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The Role of Artificial Intelligence in Curly Hair Analysis: A Literature Review

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Introduction

The world has recently witnessed significant developments in the field of artificial intelligence (AI), and we see its strong presence in many fields, including beauty, and many applications have emerged, such as camera-based skin analysis tools. This has highlighted the need to use AI in hair analysis, as it is a fundamental element of a person's identity. However, hair care, especially curly hair, remains a challenge, due to the curly hair wide variety of textures (it varies from 2 to 4 with subcategories from a to c) and it requires specific routines and products that are completely different from straight or wavy hair.

Despite this, most currently available intelligent systems lack sufficient analysis for this hair type. Most databases that used to train algorithms contain images of people with straight or wavy hair, which make curly hair analysis results inaccurate or not specifically designed for the person. Given the importance of this topic, this research aims to explore the role of AI in analyzing curly hair and customizing appropriate products.

Summary research paper's:

Paper 1: Artificial Intelligence in Hair Research: A Proof-of-Concept Study on Evaluating Hair Assembly Features

This paper presents the use of artificial intelligence (AI) to evaluate the effect of hair care products on hair volume, straightness, and flyaways, this done by analyzing images of straight hair treated with different products, using machine learning algorithms, 2D image analysis, and human tests for comparison. It explains why hair shape and appearance are important, and demonstrates that consumers are interested in modifying hair to suit their taste. It also mentions that companies produce variant hair care products to determine their effectiveness and they conduct evaluation tests often performed by manual human visual assessments, which are sometimes inaccurate.

This study has two main objectives, first one is to use computer vision and machine learning techniques to measure the effect of treatments on hair assembly, so that it is possible to identify whether hair volume has increased or its appearance has changed after a particular treatment, and the second one is to compare the performance of AI with human assessments. It also demonstrates that shape, size, and flyaway are not just aesthetic, but also result from physical and chemical properties, thus reinforcing the importance of automated analysis tools such as AI to measure these properties more precisely.

Paper 2: Towards Creation of a Curl Pattern Recognition System

This paper proposes an automated system for classifying curl patterns using computer vision and convolutional neural networks (CNNs). The goal is to build a model that recognizes hair patterns from an image, then uses this classification to recommend appropriate hair care products.

The system utilizes established systems for classifying curly hair:

- **Andre Walker System:** the primary system used to classify hair into four main categories each with subcategories.
- **LOIS System and FIA System:** alternative models that offer more comprehensive classification using additional features such as volume, density, shine, etc.

To collect various hair images they used web scraping tools, as well as images taken from 30 volunteers. The images were then processed and converted to grayscale after that to binary images. By using “Active Shape Models” features were extracted and trained on a CNN model fed with 30x30 pixel images. The system was able to recognize curl patterns and recommend appropriate products based on the pattern.

Paper 3: Reimagining Hair Science: A New Approach to Classify Curly Hair Phenotypes via New Quantitative Geometrical & Structural Mechanical Parameters

This paper aims to reimagine curly hair classification using new and accurate geometric and mechanical measurements instead of traditional classifications based solely on external appearance and general appearance, such as the Andre Walker or L’Oréal systems.

The paper shows that traditional systems are insufficient to distinguish the differences within curly and coily hair types, which are a challenge users face when choosing appropriate products. Therefore, it aims to develop a new system based on precise geometric measurements such as the total length of the hair path (L), number of curls, pitch, diameter, and ellipticity (e), in addition to mechanical properties such as the tensile stress-strain relationship until the hair is stretched and breaks. It seeks to link these properties to hair type and appropriate products.

This study was conducted by collecting real hair samples from 12 female volunteers at Spelman College with curly and coil hair. The researchers used precision instruments such as scanning electron microscopy (SEM), photogrammetry, tensile strength analyzer (TA), and dynamic mechanical analyzer (DMA) to measure hair shape, the number of bends per 3 cm (contours), the length-to-bend ratio (contour/pitch), and the stress-strain relationship. The results showed that curly and kinky hair have different properties that influence their performance and response to products. And they proposed a new quantitative classification system based on these geometric values.

Paper 4: ²KEBOT: An Artificial Intelligence Based Comprehensive Analysis System for FUE Based Hair Transplantation

This paper introduces the KEBOT system, which utilizes the artificial intelligence to accurately analyze hair before and after hair transplantation procedures, and provide surgeons with accurate reports to help in evaluating the procedure. The system consists of:

- A 6-axis robot that moves around the patient's head.
- A depth camera that generates a 3D model of the head.
- A high-resolution RGB camera with a telecentric lens.
- A dedicated light source to optimize the captured images.
- A processing unit.
- ²Artificial intelligence algorithms.

It aims to detect the number and location of follicles, calculate the number of hairs within each follicle, measure the diameter of each hair (in microns), calculate the hair coverage index, and generate visual and analytical reports for the physician.

The error rate of this system was measured to be less than 5% in most cases, and the results were very close to microscopic measurements.

What makes this study special is its use of advanced technologies such as YOLO, RetinaNet, and SegNet, its comprehensive coverage of all stages of transplantation (before and after), its combination of robotics and artificial intelligence, and providing accurate digital analysis to support the physician's decision.

However, its weakness is that it is designed for specific cases (men with AGA only), and does not cover different hair types or non-medical conditions. In addition, it is not intended for the end user, but rather for the physician only and there is no customization based on hair type or product.

Paper 5: ⁷Neural Strands: Learning Hair Geometry and Appearance from Multi-View Images

This ¹¹paper presents a new method for representing and generating 3D hair strands from multi-view images in a geometrically accurate, realistic, and easily modifiable way.

Previous papers have focused on recognizing hair type from static images, while the “Neural Strands model” emerges as an advanced analytical tool that enables accurate reconstruction of the full hair shape from multi-view images. This opens the door to artificial intelligence applications. The Neural Strands model not only recognizes individual hair, but also restores the full shape of the strands, even from different angles, and this is important for hair care applications because it actually analyzes the shape of each strand, its curvature, density, and growth direction. The model develops a system for generating realistic 3D hair strands from multi-angle images, using texture maps representing the shape and appearance of each strand. They use UNET (a U-shaped encoder-decoder network architecture) to generate a realistic final image (RGB + alpha). It was trained on real images, and two types of losses are used:

- A geometric loss to approximate the hair shape.
- A visual loss (rendering loss) to approximate the final appearance with real images.

This paper is considered as the first learning framework that combines hair shape and realistic appearance from multi-angle images, and it is usable in real time for generating realistic images of human hair.

Paper 6: ³DiffLocks: Generating 3D Hair from a Single Image using Diffusion Models

This paper aims to rebuild ³3D hair geometry from a single image using diffusion models which is a serious technical challenge especially for curly or complex hair, such as Afro hairstyles, due to the wide variety of shapes and the lack of realistic data.

The researchers proposed a new framework called DiffLocks to solve two main problems:

- Lack of realistic 3D data.
- Reconstruction of the fine details of each hair.

They created a massive database containing 40,000 (40 K) realistic and diverse 3D hair styles, which now serves as a reference for other researchers. The researchers used Blender to create 3D hair strands, and they trained their model using DINOv2 features to guide the generation process, giving the model the ability to understand the fine spatial details of each hair strand. The model requires no post-processing or additional random strand injections, but rather automatically generates hair containing fine details such as flyaway strands. It is worth mentioning that the model was trained only on synthetic data, yet it successfully generalized to real images.

The DiffLocks paper doesn't focus on product recommendations, but it does offer the ability to generate accurate curly hair images that can be used in model training.

Critical Analysis:

By reviewing previous papers, we can see it is clear that the field of artificial intelligence use in hair analysis is still under development. And most previous studies have focused on specific aspects, such as geometric classification, 3D reconstruction, or studying its physical properties. Even with this progress in technology, clear gaps remain. The main gaps are the lack of a comprehensive approach that integrates curly hair analysis, accurately identifying its pattern, and providing personalized recommendations. Furthermore, most previous models were not built on everyday user data such as mobile phone images, which limits their practical application. Thus, I can say that these studies serve as the foundation building blocks for developing an AI model that accurately analyzes curly hair based on images, classifies it, and provides personalized care recommendations.

Connections:

1. development from Manual Classification to Artificial Intelligence:
Most of papers demonstrate the evolution of hair problems to interpret its properties, whether for classification, generating its 3D shape, or understanding the geometric structure, from relying on human visual analysis (LOIS System and FIA System) to using AI and deep learning algorithms (such as diffusion models, and neural networks). This development illustrates how studies began with traditional methods before adopting modern techniques to improve accuracy and specificity.
2. Reliance on images as the primary source of analysis:
All studies relied on images (either single images or multi-angle images) as a starting point to extract information about hair pattern, this emphasizes the importance of the image as a primary input for analysis.
3. Variety of technical approaches to achieve the same goal:
Tools varied between diffusion models, convolutional networks (CNNs), classification algorithms, and manual techniques, although the overall goal remained within the scope of understanding the hair types.
4. Limited practical usability of some models:
Some models require multi-angle images or industrial data, making them difficult to implement for everyday users, especially in personal applications.

Conflicts between the findings:

1. **Hair Classification: Manual or Automated?**
The “Artificial Intelligence in Hair Research” paper relies on manual visual classification, and assumes that humans are capable of accurate visual determination without the aid of machine learning algorithms or network models, while the remaining papers rely on automated classification using techniques and machine learning algorithms.
2. **Is the goal classification or recommendation?**
The papers “Reimagining Hair Science” and “Artificial Intelligence in hair research” focus on accurate hair classification.
While “DiffLocks” and “KEBOT” papers focus on advanced analysis (a medical and 3D), but without any connection to user behavior or hair care routines.
Some research suggests that understanding hair patterns is sufficient, while my research demonstrates that this is insufficient without practical steps to help the end user.
3. **Is synthetic data effective?**
Towards Creation of a Curl Pattern System” encountered data quality issues and noted limited image diversity. While “DiffLocks” uses massive synthetic data (approximately 40K images) and

has proven effective in training model.

4. Can AI handle curly hair?

Some studies such as “DiffLocks”, have successfully demonstrated that AI can analyze and generate very realistic curls. While other studies consider curly hair a challenge that AI cannot overcome.

Synthesis Matrix for Literature Review:

Study	Authors	Year	Research Design	Key Findings/Results	Methodology	Limitations
Towards creation of a curl pattern recognition system	Hill Kymberlee , Abimbola Adesola, Dangal Prajjwhal, Washington Gloria, III Burge Legand	2018	Proof of concept study	They successfully developed a prototype for hair curl pattern classification using AI techniques and used well-known classifiers systems (Andre Walker, LOIS, FIA) and were also able to analyze images and extract features associated with hair pattern with good accuracy.	They collected images of several curly hair types and used OpenCV to convert the images to grayscale and then binary. They built a CNN to analyze the images and then classified the results according to well-known classification systems.	The database size was limited.And there was no actual user testing.

2 KEBOT: An Artificial Intelligence Based Comprehensive Analysis System for FUE Based Hair Transplantation	Mohammad Ikram, Imran Sarwar Bajwa, Nazeeruddin in Mohammad, Faisal Baig	2021	Applied System Design	A comprehensive system called KEBOT, based on artificial intelligence techniques, was developed to analyze and process hair transplant cases. The model contributed to improving diagnostic accuracy and customizing treatment plans.	Collecting and analyzing scalp images. Using convolutional neural networks (CNNs) to detect suitable areas for transplantation.	There is insufficient information about user interaction or actual user experience. The system does not include post-transplant recommendations or analysis of hair characteristics such as softness or curl.
Neural Strands Learning Hair Geometry and Appearance from Multi-view Images	Radu Alexandru Rosu, Shunsuke Saito, Ziyang Wang, Changlei Wu, Sven Behnke, and Giljoo Nam	2022	Deep Learning	The model learns from images taken from multiple angles, reconstructing a 3D representation of hair that closely resembles the real thing.	Combine data from different angles to create a complete representation of hair strands. Use custom functions to adjust appearance, curl, and bend.	It requires multiple angles of the same person, limiting its practical application in everyday life. It does not provide accurate hair type classification.
Artificial Intelligence in hair research: A proof-of-concept study on evaluating hair assembly features	Gabriela Daniels, Slobodanka Tamburic, Sergio Benini, Jane Randall, Tracey Sanderson, Mattia	2021	Proof of Concept Study, Machine Learning	The results demonstrated the AI's ability to distinguish between different types of assembly and morphological characteristics, and the algorithms proved effective in visually classifying hair patterns and characteristics	Collecting hair samples from volunteers.	The study did not rely on a large or diverse dataset, but was limited to the samples collected. The system also does not provide product recommendations or direct interaction with the end user.

	Savardi			without human intervention.		
1 Reimagining Hair Science: A New Approach to Classify Curly Hair Phenotypes via New Quantitative Geometrical & Structural Mechanical Parameters	Michelle E. B. Joly, Audrey R. Miller, Jena A. Shaw, Patricia A. Turner, Crystal M. Morrison, Michelle A. Gaines	2022	Experimental	A new classification of curly hair has been proposed based on geometric characteristics such as angle, curvature, and length, going beyond the traditional method of relying solely on appearance.	Collect hair samples from volunteers. Develop clear quantitative criteria for classifying hair patterns.	The experiment was conducted on limited samples.
3 DiffLocks: Generating 3D Hair from a Single Image using Diffusion Models	Huiwen Chang, Xiaohui Zeng, Hanbyul Joo, Jingwan Lu, Xiaohui Shen, Jimei Yang	2023	Deep Learning and Diffusion Model-based Design	The model produces consistent geometric properties of hair, delivering high-quality results that can be animated and integrated into 3D environments. The model outperforms previous methods in terms of accuracy and realistic appearance.	Using a Diffusion Model. Train the model on data containing 2D images and their corresponding 3D images.	There is no built-in mechanism for automatically identifying hair type or pattern (classification).

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