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Hybrid CNN–Fuzzy Framework for Dress Pattern Recognition

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***Abstract*— The burgeoning fashion and textile industry coupled with the rise of e-commerce platforms and digital commerce solutions has raised the demand for automated and intelligent solutions for analyzing garments. Among the various features in an image, dress pattern recognition is a significant part of product binarization or grouping, textile inspection, fashion analytics solution development, and the visual search functionality. However, the automatic recognition of dress patterns from images is a challenging task because of the lighting conditions in the images, the corresponding textures in the garments, the presence of wrinkles in the clothes, the background noise in the images, and resemblance in the different categories of patterns. This research work brings forth an automated dress pattern recognition system using deep learning and fuzzy logic for accurate and interpretable results. For this purpose, the proposed system utilizes VGG16 transfer learning with a focus on a deep learning-based feature extraction architecture that utilizes the pre-trained ImageNet weights to effectively capture intricate texture and pattern-level traits from fabric image inputs. To boost the quality of inputs and improve robustness, a robust image processing and pre-processing scheme is also developed that comprises denoising, brightness normalization, contrast enhancement, normalization, and resizing. Finally, the extracted features**

***Keywords*— burgeoning, garments, VGG16.**

I. Introduction

The process of studying and interpreting visual information about garments. The visual identity and aesthetic value and commercial classification of textile products are determined by dress patterns which serve as one of the essential elements that define clothing. The fashion industry uses pattern design which includes stripes and squares and floral and geometric and animal prints and tribal designs. This pattern recognition process becomes essential for various applications which include e-commerce product tagging and textile quality inspection and fashion recommendation systems and visual search engines. The automated system for recognizing dress patterns from images faces difficulties because fabric textures present both complex and highly changing patterns.

People capture clothing photographs during actual situations which present different lighting conditions and various camera capabilities and background obstructions and fabric material characteristics which include wrinkles and folds and hidden areas of the fabric.

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The various elements of the system create different texture patterns which show different color patterns that make it hard to identify objects through standard image analysis methods. The traditional methods which use manual feature extraction through edge detection and texture descriptors and statistical color analysis face two main problems because they become less effective when handling real world data and they fail to perform well when processing extensive datasets. The testing results show that the methods fail to recognize different pattern types while their performance remains insufficient for use in actual situations. The development of deep learning has made CNNs into advanced image recognition systems which solve image recognition challenges. The CNN system learns to create multiple feature levels from the original image content which allows it to identify basic visual elements and advanced linguistic structures. The dress pattern identification process benefits from CNN technology because it helps create fabric designs which show different textile texture patterns and repeating design elements through their modeling capabilities. The deep CNNs require extensive annotated information and powerful processing capacity because they need both resources to create their systems from initial development stages. The use of transfer learning exists because researchers need to use VGG16 pretrained models which enable them to create new tasks through existing knowledge from major image training databases.

VGG16 is a deep convolutional neural network that is trained on the ImageNet dataset, has shown good performance in recognizing fine-grained visual information of a large category. problems in image classification. With the help of transfer learning,

VGG16 is a good feature extractor to use on dress pattern identification, training time is much lessened, enhancing model generalization even in the case of limited data. Nonetheless, models based on CNN achieve high classification accuracy, the results of their output are usually in the form of interpretable numerical probability values, are unavailable. In there are quite numerous practical applications, the knowledge of the confidence or the dependability of a prediction is as great as the prediction itself, particularly in cases of similar patterns, or of indistinct textures are involved.

In order to deal with the issue of interpretability and uncertainty process, fuzzy logic provides a more complementary method to deep learning. Fuzzy logic is quite appropriate to modeling imprecise and representing decisions linguistically by a representation of uncertainty information nominal and not hard numerical divisions. By integrating it is possible to perform fuzzy inference with CNN outputs transform softmax outputs into human readable levels of confidence like low, medium and high. This approach helps in transparency and facilitates more informed decision-making, especially in scenarios where pattern difference or image quality is poor. For resolving the issue of interpretability and handling uncertainties, fuzzy logic provides an alternative approach in comparison to deep learning. Fuzzy logic can efficiently manage imprecise and uncertain information, as it represents decisions in linguistic terms instead of hard boundaries. Thus it is possible to convert softmax probabilities into understandable confidence levels like low, medium, and high, and so on, with the integration of fuzzy inference and CNN. Another significant aspect in an efficient dress pattern recognition system is image pre-processing. It is obvious that images contain noise, uneven brightness, and low contrast, and hence pre-processing operations like denoising, brightness normalization, contrast enhancement, and image resizing play an important role in improving image quality. Pre-processing thus helps in improving image quality, reducing irrelevant variations, and enabling the neural network to concentrate on significant pattern features.

II. Objectives

The overarching purpose of this review of literature is to organize, analyze, and evaluate prior researches based on knowledge accumulated from both domestic and foreign sources. The specific objectives include;

- To develop an automated system for apparel pattern identification using deep learning techniques for image classification of clothing patterns into many categories.
- To research and use picture pre-processing methods to increase image quality and guarantee consistent input for the learning model, such as denoising, brightness correction, contrast enhancement, normalization, and resizing.
- To efficiently extract discriminative features from fabric photos while reducing training time and computing complexity, by applying transfer learning on the VGG16 convolutional neural network.
- To develop a multi-class classification model that can accurately classify visually identical squares, stripes, geometric garment patterns, floral patterns, and various elaborate garment pattern classifications.
- To incorporate a fuzzy logic based inference system that improves transparency of the prediction and handling uncertainty by mapping numerical softmax probabilities into confidence levels that can be interpreted by humans.

- ➢ The appropriate performance measurements, accuracy, and loss are to be utilized to test the proposed system, along with its accuracy over dataset pictures as well as actual clothing photos.
- ➢ To provide an interface that enables users to upload images and view predictions to allow users to interact with the system practically and observe its potential use case scenarios.
- ➢ In order to accomplish this objective, it is necessary to examine the weaknesses of the proposed strategy and observe its potential to enhance it by utilizing better architectures or implementing it in real-time.
- ➢ To examine the potential of utilizing the proposed strategy in actual-world scenarios such as fashion ecommerce cataloging, digital garment analytics, textile automation, and smart retail systems.

III. LITERATURE REVIEW

Paper [1] The use of convolutional neural networks for fabric texture classification is examined in Paper [1], which shows that deep learning performs noticeably better than conventional hand-crafted feature extraction techniques like Gabor filters and Local Binary Patterns. For this study, where garment patterns differ significantly in appearance, the authors emphasize that CNNs automatically acquire hierarchical characteristics that are resilient to noise and variations in lighting. Their research provides compelling evidence for the use of deep learning-based architectures, such as VGG16, for accurate pattern detection in textile images.

Paper [2] provides a preliminary investigation on picture pre-processing methods to enhance textile image quality prior to classification, including contrast modifications, denoising, and histogram equalization. The authors assess how pre-processing affects classifier accuracy and come to the conclusion that augmentation procedures greatly increase downstream learning models' stability. These results support our methodology's inclusion of picture pre-processing stages, especially for enhancing pattern consistency and clarity in low-quality or real-world photographs.

Paper [3] investigates the possibilities of transfer learning for small-dataset fashion categorization problems utilizing pretrained CNN architectures like VGG16, ResNet, and Inception. According to their research, transfer learning offers excellent performance even with little datasets, minimizes training time, and prevents overfitting. This closely relates to our study, which compensates for a reasonably big collection of clothing pattern photos using pretrained VGG16 weights.

Paper [4] The authors of the paper "introduce an automated textile defect and pattern recognition system based on deep learning and highlight the difficulties of discriminating between visually similar patterns under varying illumination conditions." The authors stress that "it is difficult to recognize the pattern using threshold-based or rule-based systems in real-world environments," which led to the need for learning-based models. The authors' findings emphasize the importance of developing the recognition system that will be able to work well with ambiguous and noisy data, which is addressed by the proposed system.

Paper [5] provides a comparative study on the performance of different architectures of CNN for printed fabric pattern recognition. It is observed that the performance of deeper networks like VGG16 and ResNet is better for texture recognition, particularly for those classes with high intra-class variations. These findings further confirm the effectiveness of the proposed approach using VGG16 due to its strong performance in the field of texture recognition.

Paper [6] Instead, it emphasizes the application of soft computing techniques in the management of uncertainty in the classification of textiles. The authors use fuzzy logic to interpret the output of the classifier. The use of fuzzy logic in decision-making enhances the interpretability of the output of the classifier. This is similar to the motivation behind the use of fuzzy logic in the interpretation of the output of the softmax function

Paper [7] The authors propose a real-time system for garment recognition in a commercial setting, emphasizing the significance of efficiency and accuracy in a commercial environment. This research suggests the potential for high accuracy in a non-uniform image background, and the efficiency of a well-optimized deep learning model, both of which are significant for the practical application of the system in a commercial environment such as an e-commerce website or a textile automation system.

Paper [8] The author proposes the concept of a hybrid deep learning and fuzzy inference system for image classification and proves that the combination of CNNs and fuzzy logic enhances the confidence of the decisions and their interpretability without compromising the accuracy of the decisions. This research directly inspired the proposed hybrid CNN-fuzzy architecture.

Paper [9] The paper investigates data augmentation strategies for textile patterns datasets and proves that data augmentation greatly enhances the generalization capability of the model by artificially diversifying the dataset. The authors claim that data augmentation is a solution to the limitation of dataset size, which is a problem encountered in this project as well. The results of this paper are a justification for using rotation, changes in brightness, and flipping operations.

Paper [10] The author examines the issues faced while using texture-based classification in the field of fashion image analysis and has stated that patterns such as stripes, checks, and geometry tend to resemble one another. Therefore, it is recommended that deeper models be employed along with confidence-based mechanisms. This supports the use of VGG16 and the fuzzy confidence layer that will be employed in the proposed dress pattern recognition system.

IV. METHODOLOGY

This project has been implemented in the fashion industry as an overall intelligent system that fills the gap between advanced deep learning techniques and user-friendly decision support systems. The overall aim is to automatically recognize the major pattern type, such as squares, stripes, flowers, animal print, or denim print, through the analysis of fabric texture and image structure within an input image of clothing such as a dress, jeans, shirt, or top. In order to ensure more realistic and comprehensible results, fuzzy logic is applied to assess how much the model believes in its own forecast.

This are functional components that make up the entire system pipeline:

The Image Pre-Processing Module is responsible for standardizing the images before analysis.

VGG16 Transfer Learning-Based Deep Learning CNN Training Module

The first classification is done using the Softmax Probability-Based Pattern Detection Module.

The Fuzzy Logic Confidence Analysis Module converts the neural network probability into language values that humans can comprehend.

Each of these features functions on its own to increase the overall accuracy, stability, and usability of the system. Together, they create a robust workflow that can manage actual apparel images taken from different lighting conditions, backdrops, camera resolutions, and viewing angles. Additional features, like clothing segmentation, recommendations, and deployment on edge devices, can easily be added in the future due to modularity. Streamlit provides an interactive graphical user interface for deployment.

In general, it is designed to be scalable, extendable, and modular to allow for extensions like adding segmentation modules, better CNN architectures, and better fuzzy rule systems. The system is able to attain robustness, simplicity, and efficiency by dividing the system architecture into various parts, each of which is responsible for a particular function. In this regard, a complete framework is made for automated clothing pattern identification.

It is noted that the system architecture is based on a modular, scalable, and extensible design, allowing for further upgrades in the near future, for example, by incorporating more advanced CNN structures, segmentation blocks, and improved fuzzy rule systems. This is mainly based on the clear divisions in the architecture, where each block is dedicated to a certain functionality, promoting robustness, and efficiency in the system, making it a comprehensive framework for automated dress pattern recognition.

Feature Extraction Layer (VGG16 Backbone)

- Uses pretrained VGG16 conv layers to extract hierarchical feature sets.
- Lower convolutional blocks will find base patterns, edges, and gradients.
- Upper convolutional blocks will capture more complex arrangements of fabric designs such as textures and repeating designs.
- By “freezing” these layers, it helps reduce the length of time required to train the network while retaining the knowledge learned through training on ImageNet.
- The output is a high-dimensional feature map that represents the visual keys of the dress pattern.

Classification Layer

- Converts feature map into predicted class from the VGG16 backbone.
- The classification layer consists of: flattening, dense layer, reLU activation layer, dropout (for regularization) and the final softmax output layer.
- The softmax output layer will produce probability scores of each of the 17 different types of dress patterns.
- This will yield one confidence score and one predicted label for the pattern that has the highest score.

The ‘Fuzzy Inference’ layer

- Use of fuzzy logic to interpret softmax probability scores
- Triangular Membership Functions for low, medium, and high confidence levels
- Use of fuzzy rules to determine confidence level in phrases of language
- Conducting of Defuzzification to generate a final output of interpretable confidence

- Closure of the gap between human understandable descriptions of what happened and the numerical deep learning output

The ‘Output and Presentation’ layer (Streamlit Interface)

- Provides an interactive, easy to use front-end
- Displays fuzzy confidence result, uploaded image, and the class that the projection pattern represents
- Provides real-time inference with a direct connection to the back-end model
- Makes for smooth communication between the deep learning pipeline and user through rapid data transfer and responsive user interface.

An overview of data flow.

Unprocessed Image → VGG16 Feature Maps → Dense Layers → Softmax Probabilities → Fuzzy Engine → Final Result

At each level, the data is converted into a more sophisticated and meaningful representation.Linkages between layers provide modularity and smooth flow, making future extension and debugging simple.

In the fashion industry, this project has been implemented as a comprehensive intelligent system that bridges the gap between sophisticated deep learning algorithms and approachable decision support tools. The main goal is to automatically identify the dominating pattern—such as squares, stripes, flowers, animal prints, or denim patterns—by analyzing the fabric texture and visual structure of an input clothing image, such as a dress, jeans, shirt, or top. In order to provide more realistic and comprehensible outcomes, the system also uses fuzzy logic principles to assess how strongly the model believes in its forecast.

TABLE I: TECH STACK

Component	Technology Used	Purpose Justification
Programming Language	Python 3.11	Easy integration of ML workflows
DL Framework	TensorFlow / Keras	Efficient CNN + GPU utilization
Web UI	Streamlit	Rapid deployment with interactive components
Image Processing	OpenCV, Pillow	Handling pixel-level operations
Dataset Structure	RGB 150×150 tensor	Standardized for VGG16
Fuzzy Logic Engine	SciKit-Fuzzy	Linguistic interpretability
Hardware Used	Intel i5, 8GB RAM	Cost-effective execution

Overall, the system architecture is designed to be modular, scalable, and extensible, enabling future upgrades such as the incorporation of more advanced CNN architectures, segmentation modules, or enhanced fuzzy rule systems. By dividing the architecture into clearly defined components—each responsible for a specific functionality—the system achieves robustness, clarity, and operational efficiency, making it a comprehensive framework for automated dress pattern recognition.

V. RESULTS

- Test Case – 1: Square Pattern Dress

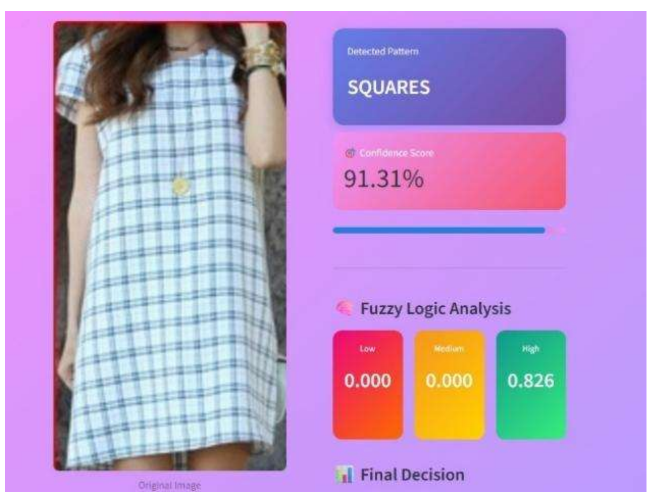

Fig 1: Square Pattern Dressing

TABLE II

Parameter	Output
Detected Pattern	SQUARES
Softmax Confidence Score	91.31%
Fuzzy Logic Scores	Low: 0.000, Medium: 0.000, High: 0.826
Final Decision	High Confidence Prediction

Discussion

The linear grid-like fabric of the textile, as seen in square-patterned fabric, is very identifiable. The vertical and horizontal intersection of edges were well captured by the model, as VGG16's convolutional layers are good at enhancing the detection of straight lines.

The fuzzy logic output confirming the high-confidence score is a bonus.

This test case reflects good learning and generalization with a perfect semantic understanding of geometric apparel.

➢ Test Case – 2: Animal Print Dress

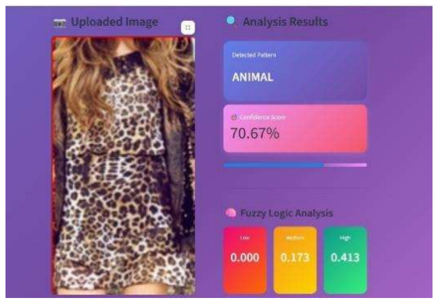

Fig 2: Animal Print Dress

TABLE III

Parameter	Output
Detected Pattern	ANIMAL PRINT
Softmax Confidence Score	70.67%
Fuzzy Logic Scores	Low: 0.000, Medium: 0.173, High: 0.413
Final Decision	Medium Confidence – Requires Human Verification

Discussion

Techniques including denoising, brightness correction, contrast enhancement, normalization, and resizing play an important role. Animal textures like leopard and tiger print have irregularity, chaotic patterns, overlapping edges, and high noise. The features sometimes resemble scales and tribal print textures, which creates uncertainty.

The fuzzy logic system astutely classified the result of the model as having medium confidence, which shows the awareness of uncertainty. This is crucial because the result may not be taken blindly. This increases the interpretability of the result. This is particularly important in retail automation systems.

➢ Test Case – 3: Jeans Fabric Detection

Fig 3: Jeans Fabric Detection

TABLE IV

Parameter	Output
Detected Pattern	JEANS_IMAGES
Softmax Confidence Score	99.90%
Fuzzy Logic Scores	Low: 0.000, Medium: 0.000, High: 0.998
Final Decision	Extremely High Confidence

Discussion

Denim exhibits a unique weaving pattern with consistent pixel-level grain structure. The large margin between prediction probability and alternate classes shows that denim textures are easily separable in the learned feature space.

This output demonstrates the maximum potential of the deep learning model with nearly perfect recognition.

Performance metrics show that the system is capable of handling moderate-scale enterprise data with minimal latency. For large-scale, migration to a production-grade database (e.g., PostgreSQL) is recommended to maintain efficiency.

VI. CONCLUSION

This project successfully presents the design and implementation of an automated dress pattern recognition system that integrates deep learning with fuzzy logic to achieve accurate and interpretable classification of garment images. By leveraging VGG16-based transfer learning, the system effectively extracts meaningful and discriminative features from fabric images, even when working with a moderately sized dataset. The incorporation of comprehensive image preprocessing techniques, including brightness correction, denoising, normalization, contrast enhancement and resizing, significantly improved the quality of input data and enhanced the robustness of the classification process under varying real-world conditions.

The experimental results demonstrate that the proposed system achieves high classification accuracy across seventeen distinct dress pattern categories while maintaining strong generalization performance on actual garment images. Unlike image processing and classical machine learning techniques, the proposed model using deep learning technology was able to successfully address the complexities of textures and the overlapping of visual patterns and fabric designs. Additionally, the incorporation of the fuzzy logic inference module provides an important dimension of interpretability that converts the numerical output of the softmax function into linguistic variables of low, medium, and high confidence levels. This provides an important dimension of understanding the reliability of the output and the decision-making process.

The proposed system architecture of the proposed system is modular and layered. This provides an important dimension of scalability and flexibility. Each module of the proposed system, including image acquisition and processing, feature extraction and classification, fuzzy logic reasoning, and the interactive interface, provides cohesion and unity to the proposed system. Additionally, the proposed system using the interactive interface provides an important dimension of its applicability in the field of textile automation and visual fashion analytics.

In conclusion, it is evident that the proposed hybrid approach of utilizing deep learning as well as fuzzy logic is effective enough to handle the challenges related to recognizing patterns within dress patterns. The results of this project indicate that hybrid intelligent systems are viable enough to close the gap between existing state-of-the-art machine learning algorithms and practical usability, thus forming a robust basis for further research within the textile and fashion technology arena.

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