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USING ARTIFICIAL INTELLIGENCE IN ASSESSING THE QUALITY OF STONES AND JEWELRY DESIGN

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Abstract

This article briefly examines modern approaches to applying artificial intelligence (AI) methods to automated quality assessment of precious and ornamental stones (identification, origin determination, treatment detection, and 4C grading), as well as the potential of generative and auxiliary AI tools in jewelry design. Key algorithmic approaches (computer vision, convolutional neural networks, multimodal architectures, and spectral data processing methods) are discussed, along with case studies and commercial solutions, as well as issues of validation, standardization, and ethics. A review of key literature and practical results is provided.

Keywords: Artificial intelligence, stone quality assessment, machine learning, computer vision, gemology , generative design, jewelry, spectroscopic analysis

Introduction

The scientific novelty of this article lies in its systematization of modern methods for applying AI to assessing the quality of stones and jewelry design, including multimodal models and generative algorithms, as well as in identifying the trend of these technologies transitioning from research to practical use in gemology and the jewelry industry.

Assessing the quality of precious and ornamental stones is a complex task requiring the integration of visual, physicochemical, and market criteria. Standard gemological procedures include expert microscopic evaluation, spectroscopic and elemental analysis, and official certification. However, these methods are often labor-intensive, subjective, and require significant investment in expensive equipment and highly qualified specialists.

The rapid development of digital technologies and artificial intelligence (AI) methods opens up opportunities for the creation of a new generation of automated solutions that can radically improve the efficiency of stone quality assessment and optimize the jewelry design process.

Modern gemological laboratories actively use high-precision analytical methods, such as energy-dispersive X-ray fluorescence (ED-XRF) and laser ablation-assisted inductively coupled plasma mass spectrometry (LA-ICP-MS), to identify, determine the geographic origin, and detect treatments of stones [1]. These methods generate huge arrays of multidimensional data, the efficient and rapid processing of which goes beyond the capabilities of traditional analysis.

Existing studies using computer vision methods confirm that automated algorithms can demonstrate higher accuracy and significantly reduced processing time compared to expert gemologists. For example, in one study on gemstone classification, an algorithm achieved 69.4% accuracy, outperforming experts whose accuracy ranged from 42.6 to 66.9%, while significantly reducing analysis time [2].

Systems based on deep neural networks (e.g. the GEMTELLIGENCE model) have demonstrated the ability to automatically determine the origin of stones and identify their treatments with an accuracy comparable to expensive instrumental methods such as ICP-MS, highlighting the potential of AI to speed up and reduce the cost of gemological examination [3].

Beyond gemstone grading, AI is finding significant applications in jewelry design. Generative neural networks and machine learning algorithms significantly accelerate the sketching, prototyping, and visualization stages, opening up new horizons of creativity and efficiency for the jewelry industry.

The purpose of this article is to present a comprehensive overview of modern approaches to the application of artificial intelligence in stone quality assessment and jewelry design, analyze the algorithmic methods used, practical implementation cases, and key issues.

We have provided a detailed overview of key AI algorithmic approaches used both for automated gemstone quality assessment and to support the jewelry design process.

1. Computer vision and convolutional neural networks (CNNs). Computer vision methods based on convolutional neural networks (CNNs) are a key tool for visual assessment tasks. They are used for automatic classification of stone varieties, detection of internal defects and inclusions, and grading based on visual characteristics (color, clarity).

Application examples: CNN models are used for gemstone classification (for example, achieving 98% accuracy when classifying 12 popular gemstone types on large datasets). Classical machine learning methods (SVM, KNN) are also applied using features extracted from images (color histograms, Haralick texture features).

Advantages: high speed of automated image processing, reduced subjectivity of assessment.

Disadvantages: sensitivity to shooting conditions (lighting, camera quality), requirement for a large volume of marked data, limited by visual features (does not allow determining chemical composition or hidden processing).

2. Multimodal models (Images + Spectra + Chemical data). To solve complex gemological problems, such as accurately determining the geographic origin of a stone or identifying invisible treatments, it is necessary to synthesize data from different sources. Multimodal models combine visual data (photographs, micrographs) with spectroscopic (IR/ FTIR , UV-FL) and chemical data (XRF, LA - ICP - MS) [3].

Application examples: models combining convolutional networks and attention mechanisms (attention models) can use multimodal data to achieve performance comparable to expensive instrumental analysis (e.g., ICP - MS).

Advantages: significant increase in the accuracy, reliability and completeness of the assessment.

Disadvantages: requires complex infrastructure to collect and synchronize data, as well as access to expensive instrumentation.

3. Spectral/chemical data processing and classical ML methods . If the task focuses exclusively on the analysis of chemical composition or spectra, rather

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than on visual characteristics, classical machine learning (ML) methods such as SVM, random forest, or gradient boosting are applied. These algorithms work with numerical features extracted directly from spectral curves or elemental composition data [4].

Application examples include the use of ML to classify rock materials, as well as to identify technological changes (e.g. heat treatment) or to determine specific origins (e.g. tropical/continental) based on trace element analysis.

Advantages: efficient processing of numerical, non-visual data; allows for the identification of features invisible to the human eye.

Disadvantages: Requires high-quality data preprocessing; results are often less intuitive and more difficult to visualize.

4. Generative models and jewelry design. In the field of jewelry design, generative AI (Generative AI), including Generative Adversarial Networks (GAN), Diffusion Models and transformers are used for creative support and process automation.

Examples of application: using programs (Midjourney, DALL·E, Stable Diffusion, etc.) to generate realistic sketches and visualizations of new jewelry shapes. Generative AI significantly impacts the ideation phase, allowing for the rapid exploration and prototyping of a large number of ideas [5].

Benefits: expanding the creative spectrum of designers, accelerating prototyping and visualization.

Disadvantages: results often require expert refinement to ensure technological feasibility, compliance with quality standards and production requirements.

Table 1 - Comparison of the main algorithmic approaches

No.	Approach	Data type	The main task	Advantages	Restrictions
1	Computer Vision / CNN	Images photo / micro	Classification of stones, identification of defects	Fast processing, visual orientation	Requires a lot of data, dependent on photo quality
2	Multimodal models	Images + spectra + chemistry	Determination of origin, identification of processing	High accuracy, combination of different data sources	Complexity of implementation, requires a lot of different data
3	Classical ML on spectra	Spectra, chemical properties	Classification by chemistry, detection of processing	Works well with numerical data, more transparent models	No visual information, requires chemical expertise
4	Generative AI / design	Text - prompts , images	Generation of jewelry sketches, visualization	Accelerates design, stimulates creativity	Requires an expert designer to check the product's manufacturability

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Therefore, algorithmic approaches are truly diverse and complementary : visual methods are convenient for initial screening and automated evaluation, multimodal and chemical models provide deeper analysis, and generative AI tools open up new possibilities in jewelry design. Depending on the task (quality assessment or design), it is recommended to select the appropriate technology or combine several approaches.

At the same time, key tasks remain such as the creation of high-quality labeled data, ensuring standardized survey/analysis procedures, expertise in interpreting results, and the correct linking of algorithmic conclusions with gemological standards.

We examined real-world examples of the practical implementation of artificial intelligence technologies in the field of gemstone appraisal and jewelry design.

1. Automatic classification of 68 gemstone categories. Objective: to evaluate the ability of computer vision to classify a large number (68) of gemstone varieties based on visual characteristics.

Technology: a combination of classical machine learning methods (Random Forest) with visual features (RGB color histogram and LBP texture features). The model was trained on 2,042 images.

Result: 69.4% accuracy was achieved on the test sample. Expert gemologists demonstrated accuracy in the range of 42.6% to 66.9%, spending between 42 and 175 minutes on the task. The algorithm completed the classification in 0.0165 seconds [2].

Conclusion: AI outperforms experts in speed and reproducibility , highlighting its potential as a rapid preliminary assessment tool, even if accuracy still requires improvement.

2. CNN case study on 12 popular gemstones (24,000 images). Task: highly accurate classification of a limited set (12) of common gemstones.

Technology: deep convolutional neural network (CNN) trained on a large dataset of 24,000 images.

Result: very high accuracy was achieved - 98% on the test sample [6].

Comment: This result demonstrates the effectiveness of CNN for highly distinguishable and/or widely represented classes in the data, but requires testing

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on "challenging" real-world cases (e.g., stones with similar colors or different treatments).

3. Multimodal approach – GEMTELLIGENCE. Objective: to create a decision support system for a gemological laboratory capable of determining the origin and identifying stone treatments using comprehensive data.

Technology: a multimodal deep neural network (CNN + attention module) that combines spectroscopic (FTIR, UV/ visible) and chemical (XRF/ICP-MS) data. The system is capable of operating even with partial lack of input data.

Application: implemented in the Gübelin laboratory Gem Lab (Switzerland) to support experts using a database of 28,000 samples.

Result: the stated accuracy of the assessment is comparable to expensive instrumental methods such as ICP-MS, with significantly lower costs for equipment and analysis time [3].

4. Machine learning for determining the origin of rubies and sapphires. The goal: to automate the process of determining the geographic origin of rubies and sapphires, which critically impacts their market value.

Technology: Classical machine learning (ML) algorithms trained on trace element data (obtained via EDXRF, LA-ICP-MS).

The result: successful classification of origin, which increases the reproducibility and objectivity of the assessment process, which previously depended on expert experience and complex instrumental analysis [7].

Thus, the application of artificial intelligence in gemstone valuation demonstrates significant potential, based on a number of key benefits and findings supported by practical case studies:

1. AI algorithms provide unprecedented speed gains. In classification tasks, the algorithm's recognition speed can be orders of magnitude faster than that of a human gemologist (for example, 0.0165 seconds versus tens of minutes). This makes AI an ideal tool for the initial rapid sorting and evaluation of large volumes of stones.

2. Primary-level methods based solely on computer vision can already outperform human experts in certain classification tasks, although they do not achieve perfect accuracy for all classes. However, solving highly complex problems, such as accurately determining origin, revealing hidden processing, or identifying

synthetic stones, requires the use of combined (multimodal) methods that combine visual, spectral, and chemical data.

3. The success and high accuracy of AI solutions depend on the availability of large and well-labeled datasets. Examples such as the GEMTELLIGENCE project, which used a database of 28,000 samples, highlight the need for investment in the creation and expansion of specialized gemological databases. datasets .

4. AI solutions are already moving from academic research to commercial and laboratory applications (for example, automatic classifiers for retail and laboratory support systems). The main limitation is that visual methods cannot fully function without additional data (refractometry, density, spectroscopy). Without this data, as the researchers note, "the system will not be able to distinguish natural stones from synthetic ones".

5. For AI to be widely adopted in the industry, it is necessary to integrate AI solutions with existing gemological standards and certification procedures. Models being developed by the GIA and other leading laboratories provide a benchmark for this integration, ensuring trust in automated results.

To effectively and responsibly implement artificial intelligence technologies into gemstone valuation practices, it is recommended to follow a step-by-step strategy:

1. Stages of implementation and choice of technologies.

Start with image-based screening. Implementation should begin with simple tasks, such as automated sorting and preliminary assessment of stones based on their visual characteristics (color, shape, presence of large inclusions). This requires relatively less complex infrastructure (computer vision and CNN).

Use multimodal models for complex tasks. For important and high-value tasks, such as precise origin determination, detection of hidden processing, or identification of synthetics, it is necessary to combine imaging data with spectroscopy and chemical analysis using multimodal AI models.

2. Data management and integration.

Developing an internal database. It is important to maintain and continually develop a well-labeled, proprietary database of samples. This database should include expert-verified information on origin, processing type, composition, and defects, as data quality directly determines the accuracy of AI models.

Integrating AI as a support tool. AI solutions should be integrated into the existing workflow of a laboratory or retailer, serving primarily as an aid and support tool for the expert, rather than as a complete replacement. Human supervision remains essential, especially for high-value stones.

3. Validation , monitoring and ethics.

Validation and monitoring. Rigorous validation and monitoring procedures must be established, regularly comparing model outputs with expert opinions. This will allow for prompt error detection, especially when new processing methods or synthetic analogues are introduced, and for model updates.

Considering Ethical and Legal Aspects. When implementing AI, ethical and legal issues must be carefully considered, including data protection and use, transparency of the decision-making process (AI explainability), and liability for misclassification, given the high value of precious stones.

Practical cases show that AI is already moving beyond laboratory experiments and is beginning to be implemented in the gemological and jewelry industries. Particularly significant are cases where models achieve accuracy comparable to expensive analytical methods and expert assessments, but with greater speed and reproducibility. However, fully addressing the challenges (origin, synthetics, complex processing) requires a comprehensive approach with multimodal analysis and close integration with expert knowledge.

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