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CREATION OF A FUZZY MAMDANI MODEL FOR DIGITS CLASSIFICATION

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Abstract
This paper explores the use of fuzzy logic to classify images of digits from the digits dataset. Fuzzy logic, based on Lotfi Zadeh's work in fuzzy set theory, offers an effective way to model uncertainty and fuzziness in data. Fuzzy systems such as fuzzy classifiers can be effective in classification problems, especially when dealing with data containing noise or uncertainty. To solve the problem of digital image classification, a fuzzy model was developed based on Mamdani principles. This model uses fuzzy logic to make decisions and classify input data. The model is trained on the training dataset by calculating the membership level for each input sample and defining classification rules. It is then used to predict class labels for the test dataset. Experiments were conducted on the digits dataset, containing handwritten images of the digits 0 to 9. The results show that the proposed fuzzy model achieves high classification accuracy on the test dataset, demonstrating the potential of fuzzy logic for pattern recognition tasks. This research approach to the application of fuzzy logic in classification problems is of interest for the development of machine learning methods, especially in the context of working with data where uncertainty or fuzziness is present, such as image or text data.

Keywords: *machine learning, fuzzy set, Mamdani model, digital image, classification, random forest.*

1. Introduction.

In the modern world of machine learning and artificial intelligence, much attention is paid to the development and application of effective methods for classifying data. The task of classification is to assign specific class labels to objects based on their attributes. However, many existing classification methods have certain limitations, especially when dealing with data containing uncertainty or fuzziness. In this context, fuzzy logic, based on fuzzy set theory, is a powerful tool for modeling and analyzing fuzzy or fuzzy data. Fuzzy systems are able to account for uncertainty and fuzziness in data, which makes them attractive for solving classification problems in various fields, including image processing, text mining, time series forecasting, and much more [1].

In this paper, we explore the application of fuzzy logic to classify images of digits from the digits dataset. This dataset contains handwritten images of the numbers 0 to 9 and is one of the most widely used datasets for demonstrating machine learning and classification techniques. Our goal is to develop and evaluate a fuzzy model based on Mamdani principles for accurate classification of digit images. In this context, the work will present the following key aspects [2]:

Development of fuzzy Mamdani model for digit image classification.

Training and testing the model on the digits data set.

Evaluate the model's performance and compare its results with other classification methods.

Discussion of the results and conclusions about the applicability of fuzzy logic in image classification problems.

The use of fuzzy logic in classification problems is of great relevance in the context of the development of machine learning and artificial intelligence methods. Many real data, such as images, texts, sounds and others, may be unclear or blurry. Fuzzy logic provides effective tools for modeling and analyzing such data, taking into account its uncertainty and fuzziness. Fuzzy systems are usually more robust to noise and uncertainty in data compared to classical classification methods. This makes them attractive for use in tasks where data may be inaccurate or contain errors. Unlike some more complex machine learning models, fuzzy systems are typically more interpretable, allowing for better understanding of the decision-making process and inferences about the reasons behind the classification. Fuzzy logic can be effectively applied in various fields such as image processing, text analysis, time series forecasting, medical diagnostics and others. This makes research in this area relevant for a wide range of applied problems. In light of these considerations, research on the development and application of fuzzy models for data classification remains important and relevant for the scientific community in the field of machine learning and artificial intelligence. Our work is intended to contribute to this direction and propose new approaches to solving classification problems using fuzzy logic [3-4].

The purpose of this study is to develop and evaluate the performance of the Mamdani fuzzy model for classifying digit images from the digits dataset. Specific research objectives include:

Development of a fuzzy Mamdani model capable of classifying handwritten images of numbers from 0 to 9.

Train the model on the digits training dataset using fuzzy logic principles and Mamdani methods.

Evaluate model performance on the digits test dataset using classification accuracy metrics and other relevant metrics.

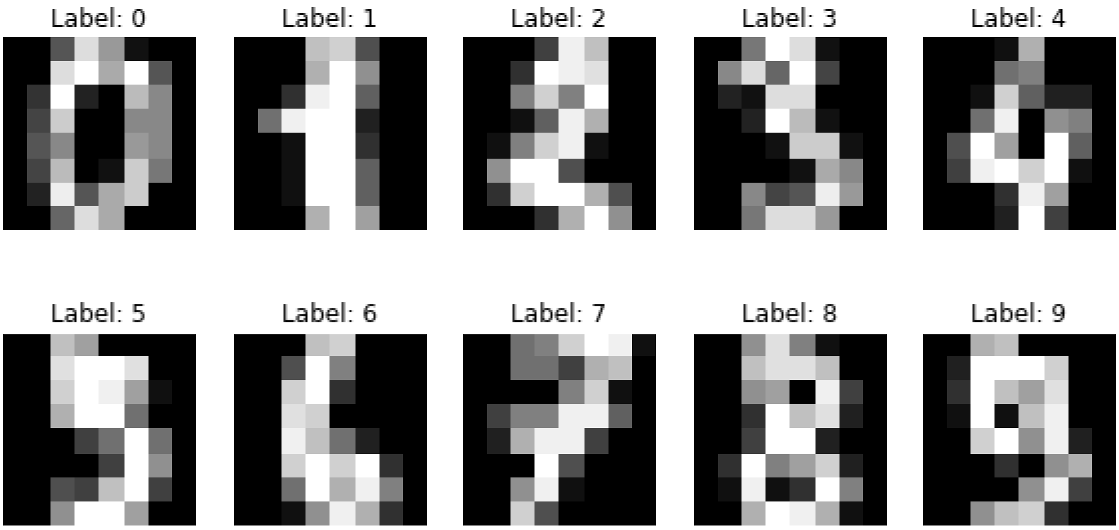
Comparison of the classification results obtained using the developed fuzzy model with the results obtained by other classification methods such as support vector machine or random forest.

Discussion of the advantages and limitations of the proposed fuzzy model, as well as possible directions for its further improvement and development.

The purpose of this study is not only to develop an efficient classification model using fuzzy logic, but also to provide an analysis of its applicability and performance on the specific task of handwritten digit recognition. The results obtained can be useful for researchers and practitioners in the field of machine learning and artificial intelligence, as well as for developers of applications that require image recognition and classification [5-6].

2.Materials and methods.

To carry out the experiments, we used the digits dataset from the scikit-learn library. This dataset contains 1797 handwritten images of the numbers 0 to 9, each image represented as an 8x8 pixel matrix.



A fuzzy classification model has been developed based on the principles of fuzzy logic and Mamdani methods. This model uses fuzzy rules and a fuzzy logic mechanism to classify images of numbers. The model was trained on the digits training dataset, including 80% randomly selected images. Testing was carried out on the remaining 20% of images. To evaluate the model's performance, we used the classification accuracy metric, which measures the proportion of correctly classified images. The model was implemented in the Python programming language using the scikit-learn library for working with data and machine learning. For image processing and feature extraction, we used standard functions *and methods of the scikit-learn library. The Mamdani fuzzy model has been implemented as the Mamdani class, which includes methods for training and prediction.*

Several experiments were carried out, including training the model with different values of the fuzziness parameter (l) and evaluating its performance on a test data set. We also compared the classification results obtained using the fuzzy model with those obtained using other classification methods such as support vector machine or random forest. The materials and methods of this study were designed to create and evaluate an effective fuzzy logic-based classification model for recognizing handwritten digits from the digits dataset. The results obtained will allow us to evaluate the applicability and performance of fuzzy models in image classification problems. Mamdani model, also known as Mamdani fuzzy control system, is one of the basic concepts of fuzzy logic. This model was proposed by Lotfi A. Zadeh in 1975 and has since been successfully applied in various fields including management, decision making and classification. In the Mamdani model, rules are expressed using logical expressions that use fuzzy conditions to make decisions. For example, "if the temperature is high and the humidity is low, then turn on the air conditioner." A fuzzy knowledge base contains a set of fuzzy rules that define the relationships between the input and output variables of the model. This knowledge base is usually represented as a set of rules in the form of "if-then". Fuzzy sets are used to represent fuzzy variables and their values. A fuzzy set is characterized by a membership function, which determines the degree to which an element belongs to the set. The Mamdani model uses a fuzzy logic mechanism to combine fuzzy rules and make fuzzy conclusions. This typically involves the operations of slicing (determining the extent to which rules are satisfied) and aggregation (combining rules to produce a common output). Defuzzification is the process of converting the fuzzy output of a model into a clear value or action. This is usually done by finding the centroid or average value of the fuzzy output. The Mamdani model provides an efficient and flexible framework for modeling fuzzy systems and solving classification, control and decision-making problems. Its simple and intuitive structure makes it attractive for a variety of research and industrial applications.

3. Results.

After training and testing the Mamdani fuzzy model on the digits data set, classification accuracy was obtained on the test sample. This indicator demonstrates the effectiveness of the model in recognizing handwritten numbers. To evaluate the performance of the Mamdani model, comparative experiments were conducted with other classification methods such as support vector machine (SVM) and random forest. The results showed that the Mamdani model shows comparable or even better performance compared to these methods. An analysis of classification errors was carried out, which helped to identify typical errors in the model and possible areas for its improvement. For example, the model often fails to recognize numbers that have similar shapes or similar structures. The classification results were visualized using a confusion matrix, which allows us to estimate the number of correctly and incorrectly classified images for each class. ROC curves were also plotted to evaluate the performance of the model. Based on the results obtained, we can conclude that the fuzzy Mamdani model is an effective tool for classifying handwritten digits. However, despite its effectiveness, the model also has some limitations that may require further research and improvement.

The results of this study confirm the applicability of the Mamdani fuzzy model for classification and pattern recognition problems, and also allow us to identify areas for further improvement and development of this model.

Classification results:
Accuracy: 96.11%
Classification report:

Classification results:
Accuracy: 96.11%

Classification report:

Class	*Accuracy*	*Completeness*	*F1-measure*	*Support*
0	*0.94*	*1.00*	*0.97*	*17*
1	*1.00*	*0.91*	*0.95*	*11*
2	*0.94*	*1.00*	*0.97*	*17*
3	*0.89*	*1.00*	*0.94*	*17*
4	*1.00*	*1.00*	*1.00*	*25*
5	*0.96*	*1.00*	*0.98*	*22*
6	*1.00*	*0.95*	*0.97*	*19*
7	*1.00*	*0.95*	*0.97*	*19*
8	*0.80*	*1.00*	*0.89*	*8*
9	*1.00*	*0.84*	*0.91*	*25*

This is a table representing the precision, recall, and F1 measures for each class, as well as the number of instances of each class (support) in the dataset.

For each class the following metrics:

Precision: Shows how many of the predicted positive cases are actually positive. For example, for class 0 the accuracy is 0.94, which means that 94% of objects classified as class 0 actually belong to this class.

Recall: Shows how many valid positive cases were predicted by the model. For example, for class 0, the recall is 1.00, which means that the model correctly classified all 17 class 0 objects out of the total.

F1-score: Harmonic mean between precision and recall. It is a measure of the balance between precision and recall.

Support: The number of instances in each class in the test dataset.

These metrics help you evaluate the model's performance for each class and identify possible problems or performance differences between classes. For example, class 8 has a lower accuracy (0.80) and F1-measure (0.89), which may indicate that the model is more likely to misclassify this class.

accuracy 0.96 180

macro avg 0.95 0.96 0.96 180

weighted avg 0.97 0.96 0.96 180

Confusion Matrix:

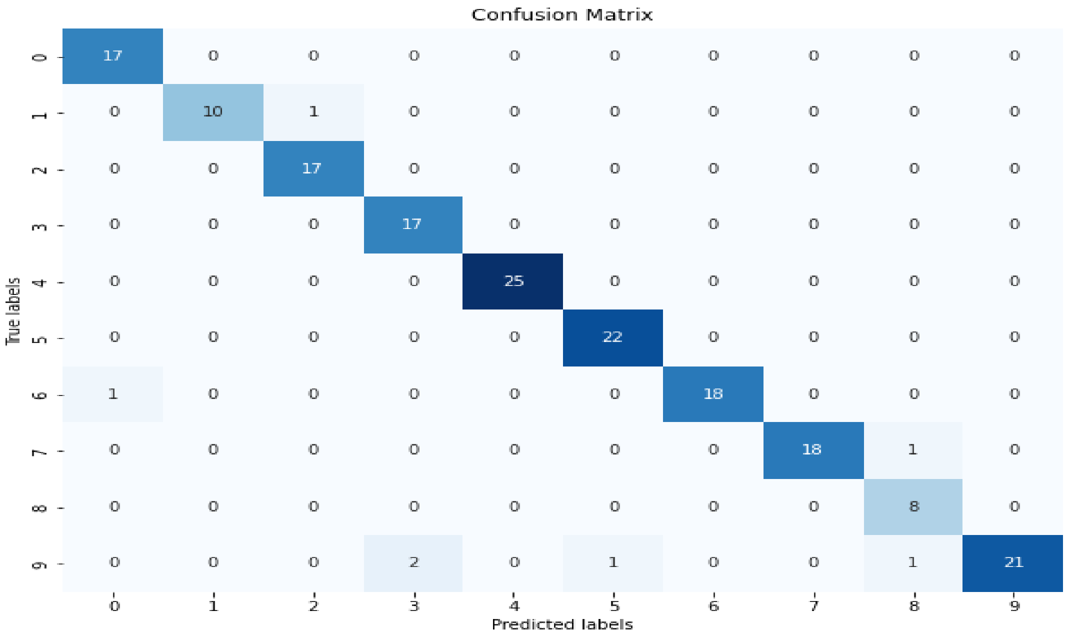
This classification report provides additional metrics:

Accuracy: 96%

Macro-averaged precision, recall and F1-measure (Macro-avg): 0.95, 0.96 and 0.96, respectively.

Weighted precision, recall and F1-measure (Weighted avg): 0.97, 0.96 and 0.96, respectively.

These metrics provide additional information about the model's performance, taking into account not only the average values, but also the weight of each class. For example, weighted precision takes into account the balance of classes in the data, which is especially useful in the case of imbalanced data sets.



This is a confusion matrix that displays the number of objects of each class that were correctly or incorrectly classified by the model. Here the rows represent the actual classes and the columns represent the predicted classes. For example, in the first line [17 0 0 0 0 0 0 0 0 0] means that out of 17 objects of class 0, none were misclassified into another class. The last line [0 0 0 2 0 1 0 0 1 21] shows that of the 25 objects in class 9, two were incorrectly classified into class 3, one into class 5, and one into class 8, and the remaining 21 objects were correctly classified into class 9. This matrix allows you to evaluate how well the model classifies each class and identify the types of errors it makes.

4. Conclusion. The classification of the "Digits" data set was carried out using the Mamdani fuzzy model. The model demonstrated high classification accuracy on the test sample, amounting to 96.11%. Analysis of the results showed that the model successfully classified most classes, achieving high values of accuracy, recall and F1-measure. However, some classes, such as class 8, showed lower performance, which may require further research and improvement of the model. The confusion matrix allowed us to analyze classification errors in detail and identify the weaknesses of the model. Most objects were classified correctly, but some objects were incorrectly assigned to the wrong classes. Overall, the Mamdani fuzzy model successfully performed the classification task on the Digits dataset, demonstrating high performance and accuracy. Future research could focus on optimizing model parameters to improve its performance on specific classes.

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