distinct or unique values were selected and modeled as variables to the fuzzy logic system. The features are: number of vertical lines (VL), number of left diagonal lines (LD) and the number of intersection points (IP). The mean value of each extracted features for five image samples of each alphabet was computed as shown in Table 1. To ensure that each alphabet appears exclusively within a fuzzy set with no overlap, the sum of pixels of the image (SOP) was computed and added as a distinguishing feature. The average of the minimum and maximum SOP value for each alphabet category was computed and the result is as shown in Table 1.

Table 1: Selected Features of Offline Handwritten Alphabets

VL	LD	IP	SOP
0.05	0.03	0.04	25.00
0.09	0.02	0.03	25.00
0.08	0.05	0.01	26.06
0.10	0.03	0.03	35.64
0.09	0.03	0.03	34.57
0.14	0.03	0.00	13.30
0.19	0.05	0.03	32.45
0.02	0.03	0.02	43.09
0.08	0.05	0.01	22.87
0.20	0.00	0.02	26.06
0.14	0.03	0.00	22.87

3.2 Fuzzification of Input Data

The selected features of the offline handwritten alphabet of Table 1 are taken as the input to the fuzzy inference system, while the English alphabet (A – K) are considered as the output. The maximum and minimum values of the parameters were first studied, and these were used for the fuzzification process. From the obtained data, the fuzzy sets for VL, LD, IP and SOP were defined and are as shown in Table 2.

Table 2: Fuzzy Set for Offline Handwritten Alphabet Parameters

Parameter	Parameter specification	Notation	Range
Number of vertical lines (VL)	Positive Very Small	PVS	0 – 0.09
	Positive Small	PS	0.08 – 0.2
Number of left diagonal lines (LD)	Positive Very Small	PVS	0 – 0.03
	Positive Small	PS	0.02 – 0.05
Number of intersection points (IP)	Positive Very Small	PVS	0 – 0.03
	Positive Small	PS	0.02 – 0.05
Sum of Pixel (SOP)	Positive Very Small	PVS	0 – 15
	Positive Small	PS	14 – 25
	Positive Medium	PM	23 – 35
	Positive Large	PL	32 – 43
	Positive Extra Large	PXL	42 – 50

3.3 Fuzzy Logic Membership Function

Membership functions (MF) are used in the fuzzification and defuzzification steps of a Fuzzy Logic System, to map the non-fuzzy input values to fuzzy linguistic terms. It quantifies a linguistic term with each point in the input space mapped to a membership value between 0 and 1. The common fuzzy logic membership functions are the triangular, trapezoidal, and the Gaussian MF (Walia et al., 2015). In this study, the trapezoidal membership function was employed in the fuzzification of input variables and the triangular MF for the output. The Trapezoidal MF mappings for the fuzzy sets VL and SOP, in the MATLAB environment are shown in Figures 2 and 3 respectively.

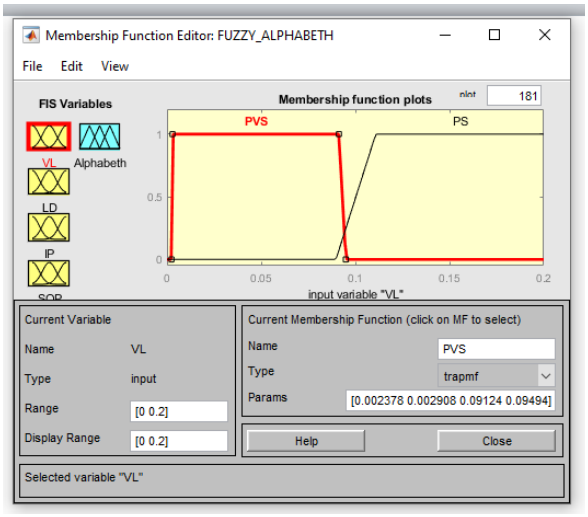

Figure 2: Membership function for VL parameter parameter

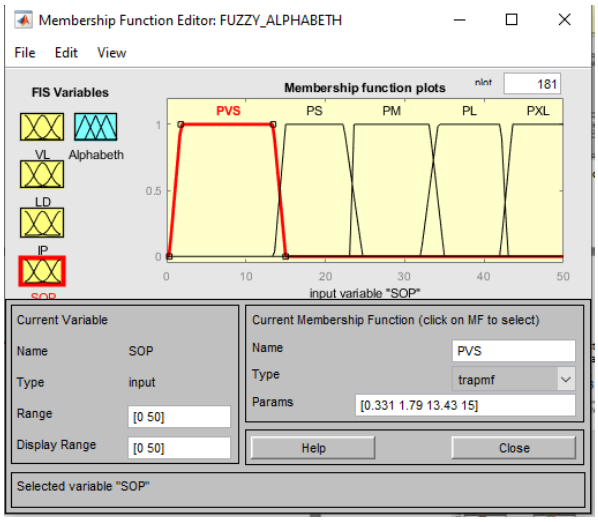

Figure 3: Membership function for SOP

3.4 Fuzzy Rule Base

In a Fuzzy Logic System, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion(Iancu, 2018). Eleven (11) different rules were formulated for this model as shown in Figure 6. Sample fuzzy rules for the recognition of offline handwritten alphabets are shown in Table 3.

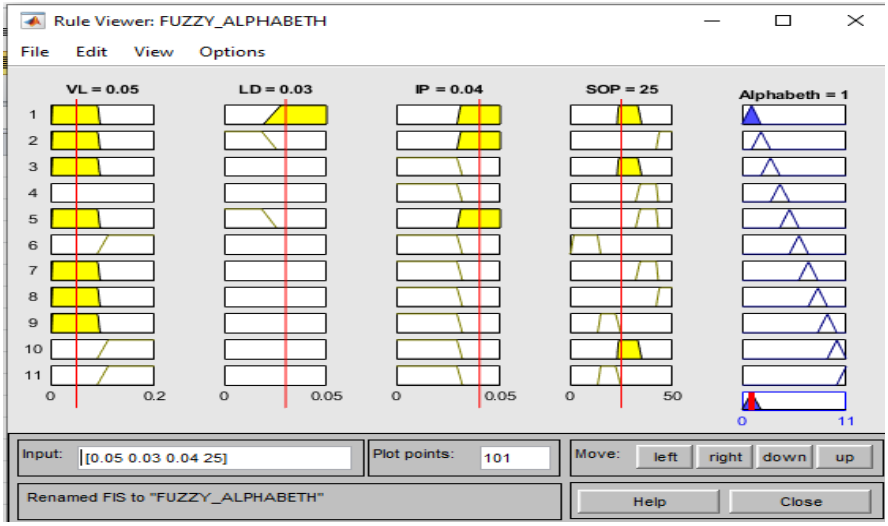

Figure 4: Rule viewer for the developed fuzzy model

Table 3: Sample Fuzzy Rules for the Developed Model

Fuzzy Rules
1. If (VL is PVS) and (LD is PS) and (IP is PS) and (SOP is PM) then (Alphabet is A)
2. If (VL is PVS) and (LD is PVS) and (IP is PS) and (SOP is PXL) then (Alphabet is B)
3. If (VL is PVS) and (IP is PVS) and (SOP is PM) then (Alphabet is C)
4. If (IP is PVS) and (SOP is PL) then (Alphabet is D)
5. If (VL is PVS) and (LD is PVS) and (IP is PS) and (SOP is PL) then (Alphabet is E)

The developed fuzzy logic model has one output variable named Alphabet. The variable is assigned the alphabets A – K, the first eleven alphabets considered in this study. The range of the output variable is between 1 and 11 corresponding to eleven triangular membership functions for alphabets A – K. The fuzzified output Alphabet Triangular MF is as shown in Figure 7. This is then defuzzified to obtain a single crisp output for each of the recognized alphabet.

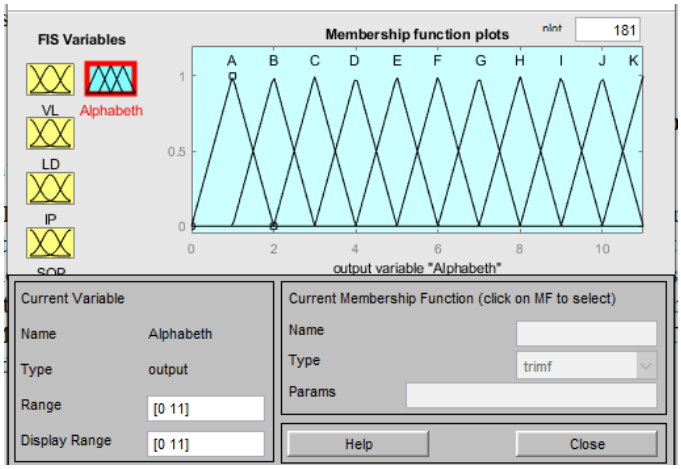

Figure 5: Membership function for Alphabet Output parameter

3.5 Defuzzification

The Fuzzy Inference engine gives a fuzzy output which is defuzzified to obtain a crisp output. Defuzzification is performed according to the membership function of the output variable, in this case, the Alphabet MF. A number of defuzzification methods exists, these include: centroid method, bisector method, mean of maximum method, last of maximum (Chakraverty, Sahoo, & Mahato, 2019). For this study, the centroid method was employed. The equation for calculating the centroid is given in equation 1

$$W^* = \frac{\sum_{i=1}^{n} j_i . A_i}{\sum_{i=1}^{n} A_i} \quad (1)$$

Where: W* is the centroid position, j_i is the center of the area of the fuzzy set at instant i, while A_i is the area of the fuzzy set at instant i, n is the number of elements in the fuzzy set and i =1, 2...n (Ibrahim et al., 2021).

3.6 Model Error Analysis

The statistical methods such as absolute percentage error (APE), mean absolute percentage error (MAPE) are popular method for testing model performance (Tofallis 2015, Kim & Kim 2016). The Absolute percentage error (APE) was used to compute the percentage deviation between the actual and system alphabet recognition output shown in Equation 2 (Ibrahim, et al. 2021).

$$\text{APE } (\%) = \left| \frac{actual\ output\ (i) - predicted\ output(i)}{actual\ output\ (i)} \right| \times 100 \quad (2)$$

$$\text{MAPE } (\%) = \frac{1}{n} \sum_{i=1}^{n} APE(i) \quad (3)$$

where:
n is the number of fitted points,
The recognition efficacy of the model was further analyzed using Mean square error (MSE) and Root Mean square error (RMSE) evaluation metrics as shown in equations 4 and 5 respectively.

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (e_i)^2 \quad (4)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (e_i)^2} \quad (5)$$

4 RESULTS AND DISCUSSION

In this study, a fuzzy logic model for the recognition of offline handwritten alphabet by considering the geometrical features and sum of pixel of the handwritten images has been implemented in the MATLAB environment. In order to test the developed model, random positive numbers corresponding to the fuzzy input variables for each of the alphabets were generated; these numbers were fed into the fuzzy logic model and the results were recorded as shown in Table 4. The recognized output was compared with the actual output, the percentage error between the actual alphabet number and the predicted alphabet number showed the effectiveness of the recognition model; the smaller the percentage error the better the accuracy of the recognition system. It was observed from Table 4 that the APE between the actual and system output varied between 0% minimum to 7% maximum. The MAPE obtained for the model was 1.72% which is considerably low.

With a high degree of closeness between the actual and values, the suitability of the developed fuzzy logic model for recognition of offline handwritten alphabet is established. The absolute error of the system output from the actual output was computed and plotted as shown in Table 4, it was deduced from the chart that the error margin between the actual and system output is maximum at 0.45 when the recognized alphabet is 5 which represents the alphabet E and minimum at 0, when the alphabets A, C, D, F, H, I, J are recognized. This shows a significant and minimal error value for the fuzzy model. Further model evaluation gave an MSE of 0.03 and RMSE of 0.16 respectively.

Table 4: Result of Actual and Recognition Output for Offline Handwritten Alphabets

Reference Output	Input Variables						
	VL	LD	IP	SOP	Recognition Output	Error	APE
1	0.09	0.04	0.05	28.08	1.00	0.00	0
2	0.04	0.02	0.03	28.85	2.14	-0.14	7
3	0.07	0.04	0.02	31.15	3.00	0.00	0
4	0.16	0.05	0.02	41.92	4.00	0.00	0
5	0.09	0.03	0.03	34.23	4.55	0.45	9
6	0.15	0.04	0.00	8.85	6.00	0.00	0
7	0.14	0.03	0.03	33.46	6.99	0.01	0.14
8	0.07	0.04	0.02	45.77	8.00	0.00	0
9	0.07	0.05	0.03	19.62	9.00	0.00	0
10	0.16	0.00	0.01	29.62	10.00	0.00	0
11	0.17	0.04	0.00	20.38	10.70	0.30	2.73
							1.72
							MAPE

5 CONCLUSION

A fuzzy logic based model for the recognition of offline handwritten English alphabet has been developed. The model uses the geometrical features extracted from pre-processed alphabet images as input. The features are the number of vertical lines (VL), the number of left diagonal lines (LD), the number of intersection points (IP) and the sum of pixel (SOP) values. The system output are numbers corresponding to the recognized alphabets. The fuzzy system actual outputs have been compared with the reference outputs; the maximum error observed was 0.45 which is considerably minimal. The MAPE value obtained for the model was 1.72 %. The MSE and RMSE are 0.03 and 0.16 respectively. The method is simple to implement, requires a very low computational cost and reliable.

ACKNOWLEDGEMENT

The author would like to thank Dr. A.T. Ajiboye of the department of Computer Engineering, University of Ilorin and Prof. A.S. Falohun of Computer Engineering Department, LAUTECH Ogbomoso for their valuable guidance and support for this work.

REFERENCES

Alhassan, M. S. E., & Hagras, H. (2020). A congestion control approach based on weighted random early detection and Type-2 fuzzy logic system. *Int. J. Comput. Sci. Trends Technol.(IJCST), 8*(4), 83-94.

Chakraverty, S., Sahoo, D.M., Mahato, N.R. (2019). Defuzzification. In: Concepts of Soft Computing. Springer, Singapore. https://doi.org/10.1007/978-981-13-7430-2_7

Dileep, G. D., & Ramesh, R. (2012). A feature extraction technique based on character geometry for character recognition *arXiv preprint, arXiv* (pp. 1202-3884).

Hamdan, Y. B. (2021). Construction of statistical SVM based recognition model for handwritten character recognition. *Journal of Information Technology, 3*(02), 92-107. https://doi.org/10.36548/jitdw.2021.2.003

Iancu, I. (2018). Heart disease diagnosis based on mediative fuzzy logic. *Artificial Intelligence in Medicine, 89*, 51-60. https://doi.org/10.1016/j.artmed.2018.05.004

Ibrahim, O., Owonikoko, W. O., Abdulkarim, A., Otuoze, A. O., Afolayan, M. A., Madugu, I. S, Adedayo, K. E. (2021). Performance Evaluation of Different Membership Function in Fuzzy Logic Based Short-Term Load Forecasting. *Pertanika Journal of Science & Technology, 29*(2). http://dx.doi.org/10.47836/pjst.29.2.14

Kim, S. and H. Kim (2016). A new metric of absolute percentage error for intermittent demand forecasts. *International Journal of Forecasting, 32*(3): 669-679. https://doi.org/10.1016/j.ijforecast.2015.12.003

Manisha, C. N., Reddy, E. S., & Krishna, Y. (2016). Role of offline handwritten character recognition system in various applications. *International Journal of Computer Applications, 135*(2), 30-33. https://doi.org/10.5120/ijca2016908349

Mohammed, H. A., & Hagras, H. (2020). A Type 2 Fuzzy Logic Based System for Basal Metabolic Rate Prediction of Diabetes Patients in Sudan. *International Journal of Computer Science Trends and Technology (IJCST),* 8(3), 95-104.

Pugazhenthi, D., & Vallarasi, S. A. (2015). Offline character recognition of printed Tamil text using template matching method of Bamini Tamil font. *Indian Journal of Science and Technology, 8*(35), 1-4. DOI: 10.17485/ijst/2015/v8i35/86811

Shen, L., Chen, B., Wei, J., Xu, H., Tang, S.-K., & Mirri, S. (2023). The Challenges of Recognizing Offline Handwritten Chinese: A Technical Review. *Applied Sciences, 13*(6), 3500. https://doi.org/10.3390/app13063500

Tofallis, C. (2015). "A better measure of relative prediction accuracy for model selection and model estimation." *Journal of the Operational Research Society, 66*(8): 1352-1362. https://doi.org/10.1057/jors.2014.103

Walia, N., Singh, H., & Sharma, A. (2015). ANFIS: Adaptive Neuro-Fuzzy inference system-a survey. *International Journal of Computer Applications, 123*(13). https://doi.org/10.5120/ijca2015905635

Wang, Y., Xiao, W., & Li, S. (2021). *Offline handwritten text recognition using deep learning: A review.* Paper presented at the Journal of Physics: Conference Series. DOI 10.1088/1742-6596/1848/1/012015